COMP4DRONES

DELIVERABLE

D2.1 – Framework Specification

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DISCLAIMER

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Definitions, Acronyms and Abbreviations

Acronym	Title
AGL	Above Ground Level
ADT	Air Data Link
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
APM	Auto Pilot Module
APS	Automated Planning & Scheduling
ARC	Air Risk Class
Air traffic management (ATM)	Consists primarily of air traffic control (ensuring that aircraft are safely separated in the sky and at airports), air traffic flow management (sending flight plans to a central repository, analysing and computing them) and aeronautical information services (compilation and distribution of aeronautical information needed by airspace users, e.g. on safety).
BIM	Building Information Modelling
BVLOS	Beyond visual line–of–sight
CSAT	Cooperative Search, Acquisition, and Track
Command and control (C2) link	Data link between the drone and the remote pilot station, which manages the flight.
ConOp	U-space Concept of Operations
COTS	Commercial-off-the-shelf
CTR	Controlled traffic region or control zone
DAA	Detect and Avoid (see below)
DAI/DAS	Data Acquisition Interface, Data Acquisition System
Drone	See UAV
'Detect and avoid'	Capability of the drone to remain at safe distance from, and to avoid collisions with other aircraft.
EASA	European Aviation Safety Agency
FPGA	Field-programmable gate array: programmable hardware
Geofencing	Software using GPS signals to stop drones flying into certain areas.
GDT	Ground Data Link
GNSS	Global Navigation Satellite System receivers, using the GPS, GLONASS, Galileo or BeiDou system
GRC	Ground Risk Class
HUMS	Health and Usage Monitoring Systems
IAQ	Indoor Air Quality
IMA	Integrated Modular Avionics, a system architecture enabling to run multiple avionic functions on a single device.

IMM	Intelligent Mission Management
IMU	Inertial Measurement Unit
IOLC	Intelligent Outer Loop Control
IPS	Indoor Positioning System
ISHM	Intelligent System Health Management
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
KET	Key Enabling Technologies
LIDAR	System for measuring distance to a target by illuminating it with pulsed laser light and measuring the reflected pulses with a sensor.
LOA	Level of Autonomy
LTE	Long-Term Evolution (LTE) is a standard for high-speed wireless communication for mobile devices and data terminals.
MIMO	Multiple input multiple output: wireless middleware.
MET	Meteorological Information Management
NAA	National Aviation Authority
NOTAM	Notice to airmen
OTH	Over the Horizon Communications
OVM	Onboard Vision Module
OPM	Onboard Planning Module
OSO	Operational Safety Objectives
Precision agriculture	A farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. The aim is to reduce resource consumption.
QoS	Quality of Service, performance properties of a service (often in networking)
REST	Representational State Transfer
RLOS	Radio line–of–sight
ROS	Robot Operating System. Widely used operating system in robotics and drone domain.
RPAS	Remotely Piloted Aircraft System
Remote pilot	Person who is in control of the flight path of the aircraft.
RTK	Real Time Kinematic
SA	Situational Awareness
SAIL	Specific Assurance and Integrity Levels
Segregated airspace	Airspace of specified dimensions assigned for exclusive use to specific users.
SESAR	Single European Sky Air Traffic Management
SLAM	Simultaneous Localization and Mapping
SOA	Service Oriented Architecture

SoC	System-on-chip. Multiple circuits on a single, integrated chip (IC), e.g. processor, I/O controllers and memory.
SoI	System-of-interest
SORA	Specific Operations Risk Assessment
TCAS	Traffic Collision Avoidance Systems
TMPR	Tactical Mitigation Performance Requirement
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicles are air vehicles and associated equipment that do not carry a human operator
UGV	Unmanned Ground Vehicle
USV	Unmanned Surface Vehicle
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle communication
VLOS	Visual line–of–sight
VLL	Very Low-Level operations
VTOL	Vertical Take-Off and Landing
V&V	Verification and Validation
WAMI	Wide Area Motion Imagery

Executive Summary

Drones/UAVs can perform air operations that manned aircrafts struggle with. Their use brings significant economic savings and environmental benefits whilst reducing the risk to human life. Drone-based service and product innovation, as driven by increased levels of connectivity and automation, is limited by the growing dependence on poorly interoperable proprietary technologies and the risks posed to people, to other vehicles and to property.

The UAV market already has a great variety of hardware, software and operational products to offer. However, the key element for global UAV success story is not just defined by these aspects – it largely depends on local **regulation**. The international regulatory bodies work together in the context of JARUS (Joint Authorities for Rulemaking on Unmanned Systems) initiative. In addition to national authorities, Europe participates in this work through EASA (European Aviation Safety Agency). The integration of UAVs into non- separated airspace requires **essential technologies**, which do exist but are not yet mature enough for cross-regional implementation due to missing technical standards.

This deliverable provides an **initial COMP4DRONES framework specification**. First, it introduces a set of **key concepts** that are needed to define this framework such as U-Space and SORA (Specific Operations Risk Assessment) concepts. Second, we discuss the **current state of the drone systems** which include the drone itself, the ground control station, and the communication between them. We also describe some of the drone sub-systems such as navigation, positioning, autonomic management, etc. Third, a brief **summary of the project demonstrators** is presented and used to identify the **common usages of drones** which are classified into fly stages (e.g. take-off, cruise, etc.) and mission specific operations (e.g. survey land, check crop health, inspect offshore infrastructures, etc.).

Fourth, based on the common usages, we identify the **key technologies** of this framework that need to be developed (i.e. the **COMP4DRONES** framework). Fifth, these technologies include **U-space capabilities** (e.g. geofencing, security, and telemetry, etc.), **system functions** (e.g. flight control, positioning, coordination, etc.), **payloads** (camera, LIDAR, etc.), and **tools** (system design, data analytics, mission planning, etc.).

Sixth, the project contributions to improve the existing technologies to ease the drones' customization and their safe operation are described. The improvements are divided into four groups: **integrated modular reference architecture, safe autonomous decisions, trusted communication, minimization of the system design and verification**. Finally, a general **methodology** for drone systems development is presented that will be elaborated in other deliverables.

1 Introduction

The potential applications for drones, especially those in manned areas or into non-segregated airspace, are currently not possible without the **development and validation of certain key enabling technologies**. The development and integration of these key enabling technologies require the drone to be equipped with sophisticated sensors to have precise knowledge of the environment (perception), trusted communication capabilities (identification, availability and cyber-security) and the ability to make intelligent decisions autonomously in real time to react to unforeseen situations (detect & avoid, safe coordination, contingency).

The embedded architecture of drones, shares limitations with most embedded computer systems: limited space, limited power resources, increasing computation requirements, complexity of the applications, time to market requirements, etc. These constraints are even stronger for small drones, weighing less than 150 kg. Small drones are low-cost, often provided by SMEs and Midcaps; they need to be **safely customizable at low efforts and cost**.

This deliverable provides an **initial framework specification**. The aim of this framework is to identify the key enabling technologies with their supporting methodology and tools. This document is structured into eight sections.

Section 2 introduces challenges for developing drone systems, and a set of **key concepts** that are needed to define this framework. These concepts include U-Space, and SORA (Specific Operations Risk Assessment). First, **U-Space** is a set of new services and specific procedures designed to support safe, efficient, and secure access to airspace for large numbers of drones. Second, the **Specific Operations Risk Assessment (SORA)** provides guidance to both the competent authority and the applicant as to what is required for a National Aviation Authority (NAA) authorization required to fly an Unmanned Aircraft System (UAS) in a given operational environment. The SORA is primarily aimed at the "Specific" category of UAS (as defined by EASA Technical Opinion 01/2018).

In **Section 3**, the **current state of the drone systems is discussed.** The systems include the **drone** itself, the **ground control station**, and the **communication** between them. The drone (UAV) is composed by three main parts: (a) the *platform* includes the structure, engines, servomotors, etc. (b) the *avionics* is formed by all the electronic systems and peripherals that allow the UAV's flight: the communications link, the flight controller or the navigation system; (c) the *payload* is made by one or several sensors needed to carry out the UAV's mission. The most common payloads are cameras, but it can exist some different such as radars, LiDARs, environmental sensors, etc.

A brief **summary of the project demonstrators** is presented in **Section 4**. The demonstrators cover five domains: (a) application of drones for optimization of **transport** control, operation and infrastructure management; (b) smart application of drones for digitalization of the state of a **construction** process, and analysis of underground constructions status; (c) **logistic** using heterogeneous drones fleet; (d) drone and wheeled robotic systems for **inspection, surveillance** and rescue operations with enhanced navigation and autonomous abilities; (e) smart and precision **agriculture**. These demos are then used to identify the **common usages of drones**. The usage is classified into: fly stages (e.g. take-off, cruise, etc.), and mission specific operations (e.g. survey land, check crop health, inspect offshore infrastructures, etc.).

In **Section 5**, we describe the **overall project workflow** with a focus on the identification of the key enabling technologies, the task of this deliverable, based on the demos' descriptions. To do so, we describe, a **general architecture (structure) for the drone system** which is then used by a process to identify the different components/ technologies of the system.

Based on the common usages, in **Section 6**, we identify the **key technologies** of **COMP4DRONES** framework that need to be developed. These technologies include **U-space capabilities** (e.g. geofencing, security, and telemetry, etc.), **system functions** (e.g. flight control, positioning, coordination, etc.), **payloads** (camera, LIDAR, etc.), and **tools** (system design, data analytics, mission planning, etc.).

The project contributions to improve the existing technologies to enable ease customization of drones and their safe operation are described in **Section 7**. The improvements are divided into four groups: **integrated modular reference architecture, safe autonomous decisions, trusted communication, minimization of the system design and verification**.

Finally, in **Section 8**, a general **methodology** for drone systems development is presented that will be elaborated in other deliverables.

2 COMP4DRONES Framework Motivation

In this section, we motivate the need for defining and creating the **COMP4DRONES** framework to enable easy and customizable development of drone systems. Then, the **U-space concepts** and **Specific Operations Risk Assessment** (SORA) are presented to introduce to understand the context for the framework specifications.

2.1 Challenges for Developing Drone Systems

Unmanned Aircraft Vehicles (**UAV**[1]), also commonly referred to as **drones**, are air vehicles and associated equipment that do not carry a human operator, but instead fly autonomously or are remotely piloted. Drones are increasingly being considered for commercial and government civilian applications ranging from firefighting to agriculture through the generation of climate data and border surveillance and more. They can perform air operations that manned aircrafts struggle with, and their use brings significant economic savings and environmental benefits whilst reducing the risk to human life. They have already made the leap to leisure market, reaching millions of sales. Evolution on technology, regulations and society acceptance should favour an accelerated deployment of drones in civilian applications, other than leisure.

Drone-based service and product innovation, as driven by increased levels of connectivity and automation, is curtailed by the growing dependence on poorly interoperable proprietary technologies and the risks posed to people on the ground, to other manned and unmanned vehicles and to property (e.g. critical infrastructure).

The UAV market already has a great variety of hardware, software and operational products to offer. However, the key element for global UAV success story is not just defined by these aspects – it largely depends on local regulation.

Drones integration into the airspace require rules to ensure safety, environmental protection, as well as security and privacy, limited flight zones and criteria for the usage of these zones cooperatively are mandatory.

A full integration of UAVs into non-separated airspace requires essential **technologies**, which do exist but are not yet mature enough for cross-regional implementation due to missing technical standards.

As with any new **aviation technology**, the regulatory issues to be considered are numerous and complex. The two most significant from an operational perspective are:

Airspace management: Maintaining an increasingly diverse airspace while keeping all air traffic moving safely and efficiently will be a significant challenge. In the short-term, this will mean that permits for Vertical Take-Off and Landing (VTOL) operations will be

[1] The term Unmanned Aerial Vehicles (UAV) includes Remotely Piloted Aircraft Systems (RPAS) as well as Unmanned Aircraft Systems (UAS)

issued on a per flight basis and will, at least initially, limit the industry's capacity and growth potential.

Certification: Many national regulators are still struggling with the task of providing a regulatory environment for small Unmanned Aerial Vehicles (UAV) with no payloads or passengers. VTOLs potentially add both of these complexities to an aircraft type that comes in both manned and unmanned formats.

The international regulatory bodies work together in the context of JARUS[2] (Joint Authorities for Rulemaking on Unmanned Systems) initiative. In addition to national authorities, Europe participates in this work through EASA[3] (European Aviation Safety Agency).

Regarding the innovation aspect, the Single European Sky Air Traffic Management (SESAR) Joint Research Undertaking is developing a set of services and procedures to help drones access airspace safely and efficiently. In order to realize this potential, SESAR is developing the concept of U-space[4]. U-space is a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. SESAR's vision is that of a harmonized, as opposed to a fragmented, single market for drones.

This issue was identified to have high impact on European innovation by the *European ATM[5] Master Plan: Roadmap for the safe integration of drones into all classes of airspace*[6] and the *European Drones Outlook Study: Unlocking the value for Europe*[7], both published by SESAR JU. ***These reports demand R&D investments and incentives for the convergence of shared technologies and markets as a remedy***. Actions creating globally harmonized, commercially exploitable yet widely accessible R&D ecosystems in the following areas should be developed *according to SESAR JU*:

1. Detect and avoid (D&A): including cooperative and non-cooperative traffic, geofencing and resource constraint-based solutions to support smaller drone operations.
2. Datacom and spectrum: datalinks for command and control, communication for ATM, combination of different solutions: satellite, mobile phone networks, etc.
3. Security and cyber resilience: including risk mitigation related to malicious or accidental takeovers of datalinks leading to accidents, theft or deliberate use of drones to damage infrastructures.
4. Human factors and training: including situation awareness, transition to more automated drones, contingency and failure management.

[2] Joint Authorities for Rulemaking on Unmanned Systems, http://jarus-rpas.org/
[3] https://www.easa.europa.eu/
[4] https://www.sesarju.eu/U-Space
[5] ATM : Air Traffic Management
[6] SESAR JU, "European ATM Master Plan: Roadmap for the safe integration of drones into all classes of airspace," 2017
[7] SESAR JU, "Report: European Drones Outlook Study," 2016

5. Validation and demonstration: risk-based logic would enable the collection of data and observations to further refine concepts, while increasing public acceptance.
6. Air Traffic Management (ATM): to integrate drones in all classes of airspace.

The focus of COMP4DRONES complements SESAR JU efforts in regards to areas 1 to 5 with particular emphasis on *software and hardware architecture of drone systems*.

The adoption of civilian drones still remains a challenge due to the complexity of physical environments where they operate. The U.S. Government Accountability Office (GAO), the European Aviation Safety Agency (EASA) and the European Union Committee of the UK House Of Lords outlined four primary safety concerns[8]:

1) The "inability to recognize" and "avoid other aircraft" and "airborne objects" in a manner similar to manned aircraft.
2) A lack of "technological" and "operational standards" needed to guide safe and consistent performance of drones.
3) Vulnerabilities in the command and control. (e.g. "GPS-jamming, hacking", and the potential for "cyber-terrorism").
4) A lack of comprehensive "government regulations" necessary to safely facilitate the accelerated integration of drones into the national airspace system.

The potential applications for drones, especially those in manned areas or into non-segregated airspace, are currently not possible without the development and validation of certain key enabling technologies. The development and integration of these key enabling technologies require the drone to be equipped with sophisticated sensors to have precise knowledge of the environment (perception), trusted communication capabilities (identification, availability and cyber-security) and the ability to make intelligent decisions autonomously in real time to react to unforeseen situations (detect & avoid, safe coordination, contingency).

The embedded architecture of drone shares limitations with most computer-embedded systems: limited space, limited power resources, increasing computation requirements, complexity of the applications, time to market requirements, etc. These constraints are even stronger for small drones, weighing less than 150 kg. Small drones are low-cost, often provided by SMEs and Midcaps; they need to be safely customizable at low efforts and cost.

Therefore, the aim of the project is to provide a framework of key enabling technologies for safe and autonomous drones. In particular, the project will leverage composability and modularity for customizable and trusted autonomous drones for civilian services. The focus of this deliverable is the framework specification, where a set of Unified List of Drone Usages are derived from the demos' description (Section 4.2). This list of requirements is

[8] GAO, "Report to Congressional Requesters. UNMANNED AIRCRAFT SYSTEMS: Measuring Progress and Addressing Potential Privacy Concerns Would Facilitate Integration into the National Airspace System," 18 September 2012

then used to identify the key enabling technologies that need to be developed during the project (Section 0).

2.2 U-Space Concepts[9]

U-Space is a set of new services and specific procedures designed to support safe, efficient, and secure access to airspace for large numbers of drones.

These services rely on a high level of digitization and automation of functions, whether they are on board the drone itself, or are part of the ground–based environment. U–space provides what is needed to enable and support routine drone operations, as well as a clear and effective interface to manned aviation, Air Traffic Management (ATM)/Air Navigation Service (ANS) for service providers and authorities.

U–Space will be capable of ensuring smooth operation of drones in all operating environments, including urban areas, and in all types of airspace, in particular to very low level (VLL) airspace. It will address the need to support the widest possible variety of missions, and may concern all drone users, as well as every category of UAV, as defined by EU Commission proposed regulation on unmanned aircraft operations. According to the criticality of the provided services, performance requirements will be established for both structural elements and service delivery, covering safety, security, availability, continuity, resilience and so on.

U–Space services will be delivered by service providers within the given U–space environment. They do not replicate the function of Air Traffic Control (ATC), as known in ATM: instead, they will deliver key services to organize the safe and efficient operation of drones and ensure a proper interface with manned aviation, ATC and relevant authorities.

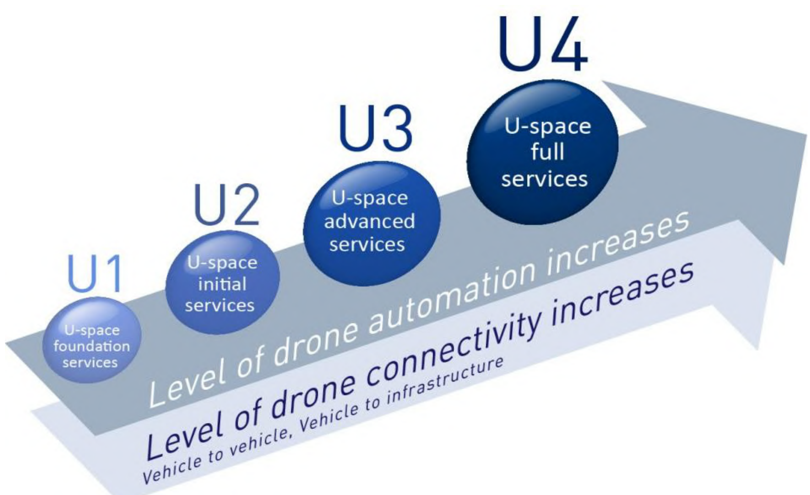

Figure 1: U-Space services and the drone's level of autonomy[10]

9 https://www.sesarju.eu/sites/default/files/documents/reports/European%20ATM%20Master%20Plan%20Drone%20roadmap.pdf

10 https://www.sesarju.eu/sites/default/files/documents/reports/U-space%20Blueprint%20brochure%20final.PDF

2.2.1 U1: U-space Foundation Services

E-registration: The service enables the registration of the operator, drone and pilot with the appropriate information according to regulation. A level of security of the service will be defined.

E-identification: The service allows the identification of a drone operator from a drone in operation (in line with the global scope of registry (ICAO) & eIDAS - regulation (EU) No 910/2014). The identification provides access to the information stored in the registry based on an identifier emitted electronically by the drone. The identification service includes the localization of the drones (position and time stamp).

Pre-tactical geofencing: The service provides the operator with geo-information about predefined restricted areas (prisons, etc.) and available aeronautical information (NOTAM, AIRAC cycle) used during the flight preparation. This service requires the identification of accredited sources and the availability of qualified geo-information related to restricted areas. This service provides information that allows the drone operator to make use of the geofencing capability of the drone.

2.2.2 U2: U-space Initial Services

Tactical geofencing: Compared to U1 pre-tactical geofencing, tactical geofencing brings the possibility to update the operator with geofencing information even during the flight.

Tracking: This refers to the service provider using cooperative and non-cooperative surveillance data to maintain track-identity of individual drones. The capability includes ground and air surveillance systems, as well as surveillance data processing systems. The performance requirements of the capability will vary in accordance with the specific requirements of each application.

Flight planning management: This service covers the receipt of a flight notification or a flight plan and provides the appropriate answer according to the characteristics of the mission and applicable regulations. This service will be available for any drone operator/user with different levels of requirements.

Weather information: The service provides drone operators with forecast and actual weather information either before or during the flight; it can also collect and make available weather information from different stakeholders. Different levels of service provision could be considered; for example:

- MET (Meteorological Information Management) information for missions in a rural environment (based on existing aeronautical information);
- Enhanced weather information for missions in urban areas;
- Micro-weather information for urban areas (urban canyoning/ autonomous vehicles)

Drone aeronautical information management: This service provides the operator with relevant aeronautical information for drone operations. It will connect to the Aeronautical information service (AIS) to guarantee coherent information provision for manned and unmanned operators.

Procedural interface with air traffic control: The service is a set of defined procedures for some mission types where there may be an impact on ATC; for example, crossing certain types of controlled airspace under prescribed conditions. The procedures ensure clear and unambiguous drone operation, and provide an appropriate flow of information between the drone operators and ATC. Such procedures will allow drones to fly in controlled airspace and near airports with more flexibility and procedural approval/rejection based on agreed rules.

Emergency management: The service receives emergency alerts from operators (e.g. Loss of control), and informs relevant actors of the ecosystem. These may include drone operators operating drones nearby, ANSPs, police, airport authorities. The service also provides the drone/operator with assistance information to manage the emergency situation (e.g. location of landing pads).

Strategic DE confliction: The service provides deconfliction assistance to a drone operator at strategic level (when the flight plan is submitted, it is compared to other known flight plans and a deconfliction in time or route could be proposed). This service could be mandatory or optional according to the operating environment.

Monitoring: Subject to appropriate data-quality requirements, this service retrieves data from the tracking service and fuses it with information related to non-cooperative obstacles and vehicles in order to create air situation for authorities, service providers, and operators. This service may include conformance monitoring.

Traffic information: This service provides the drone operator with traffic information coming from any kind of monitoring services.

2.2.3 U3: U-space Advanced Services

Dynamic geofencing: Compared to tactical geofencing in U2, the dynamic geofencing targets the drone itself and then this service requires data-link connectivity to a geofencing system that allows the data to be updated during the flight.

Collaborative interface with ATC: The service provides a mechanism to ensure proper effective coordination when drone operations using U-space services impact ATC. It encompasses shared situational awareness and procedures to enable a two-way dialogue supporting the safe and flexible operation of drones in airspace where ANS are provided.

Tactical deconfliction: This service provides information to the operators or the drones to ensure separation management when flying. The differences with the strategic deconfliction described in U2 are twofold: the drone may receive the information and this deconfliction is set for the in-flight phase. It will be necessary to appropriately define the boundaries with the use of Detect & Avoid capabilities.

Dynamic capacity management: Upon the definition of drone density thresholds (that can be dynamically modified), the service monitors demand for airspace, and manages access to that airspace as new flight notifications are received. This service may be coupled with the flight planning management service. There should be appropriate set of rules and priorities for slot allocation when a portion of airspace is expected to reach its capacity limits. Apart from the demand and capacity balancing, the service could manage capacity due to non-nominal occurrences, such as weather hazards or emergency situations.

2.2.4 U4: U-space Full Services

U4 offers the full integration with manned aviation and air traffic services and supports the full operational capability of U-space based on a very high level of automation. It is expected that the need for new services will arise during the roll-out of U3. In addition, it is envisaged that manned aircraft could be equipped to take advantage of U-space services.

2.3 SORA: Specific Operations Risk Assessment[11]

The Specific Operations Risk Assessment (SORA) provides guidance to both the competent authority and the applicant as to what is required for an NAA authorization required to fly an Unmanned Aircraft System (UAS) in a given operational environment. The SORA is primarily aimed at the “Specific” category of UAS (as defined by EASA Technical Opinion 01/2018).

Risk in this context is understood to be the combination of the frequency (probability) of an occurrence and its associated level of severity. Safety means a state in which the risk is considered as acceptable. The way to reach an acceptable risk may differ for the “Open”, “Specific” and “Certified” categories, considering both Unmanned Aircraft Systems (UAS) design integrity and the kind of intended operations. However, the safety level (i.e. probability of potential fatalities on the ground or in the air) shall remain the same for the three categories.

The operational volume is defined as including both the “Flight geography” (i.e. the UA flight path under normal operations) and the “contingency volume” (i.e. the projected UA flight path under abnormal conditions handled through contingency procedures). An out of control operation means that the UA is flying out of this operational volume (not including risk buffer), potentially leading to harm to third parties in the air or on the ground.

In order to show that the operator can keep control of the Unmanned Aircraft (UA) within the intended “operational volume” and that the operations have reached an acceptable level of risk, the SORA provides an adequate combination of design and operational mitigation mechanisms for known areas of harm to either people on the ground or in the air.

[11] https://www.eurocockpit.be/positions-publications/specific-operations-risk-assessment-sora

These mitigations have to be met with a Level of Robustness (Low, Medium, High) that is commensurate with the determined Ground and Air Risks classes. The level of robustness corresponds to an appropriate combination of the levels of integrity and the levels of assurance. The level of integrity is the safety gain achieved by the mitigation and the level of assurance is the method of showing that the level of integrity has been met.

The SORA methodology consists of ten systematic steps:

Step #1: ConOp Description

The ConOp contains all the relevant technical, operational, and system information needed to assess the risk associated with the intended operation. It includes such things as the flight path, airspace, air and ground density maps, Air Navigation Service Provider (ANSP) interface, and other information related to the intended use of the UAS.

Step #2 and Step #3: Determination of Ground Risk Class (GRC)

- Step#2: The Intrinsic Ground Risk Class (scaled from 1 to 10) is first determined, depending on the UAS weight and physical dimensions, (with indication of typical expected kinetic energy released upon ground) as well as the intended operation.
- Step#3: The Final Ground Risk Class (that may be higher or lower than the intrinsic Ground Risk Class) is determined considering design aspects which may have a significant effect on the lethality of the drone and three mitigation measures:

  1. Strategic mitigations based upon ground risk buffer and overflown population density.

  2. Mitigations intended to reduce the effect of a ground impact.

  3. An Emergency Response plan to address and limit the effect of an operation out of control.

Step #4 and #5: Determination of the Air Risk Class (ARC)

Both the initial and the residual risk after mitigations are applied.

- Step #4: The Initial ARC is assessed based on the airspace requested in the ConOp. The parameters that define the airspace class are: atypical (e.g. segregated) versus typical airspace, altitude, controlled by air traffic versus uncontrolled, airport environment versus non-airport, and airspace over urban versus rural environments.
- Step #5: The Residual ARC is the residual air risk after applying strategic mitigation measures. Two types of strategic mitigations measures exist in the SORA. Air risk mitigations are either operational restrictions (e.g. boundaries, time of operation) controlled by the UA operators or by structure of the airspace and the associated rules controlled by the relevant authorities. Strategic mitigations are applied before flight. Determination of ARC requires full coordination with an agreement by the ANSP for the given operation.

Step #6: Tactical Mitigation Performance Requirement (TMPR) and Robustness Levels

Tactical mitigations are applied during the conduct of the operation, and are used to mitigate any residual risk of a mid-air collision that may remain after the strategic mitigations have been applied.

Tactical Mitigation Performance Requirements (TMPR) address the functions of Detect, Decide, Command, Execute and Feedback Loop, for each Air Risk Class. These mitigations range from simple, for example relying on UTM infrastructure, to more complex TSO (Technical Standard Order) DAA equipment that addresses the risk of non-cooperative air traffic (those without transponders) and cooperative air traffic.

Step #7: SAIL determination

A SAIL (scaled from I to VI) is then determined using the proposed CONOPs, and the consolidation of the final GRC and residual ARC.

Step #8: Identification of Operational Safety Objectives (OSO)

For the assigned SAIL, the operator will be required to show compliance with each of the 24 OSOs, although some may be optional for lower SAILs. Each OSO shall be met with a required Level of robustness (High, Medium or Low), depending on the SAIL. OSOs cover the following areas:

- UAS Technical Issue
- Deterioration of external systems
- Human Error
- Adverse environmental conditions

Step # 9: Adjacent Area/Airspace Considerations

Compliance with safety requirements associated with technical containment design features required to stay within the operational volume regardless of the SAIL. This addresses the risk posed by an operational loss of control that would possibly infringe on areas adjacent to the operational volume whether they be on the ground or in the air.

Step #10: Comprehensive Safety Portfolio

A comprehensive Safety Portfolio is the SORA safety case submitted to the competent authority and the ANSP prior to final authorization. The Safety Portfolio contains the following information:

- Mitigations used to modify the intrinsic GRC
- Strategic mitigations for the Initial ARC
- Tactical mitigations for the Residual ARC
- Adjacent Area/Airspace Considerations

- Operational Safety Objectives

If compliance with the required safety objectives is not achieved for the given SAIL, additional mitigation measures may be needed to further reduce the GRC or/and ARC or a change to the operational volume and CONOPS may be required.

The **COMP4DRONES** framework specification will take into account the Specific Operations Risk Assessment (SORA) guidance to help the applicant in getting an NAA authorization in short time.

3 State of the Art for Drone Systems

Current drone embedded architectures are organized in loosely coupled monolithic boards, each composed of processor, memory and communication resources (e.g. flight control, planning and vision boards). This separation ensures that the subsystems operate almost independently from each other and avoids interference coming from the other parts. However, this approach does not support the continuous development of drone applications such as the ever-increasing demand on autonomy. Drone embedded platforms must meet this demand, while still providing safety, robustness and a small footprint in physical size and power consumption. Another drawback is that a huge number of different resources are required for the integration, customization and maintenance costs in terms of component provisioning and handling. In the following, we describe some of the existing drone systems.

In the first section, we describe the whole unmanned aerial system (UAS) with examples and then we describe its sub-systems.

3.1 UAS System-of-Systems View

3.1.1 General System-of-Systems View

It is important to understand that unmanned aerial systems (UAS) are not only formed by the drone (e.g. UAV) but also the ground segment where the control station is located. The figure below (Figure 2) shows a common model of standard UAS components[12].

The vehicle segment is composed by three main parts:

- The *platform* includes the structure, peripherals, servomotors, etc.
- The *avionics* is formed by all the electronic systems that allow the UAV's autonomous flight: the communications link, the flight controller or the navigation system.
- The *payload* is made by one or several sensors needed to carry out the drone mission. The most common payloads are cameras, but it can exist some different such as radars, LiDARs, environmental sensors, etc.

[12] https://www.gradiant.org/en/blog/security-and-uas-a-problem-to-be-solved/

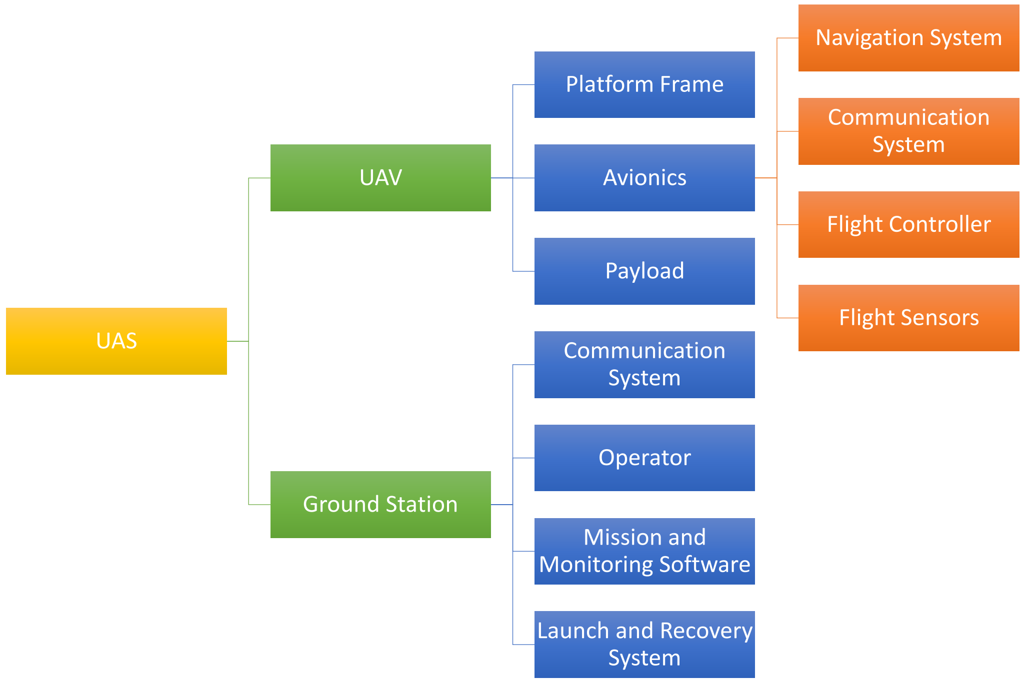

Figure 2: General model of standard UAS components

Avionics in turn is made by:

- *Navigation system*, allowing the autonomous flight of the UAV, defining position according to the pre-established route.
- *Communication links* enable the wireless communication between the UAV and the ground control station. It is common to exist different communication links both for command and control (commonly known as C2 – Command and Control connection) and for the payload. It is also important to highlight that those communications can be ground-to air (direct) or satellite (indirect).
- *Flight control* is responsible for controlling the active elements of the UAV (engine/s, spoilers, rudder, stabilizer, etc.) to follow the trajectory demanded by the navigation system.
- Examples of *flight sensors* are: GNSS receiver, inertial sensors, altimeters, pressure sensor, etc.

Another important aspect to consider is the flow of information between the UAV and its environment. The two most important operational connections from a safety point of view are: 1) the bidirectional connection between the communications system and the ground control station and 2) the flow of information from the environment to the sensors.

3.1.2 Research Examples of UAS

In this section, existing state of the art system of systems view of UAS are described.

3.1.2.1 *Paparazzi System-of-Systems Architecture*[13]

The Paparazzi system architecture is show in Figure 3. The UAV (in blue) is navigating autonomously and is monitored and controlled from the ground (in brown). The ground control station (GCS), or GCS agent, provides a graphical user interface with telemetry data received by the link agent which manages the ground-based radio modem. The link agent distributes telemetry data across the network (a single computer, a local network or the internet) where it can be used locally or remotely by the: (1) server - an agent that logs, distributes, and pre-processes these messages for the GCS and other agents; (2) messages - a real-time numeric display of all telemetry data; (3) a number of other useful agents. These agents are:

- a GCS-based flight plan editor to modify waypoints
- a UAV simulator to test flight plans and code modifications
- a real-time plotter for graphical telemetry data visualization
- a log plotter for graphical telemetry visualization after a flight

All of these processes run simultaneously and each module is independently launched and can be configured via the Paparazzi Center.

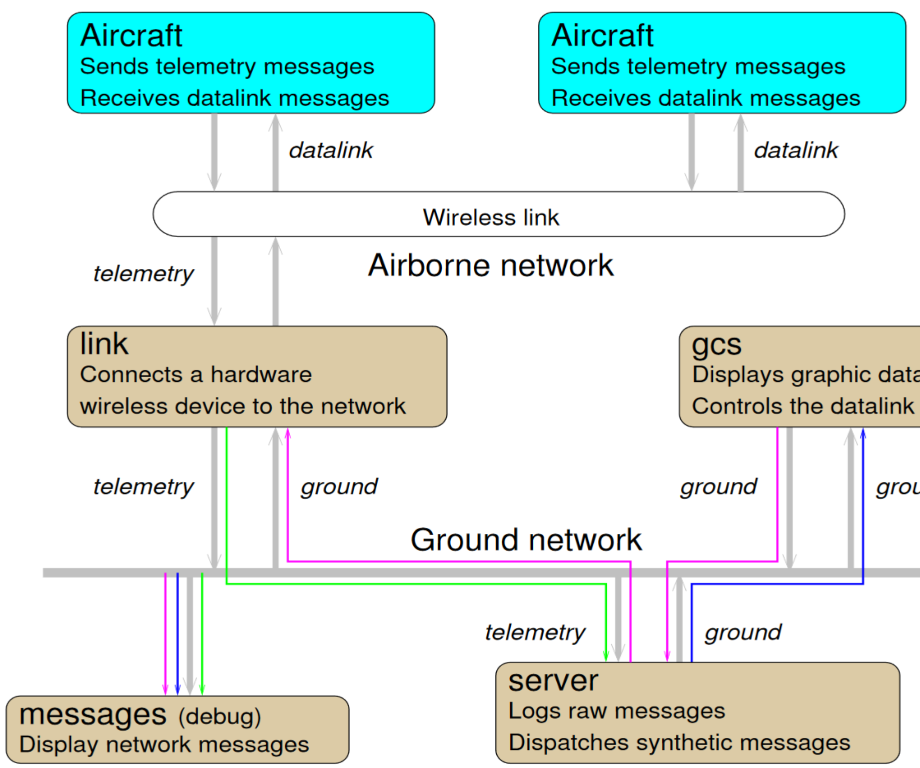

Figure 3: Global view of Paparazzi drone system

[13] G. Hattenberger, M. Bronz, and M. Gorraz, "Using the Paparazzi UAVSystem for Scientific Research," in International Micro Air VehicleConference and Competition (IMAV), 2014.

3.1.2.2 *ICAROUS System-of-Systems Architecture*[14]

The ICAROUS architecture is similar in spirit to the Service Oriented Architecture (SOA) architecture. A set of services provide various capabilities such as path planning, sense and avoid, geofence containment, task planning, etc. These services are commonly used to construct complex autonomous UAS applications. The ICAROUS architecture also specifies a framework for performing conflict monitoring and resolutions. Furthermore, a decision-making application coordinates the output of conflict monitors and resolvers to ensure safe operation. Shown in Figure 4 is a description of the functional layout of the ICAROUS architecture. Applications are logically organized into conflict monitors, conflict resolvers, mission managers, and decision makers.

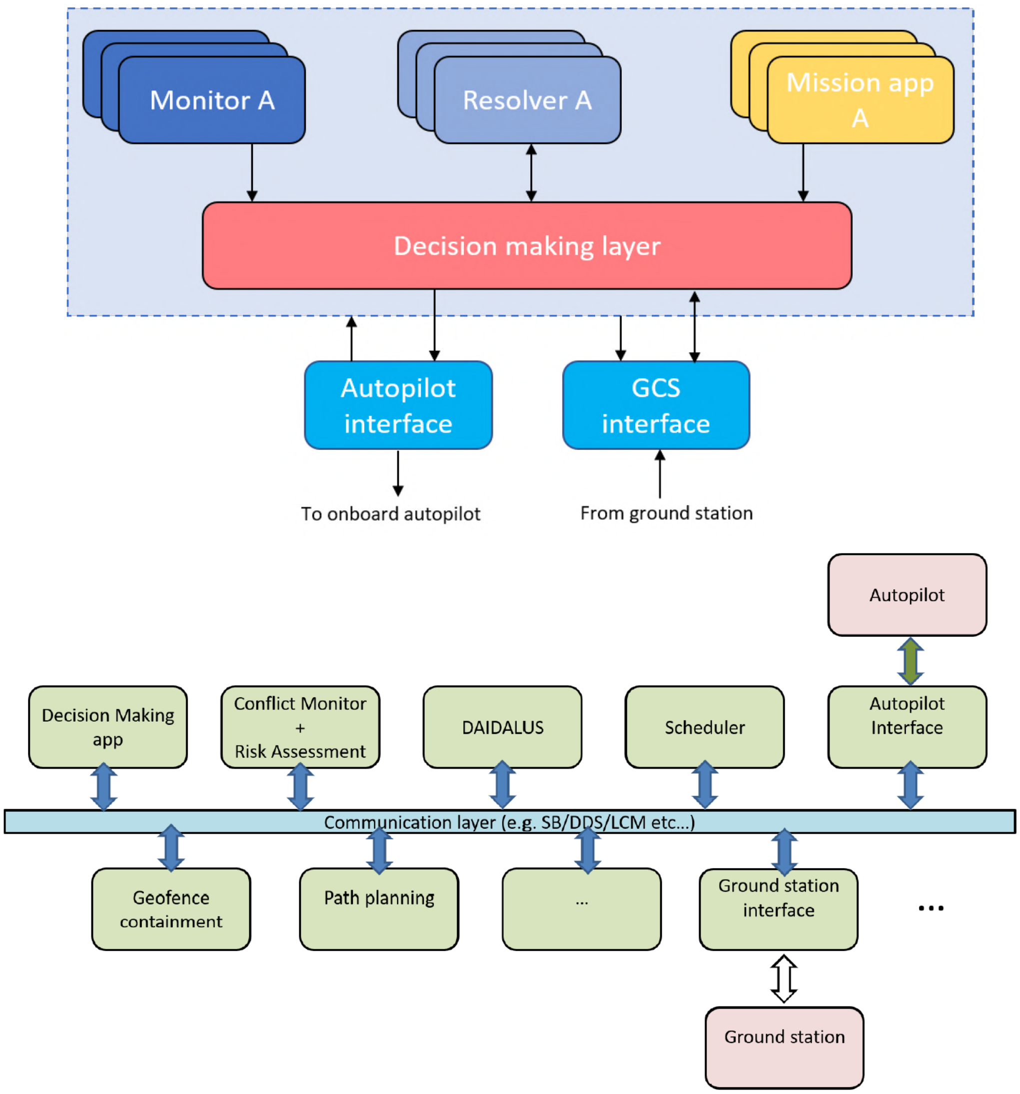

Figure 4: ICAROUS from a service-oriented architecture perspective

[14] Consiglio, M., Munoz, C., "ICAROUS: Integrated Configurable Algorithms for Reliable Operations of Unmanned System," in IEEE Digital Avionics Systems Conference, Sacramento, CA - September 25-29, 2016.

Conflict monitors are algorithms that monitor for imminent violation of airspace constraints such as geofences, conflicts due to other vehicles in the airspace, deviations from mission flight plan, etc. These conflict monitoring applications can also provide tactical resolutions. A tactical resolution is a simple manoeuvre that, if executed, is guaranteed to prevent the corresponding conflict violation. However, a tactical resolution does not predict future conflict violations and may not resolve other types of conflicts if they exist simultaneously. The notion of a conflict is abstractly represented by a set of descriptors that convey meta-level information about a conflict such as its severity, time to conflict violation, and point of no return. These descriptors enable a decision-making tool to sort them in an appropriate order to suite the mission needs and consequently invoke the corresponding resolvers.

Conflict resolvers compute resolutions to prevent imminent violation of specified constraints. There can be several resolvers, one for each conflict detector. Resolvers may also handle multiple conflicts simultaneously. Resolvers provide strategic resolutions that are computed to prevent one or more constraint violations. A resolution is also abstractly represented by descriptors that provide meta-level information about the resolution such as resolution type, time to recovery, etc.

A decision-making application receives conflict information from monitors and triggers resolvers to compute resolutions for one or more conflicts. When resolving imminent constraint violation, outputs from mission applications are ignored. The mission is resumed once all conflicts are resolved.

3.1.2.3 Johns Hopkins University Applied Physics Laboratory Swarming UAS Architecture[15]

Johns Hopkins University Applied Physics Laboratory (JHU APL) has developed small, autonomous UAVs that demonstrate cooperative behaviours to accomplish simple surveillance missions. As part of this work, JHU APL developed an autonomy framework or architecture for such systems. The JHU APL UAVs could take off and land autonomously and could swarm cooperatively to detect targets. These UAVs demonstrated simple teaming arrangements between UAVs using a number of different search algorithms. Although the algorithms that were demonstrated were relatively simple, the target locations were not preprogramed into the UAVs in advance. Mission control software was based as on a finite state automata system. The JHU APL research team also developed a multi-UAV command, control, and communications architecture that used an IEEE 802.11 wireless mobile ad hoc network. At the conclusion of this work, JHU APL proposed a UAV modular architecture that can support swarming or teaming behaviours.

This architecture is illustrated in Figure 5. This architecture contains two levels of control, each provided by separate modules. Low-level control processes are shown on the left,

[15] Robert J. Bamberger, Jr., David P. Watson, David H. Scheidt, and Kevin L. Moore, “Flight Demonstration of Unmanned Aerial Vehicle Swarming Concepts,” Johns Hopkins APL Technical Digest, vol. 27, n°11, 2006.

and high-level mission control processes are shown on the right. Wireless communications with other UAVs and with human pilots at GCSs are shown on the lower right and are mediated by a wireless communications layer. The JHU APL architecture was developed to support the operation of relatively small UAVs. It is also what could be considered a first-generation architecture that was developed in the early 2000s. The system depends on a single communications payload that is used for communication to the UAV GCS as well as two other UAVs. Larger, more complex UAVs now in operation carry multiple communications payloads and multiple sensors and can downlink sensor data to a GCS directly or through satellite communication links. So, the architecture for larger UAVs must support multiple onboard sensors and communication systems. The JHU APL architecture does not make use of an SOA and probably did not need one because of the relatively simple and small number of payloads the JHU APL UAVs carried. More complex UAVs that carry multiple payloads will likely require one or more messaging buses and perhaps an SOA to support payload and flight control messaging.

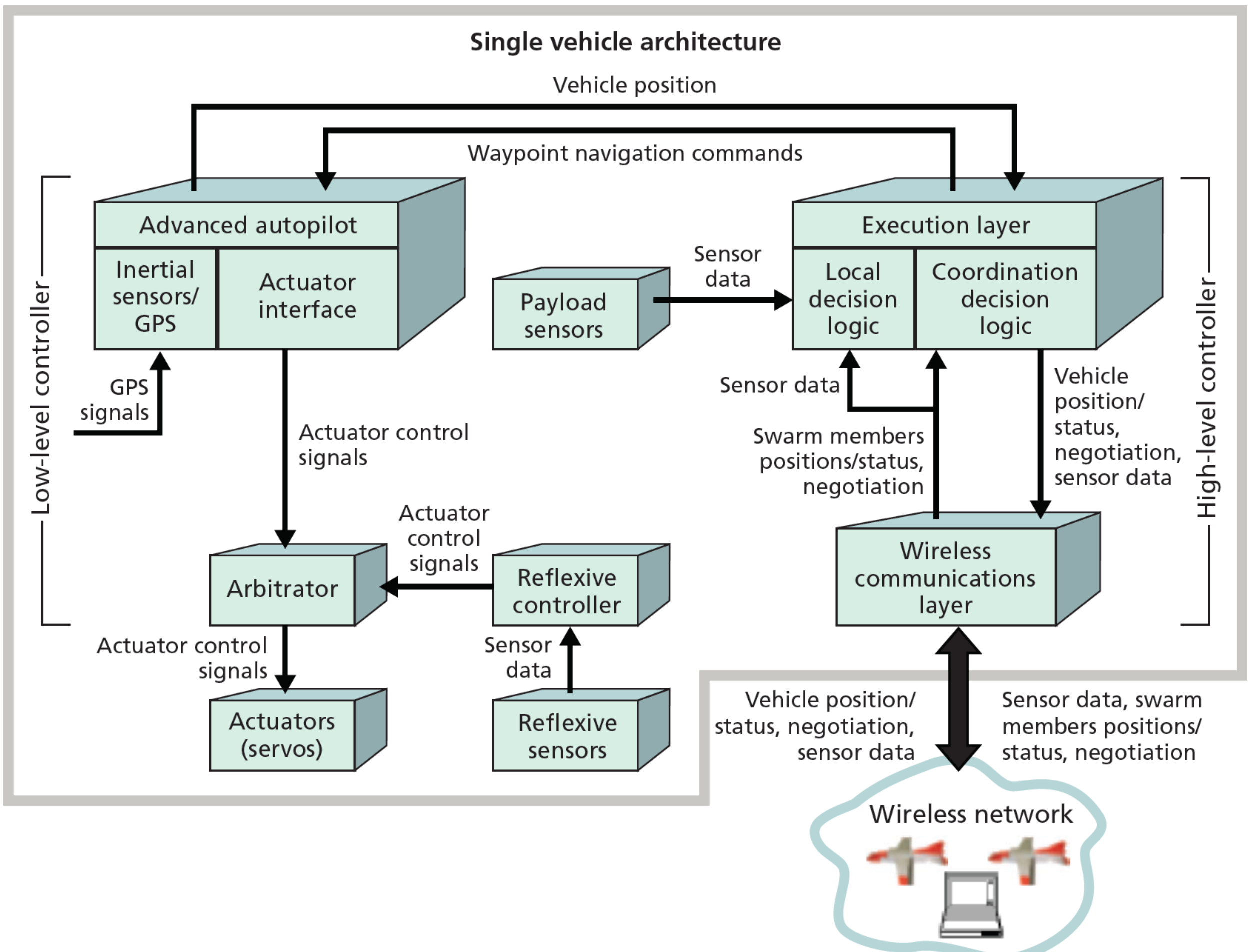

Figure 5: JHU APL autonomous UAV architecture

3.1.2.4 MIT and Aurora Flight Sciences Decentralized Autonomous UAV Framework[16]

MIT and Aurora Flight Sciences have developed and demonstrated a decentralized team of UAVs capable of cooperative search, acquisition, and track (CSAT) functions. While the primary focus of this research was to develop better algorithms to handle cooperative search and track functions, this team also developed a high-level UAV functional architecture that has some utility for thinking about how to define a modular open system architecture for UAVs in general. The CSAT architecture is shown in Figure 6.

Each UAV has a control module for planning and control of the vehicle. Because small UAVs were used in this demonstration, UAV sensor control functions were not needed. The control module had three major sub-elements as shown in the figure: the onboard vision module (OVM), the onboard planning module (OPM), and the auto pilot module (APM). The OPM generates situational awareness (SA) information, including target detection and target-tracking data from sensor data processed by the OVM. OPM SA data are then sent to OPMs on other UAVs and to the APM on the same vehicle, which used this information to generate navigation commands. Target estimates were sent from the OVM to the OPM, and waypoints were sent from the OPM to the APM. Vehicle state information was sent back by the APM to the Figure 6 other modules. Cooperative behaviour was enabled by the UAVs by sharing information between UAVs (i.e., situation awareness and targeting information). The algorithm that was employed for CSAT used relatively less bandwidth than earlier cooperative tracking algorithms that were demonstrated by previous researchers. The figure also shows how moving targets were used in this demonstration. Moving targets were controlled by a target manager, which sent target state information to the user interface (UI), which could then compare the quality of the tracking information produced by the cooperative UAV fleet to the actual target locations.

[16] J. How, C. Frasher, K. C. Kulling, L. F. Bertuccelli, O. Toupet, L. Brunet, A. Bachrach, and N. Roy, “Increasing Autonomy of UAVs,” IEEE Robotics & Automation Magazine, 2009.

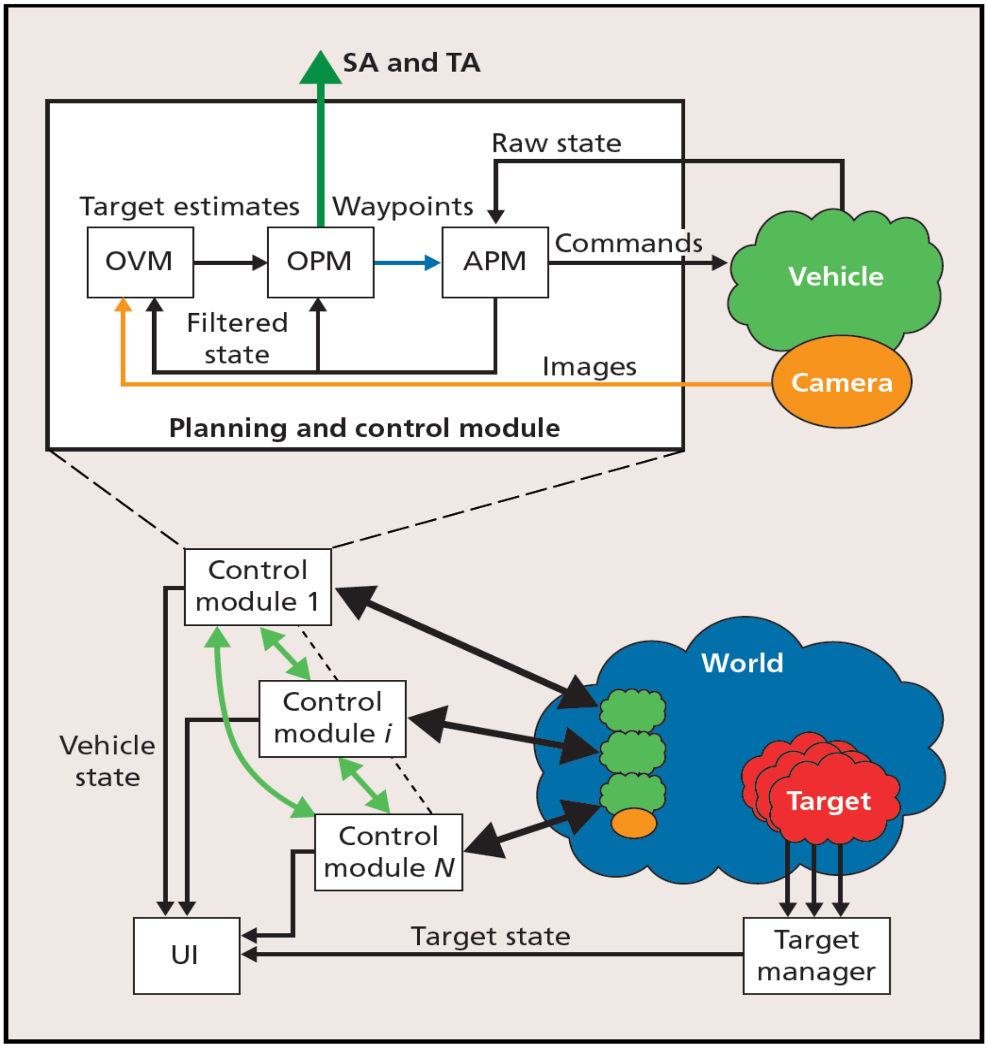

Figure 6: Module structure of the MIT CSAT architecture

3.1.2.5 MIT Lincoln Laboratory Reference Software Architecture[17]

MIT Lincoln Laboratory (MIT/LL) has developed an architecture for data and software services for UAVs. The goal of this effort is to develop a UAV information-sharing framework for existing non-autonomous UAVs that can operate in a wide range of air domains to include the national airspace system (NAS), terminal control and landing, oceanic flight, and tactical operations. The DoD and the Federal Aviation Administration (FAA) are undertaking a number of initiatives to safely integrate UAVs into the NAS. This means that these unmanned aircraft will have to be equipped with safety systems, such as traffic collision avoidance systems (TCAS) that are now used by human pilots on passenger aircraft. The plan is to incorporate similar sensors onto UAS so that they can provide an autonomous detect and avoid (DAA) capability. The proposed architecture is based on SOA with open standards for key interfaces. A key feature of this architecture

[17] Curtis W. Heisey et. al., "A Reference Software Architecture to Support Unmanned Aircraft Integration in the National Airpsace System," Journal of Intelligent Robotic Systems, 2012.

is the ability to accommodate DAA capabilities. An important near-term way of providing DAA is to leverage ground-based surveillance assets. The U.S. Army is leading the development of the ground-based detect and avoid (GBDAA) initiative. One longer-term solution is potentially an airborne-based sense and avoid capability in which DAA sensors located on board the UAV are used to avoid collisions with other aircraft.

Therefore, in the long term, this architecture must be able to accommodate off-board as well as onboard DAA information. This complicates the architecture because the UAV will have to interoperate with a diverse set of ground-based surveillance assets. This makes an SOA approach necessary, as it must provide the necessary mediation elements to interoperate with these ground-based systems. Figure 7 shows a notional set of services that this architecture would provide. Data from sensor sources onboard and off-board the vehicle would be published to the two data buses shown in the figure. Other services such as the DAA service would subscribe to sensor data and produce their own output data products. These services would be organized into a two-layer system. Each layer would have its own quality of service requirements, with the most stringent real-time performance requirements imposed on tactical services. For this reason, the architecture uses two separate message buses to ensure quality of service for real-time and near-real-time services. MIT/LL has selected DDS as the infrastructure for both the tactical data bus and the enterprise service bus. Because of the diverse nature of the sensors needed to support this architecture, a single messaging standard would not be used. In their initial development, MIT/LL has chosen to implement XML and binary format (interface definition language [IDL]) messages.

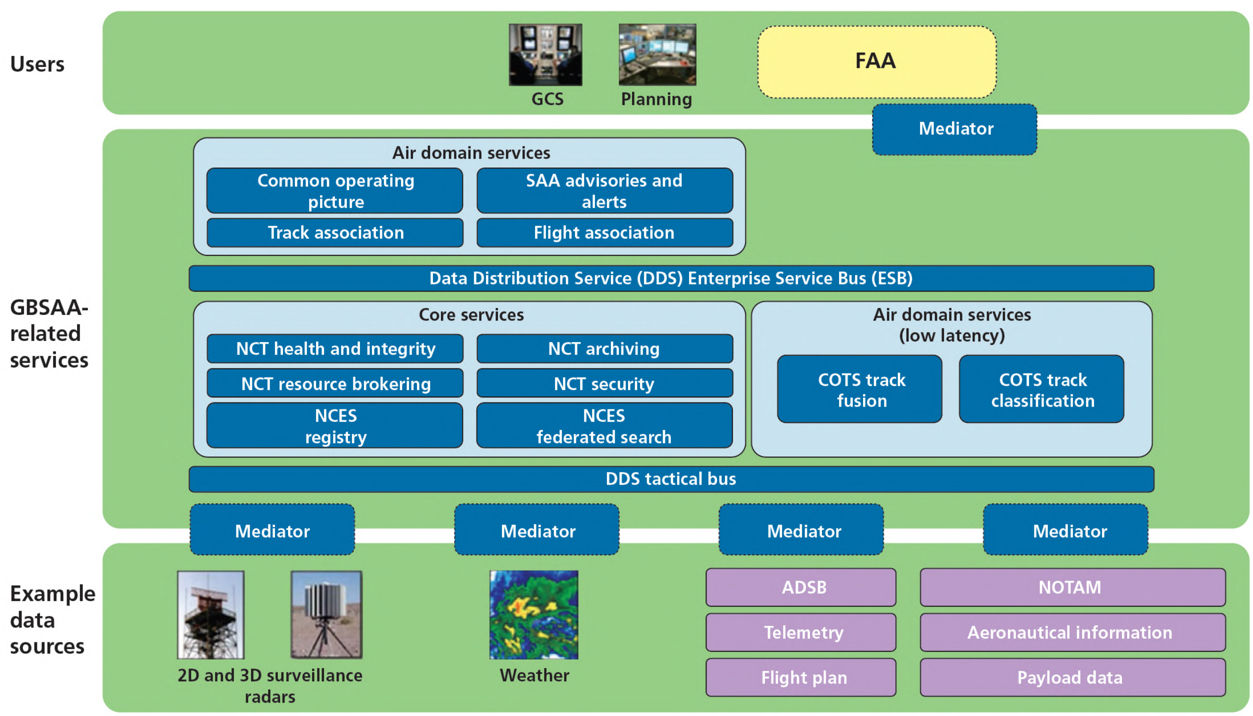

Figure 7: Notional view of possible services in the MIT/LL reference architecture

3.1.3 Industrial Examples of UAS

In this section, the payload and scenarios for the Use Cases are introduced and listed. These payload and scenarios have been used to define and specify the **COMP4DRONES** framework.

3.1.3.1 INDRA

The figure below shows the technical architecture of the Remotely Piloted Aircraft System (RPAS) MANTIS, developed by Indra. This drone will be the main UAV in the Use Case related to Transport. First, air segment is composed of Remotely Piloted Aircraft (RPA), Air Data Link (ADT) and payloads. Second, ground segment is composed of Remote Pilot Station (RPS), Ground Data Link (GDT) and auxiliary equipment. Third, air segment and Ground segment communicate through the data link segment where ADT and GDT and included.

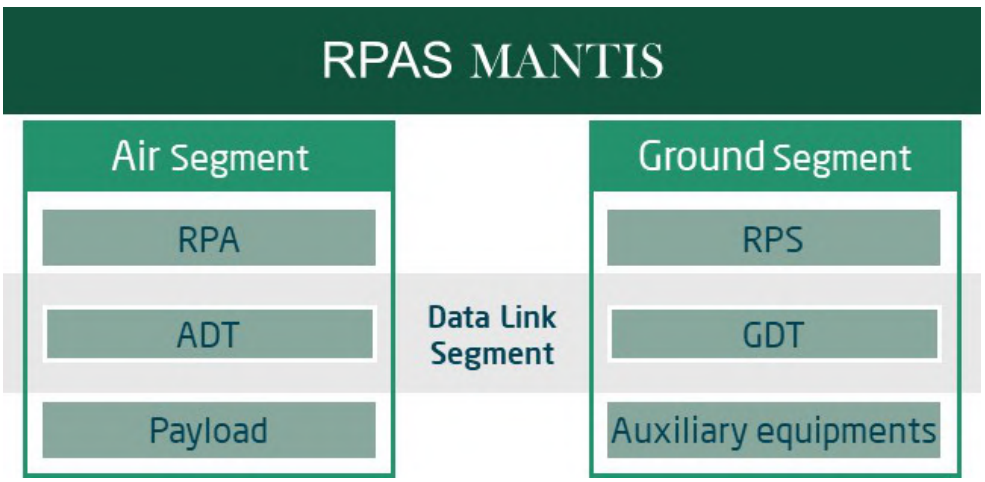

Figure 8: RPAS MANTIS technical architecture

<u>Air Segment</u>

System Air segment is composed of up to three UAV`s equipped with visible or infrared spectrum payloads. They are composed of:

A. RPA

Figure 9: RPA MANTIS

Each RPA is composed of the following interchangeable parts:

- **Nose**: Front fuselage structure that supports Electro-Optical/Infra-Red (EO/IR) payloads
- **Fuselage**: Main UAV structure that supports the electric propulsion engine, and provides allocation for electric battery and for the electronic elements that conform the avionics pack
- **Engine**: Electric engine mounted on top of the fuselage as shown in and controlled with help of a speed controller
- **GPS**: Antenna GPS mounted on top of the fuselage as shown in
- **Electric battery**: LiPo or Li-Ion technology electric battery (application dependent)
- **Avionics pack**: Collection of the following electronic parts:
    - Autopilot with GPS, inertial, magnetic, and barometric navigation sensors
    - Video processing unit for stabilization, compression and video-tracking
    - EO/IR payload video-link transmitter and telemetry/control transceiver
    - Engine controller for three phase control of the electrical motor
    - Security Switch with removable security pin-flag for disabling motor running when inserted
    - Power Supply for selective powering all the electronics
- **Central Wing**: Central part of the wing, it fits to the fuselage and includes two Flaps (one on each side). It also includes, embedded on it, the pitot sensor
- **Wing Ends**: (Right and left). There are symmetrically each other, fitting to each side of central wing. Both includes aileron and navigation light. Left one includes, embedded on it, the altimeter sensor for landing phase
- **Tail Boom**: Rear part of the structure, which contains the tail and the vertical fin, where the single vertical Rudder is placed. In the vertical plane it is also included the payload/telemetry/control video-link transmitter antenna
- **Horizontal Stabilizer**: It is mounted on top of the vertical fin. At the end of the horizontal plane there is located the Depth Rudder or Elevator.

B. ADT: ADT elements are included in RPA:

- **Transceiver/s**: To transmit payload video (EO/IR) and to transmit and receive telemetry/control. Depending on client needs, video and telemetry/control can use a single link or two at different frequencies
- **Antenna/s**: They are embedded in the vertical plane of tail boom. They can be single or two. They can be one or two, depending on if video and telemetry/control link are separate

C. Payloads: Currently, MANTIS has two types of payload:

- **Electro-Optical**: To transmit optical real video to RPS.
- **Infrared:** To transmit infrared real video to RPS.

Figure 10: RPA MANTIS EO payload

<u>Ground Segment</u>

System Ground Segment is composed by the control elements of the system, together with some other auxiliary items. All they may be placed static on ground or on a surface moving platform, on ground or at sea. They are composed by:

RPS: An autonomous (battery equipped) rugged portable unit that may be powered from standard AC supply as well from vehicle specific DC power.

It includes a powerful CPU processor, a special high brightness (1600 cd/m^2) 15” TFT screen, keyboard, trackball and specific joystick and pushbuttons for payload controls.

The included SW for UAV`s control, telemetry/control processing, payload exploitation, and user interface (*“man machine interface (MMI)”*) is STANAG 4586 compliant.

To transmit commands and receive telemetry/control and video, it is necessary to connect it to the GDT element.

GDT: Composed of the terrestrial part of the communication links with the UAV`s: fixed omni-directional and directional antennas, telemetry and control transceiver, payload video receiver, GPS receiver and azimuth positioning mechanics. It is powered by the RPS.

Auxiliary Equipment: Auxiliary equipment is those that allow executing the mission (battery charger, RPA launcher, small repair kit, etc.) as well as those that help RPS operator (simulator, flight manuals and maintenance, etc.

3.1.3.2 FADA – CATEC - The Andalusian Foundation for Aerospace Development

Two different drone platforms will be available to implement the demonstrations foreseen for the construction use case with different payloads and components aimed to demonstrate different aspect for the specific Construction Use Case (see Figure 11).

For the first demonstrator, digitalization of the state of the constructive process of a civil infrastructure, a commercial-off-the-shelf (COTS based on DJI multi-copter) solution as operational platform (TRL 8-9) will be used, with the possibility to integrate different equipment for the mission lowering its TRL to 6. The main characteristics of the mission are:

- autonomous flight operations in outdoor environment;
- pre-programmed flight plan;
- RGB camera integrated in a gimbal for image acquisition;
- onboard PC for data and image acquisition;
- offline processing of data in the context of photogrammetry for Building Information Modelling (BIM) application;
- possibility for the project partners to install proprietary application on target.

For the second demonstrator, definition of the state of the constructive process of an underground infrastructure, a commercial-off-the-shelf (COTS based on DJI multicopter) solution as operational platform (TRL 8-9) for testing more demanding features at TRL (5) will be used. The main characteristics of the mission are:

- autonomous flight operations in indoor environment, such as the interior of a tunnel under construction;
- required equipment for SLAM (Simultaneous Localization and Mapping) navigation, in a GPS-denied environment;
- integration of LIDAR sensor for reconstruction of surrounding environment;
- onboard PC for sensor data processing and SLAM;
- possibility for **COMP4DRONES** partners to install proprietary application on target.

Figure 11: Drone platform foreseen for the construction use case

3.1.3.3 TOTAL

To demonstrate the use of a swarm of UAVs to perform a logistic mission to deliver thousands of seismic sensors over an area of several tens of square kilometres, a specific drone has been developed around a specific payload able to drop 6 seismic sensors from an altitude of 50 m Above Ground Level (AGL).

To achieve the desired productivity and safety, automatized missions with multiple vectors are mandatory. Based on both COTS (UAV's parts and components) and R&D (swarm management system, UAV's architecture), the system developed to fulfil the logistic mission is composed of (see Figure 12):

- On the left, the components of interest to the C2 Center architecture is included. These components are necessary to show how some requirements will be upheld:
  - A Base Camp where the Command & Control Center is managing the overall operations,
  - Various safety and security barriers:
    - Strategic to prevent intrusions:
      - An information campaign to explain the aims and dangers of the operation,
      - Worksite signage to inform of the proximity and danger of the operation,

        - Tactical to detect them:
            - An acoustic detection perimeter around the mission area,
            - A video detection system around the mission area,
            - Infra-Red fences on strategic roads, pathways and tracks,
            - Human observers on strategic roads, pathways and tracks,
- On the right, the airborne dropping system itself.
    - Five UASs (but it may go up to 10 UASs) flying as a swarm referred hereafter as “Dropping UAS”.
    - A container called “cassette”, mounted on each Dropping UAS, able to carry six Downfall Air Receiver Technology (DART)s and equipped with a video system to detect human and obstacle presence below it to avoid harmful DART dropping.
    - A UAS dedicated to the detection of intruders in the zones where each Dropping UAS is going to drop a DART referred hereafter as “Surveillance UAS”.
    - A flight management system called EZ Chain® that determines in real time the trajectory of each UAS and takes into account geo-fencing and avoidance of other stakeholders (other UASs, staff, vehicles or intruders).
    - A single Ground Control Station controlling all UASs.

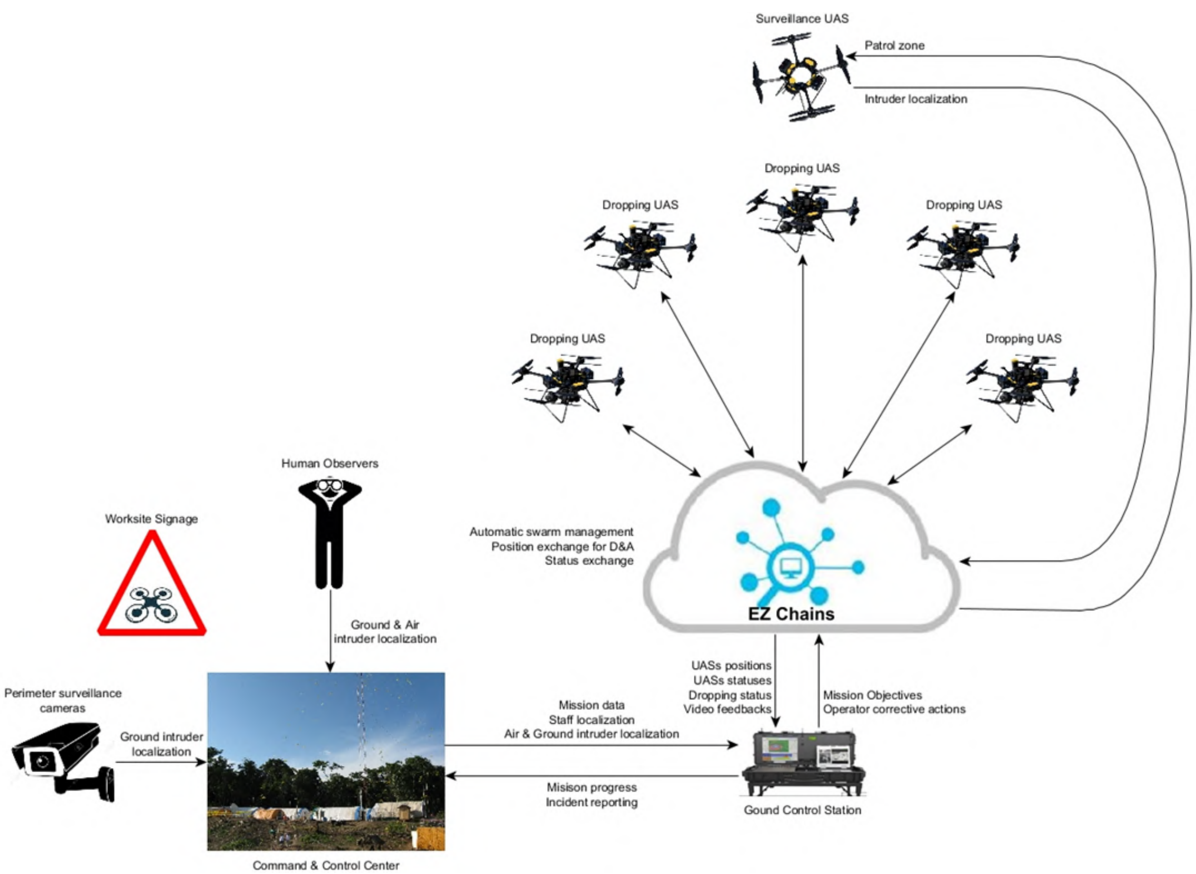

Figure 12: Swarm of drones’ architecture

The communication architecture (see Figure 13) is composed of:

- A UAS network based on a private LTE network,
- A network between the C2 Center and the GCS based on the same private LTE network as the UAS network,
- A communication link between the cassette and the DART during cassette loading and after the drop,
- A dedicated communication link to terminate the Dropping UAS flight,
- A dedicated communication link for the UAS Pilot remote controller,
- An option to have a dedicated communication link for FPV video for the UAS Pilot (may not be used depending on the UAS network technology).

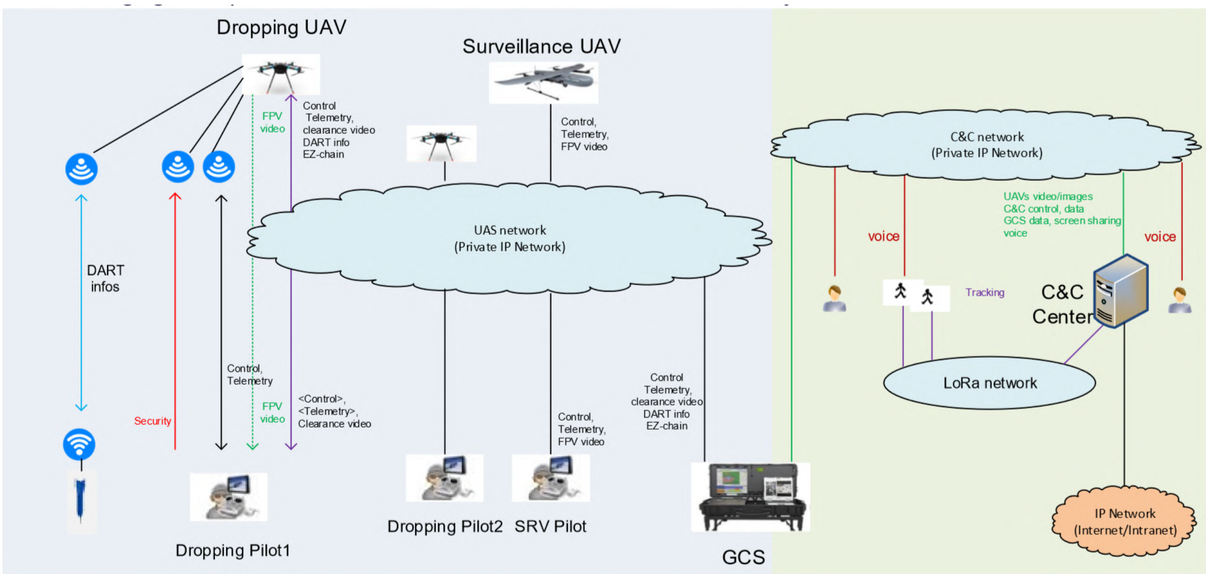

Figure 13: Communications architecture

3.1.3.4 ATE: Atechsys Engineering

Atechsys main fly configuration is about autonomous flight in rural areas. For this purpose, a flight path is pre-defined and tested using the weather data. If the test is conclusive, the flight is launched. Usually, the drone carries a payload (equipment or parcel). The drone, during its flight, checks the trajectory. And if there is any kind of failure, the drone has different warning levels, the last one being the parachute opening and shutting down power.

Today the high-level software architecture of Atechsys drones is open source. The drone can receive moving orders from four possible sources: the autonomous mode, remote control, ground station, and terminal receiving the drone. Moreover, those orders can be re-transmitted by other device (for example, a terminal for drone can relay orders or a droid).

The Atechsys drones' communication architecture (see Figure 14) is composed of:

- A UAS network based on a private LTE network,
- A network between the C2 Center, the GCS based on the same private LTE network as the UAS network, using the retransmission tower.
- A ground station (close or distant) communicating control command, position or mission plan with the drone.
- A rover that can guide the drone for landing procedure thanks to C2 link with MAVLink protocol
- Identification module on the drone communicating in Wi-Fi

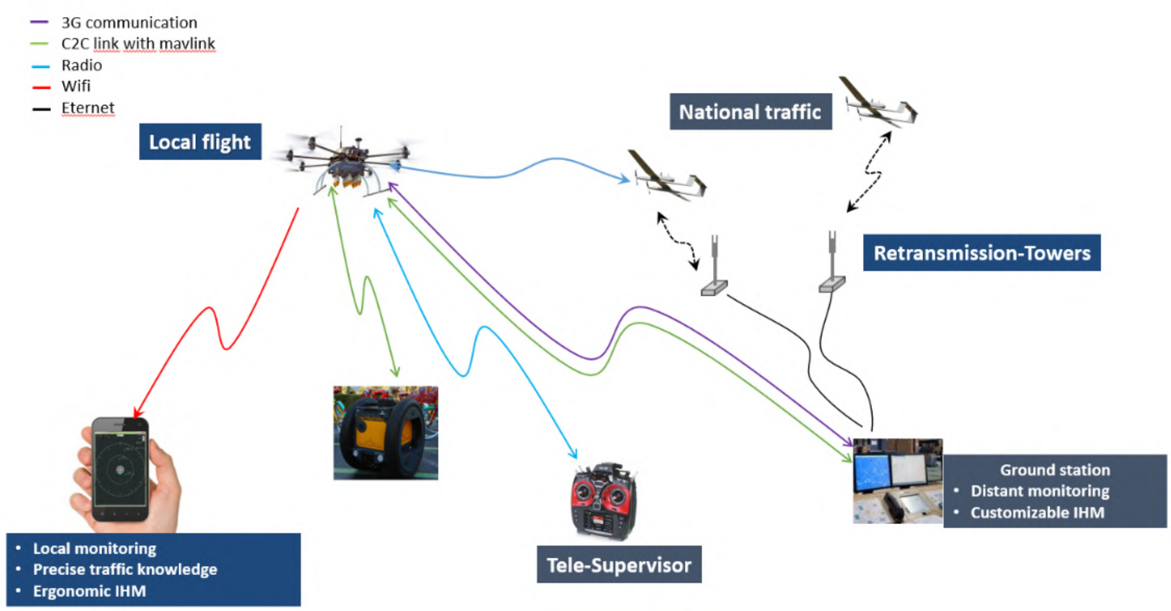

Figure 14: Atechsys drones' communications architecture

3.1.3.5 TOPVIEW

Two different drones will be available to implement the demonstration foreseen for the agriculture use case with different payloads and components aimed to demonstrate different aspect for the specific Agriculture Use Case:

1. A commercial-off-the-shelf (COTS based on DJI M210 multi-copter) solution as operational platform to test medium demanding features at the highest TRL possible (TRL 8-9):
    a. Autonomous flight operations.
    b. Georeferenced thermal infrared and RGB data acquisition with a pre-programmed flight plan.

   c. Handling of unexpected events or conditional instructions based on local onboard computation (e.g. computer vision algorithm on local video streaming).

2. An Integrated drone solution (obtained by assembling COTS parts available on the market) for testing more demanding features at a lower TRL (7) such as:

   a. Autonomous flight operations with possible interface to local U-space service provider;
   b. High Accuracy/Precise positioning with dual band multi-constellation European GNSS receivers.
   c. Handling of unexpected events or conditional instructions based on local onboard computation e.g. (Computer Vision algorithms, proximity sensors fusions, Terrain following features)
   d. Non-nominal architectures configurations (GNSS augmentation over IP, C2 over Internet with local Telecom operator, Interface with U-space local service provider)
   e. Possibility to test different opensource autopilot stack (Arducopter, ROS, Paparazzi)
   f. Possibility for **COMP4DRONES** partners to install proprietary application on target OBC (i.e. Computer vision algorithm for crown tree detection and identification aimed at modifying at run time – tactical stage - the flight plan)

Both solutions have been identified and highlighted in Figure 15 where both drones have been reported with the identified components at this stage.

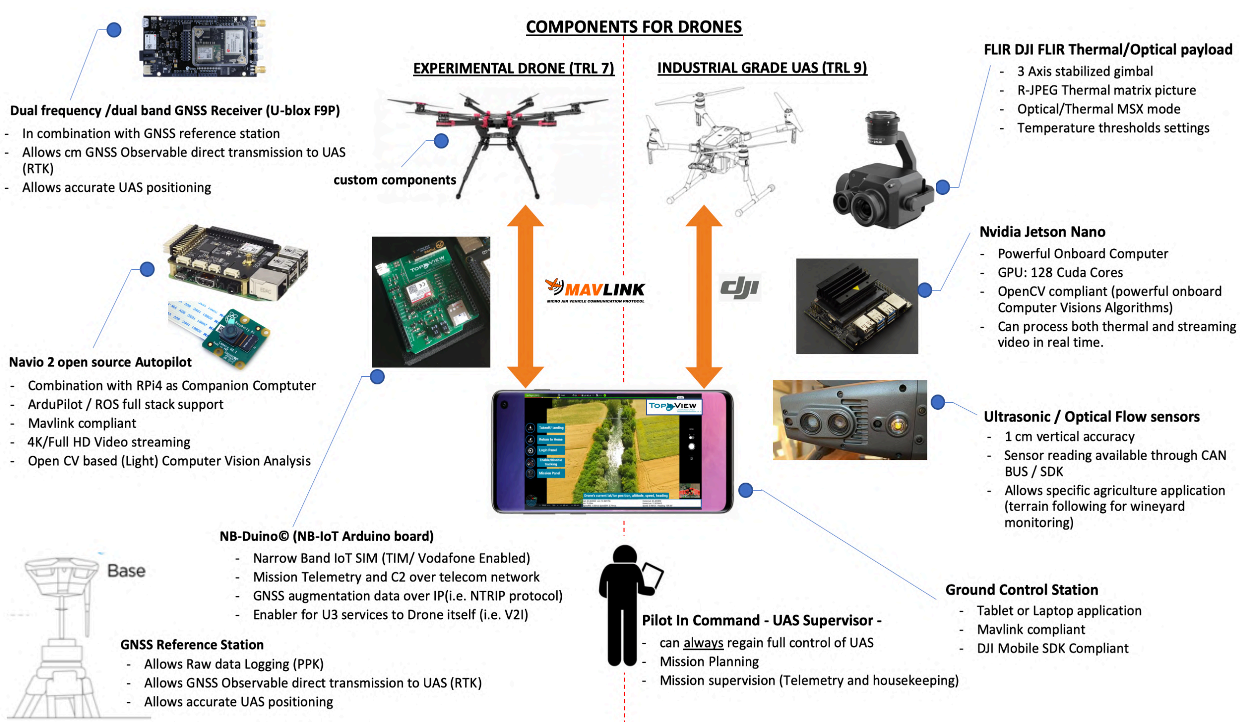

Figure 15: Drones to implement the demonstration for the agriculture use case

3.2 UAV

In this section the UAV that will be used in the Use Cases and they have been used to define and specify the **COMP4DRONES** framework are introduced and listed.

3.2.1 AIROBOT: Airobot bvba

Airobot's technology focusses on automating the complete flow of collecting and processing of accurate data. For the collection Airobot created the AiroCore: a complete flight and payload management core to turn a drone into a flying robot.

The AiroCore is the 'Motherboard' of the drone, containing the autopilot, 2 real-time flight CPU's, a payload processing module, centimetre accurate non-jammable GNSS, wireless communication, interfaces to multiple types of cameras. It has been designed with automated Beyond-Visual Line Of Sight (BVLOS) flights in mind. The layered computing architecture prevents that a software issue in, e.g. the processing of sensor data, can cause a safety risk (see Figure 16).

It also allows to remotely connect to the drone via a multitude of wireless technologies (4G/LTE, 2.4GHz, 5.2GHz). As the flight planning software runs on the drone no additional software needs to be installed on a local PC. This allows Airobot to program a drone for almost any application.

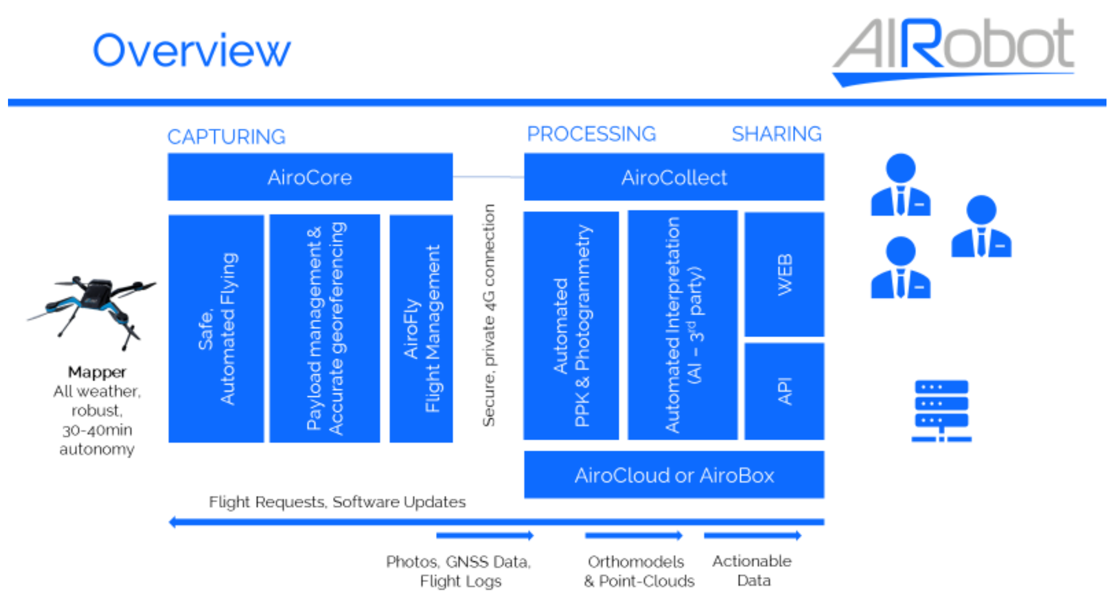

Figure 16: Airobot technology architecture

The AiroCore is integrated on an all-weather platform, the Airobot Mapper, which is capable flying in winds of 35knots and has an IP rating of IP48 (Figure 17). However, the AiroCore can be integrated on any drone platform and can speed up the development of new drone platforms. The ground control station software is AIroFly shown in Figure 18.

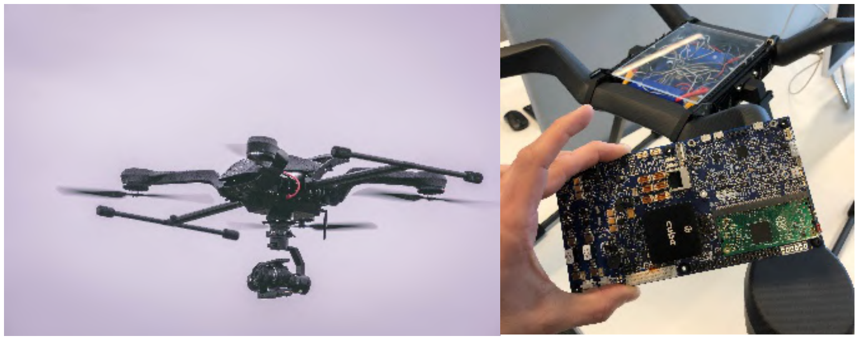

Figure 17: Mapper and AiroCore

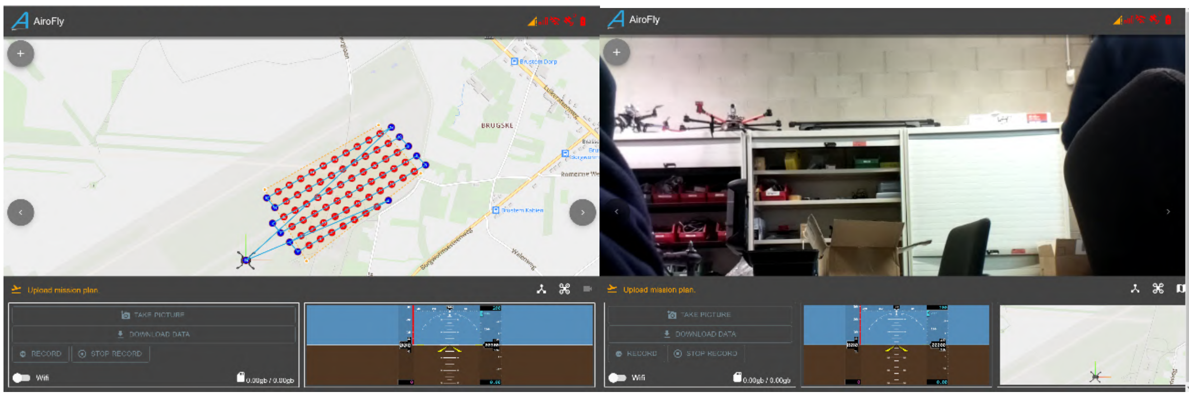

Figure 18: Remotely Accessible, On-board User Interface (AIroFly)

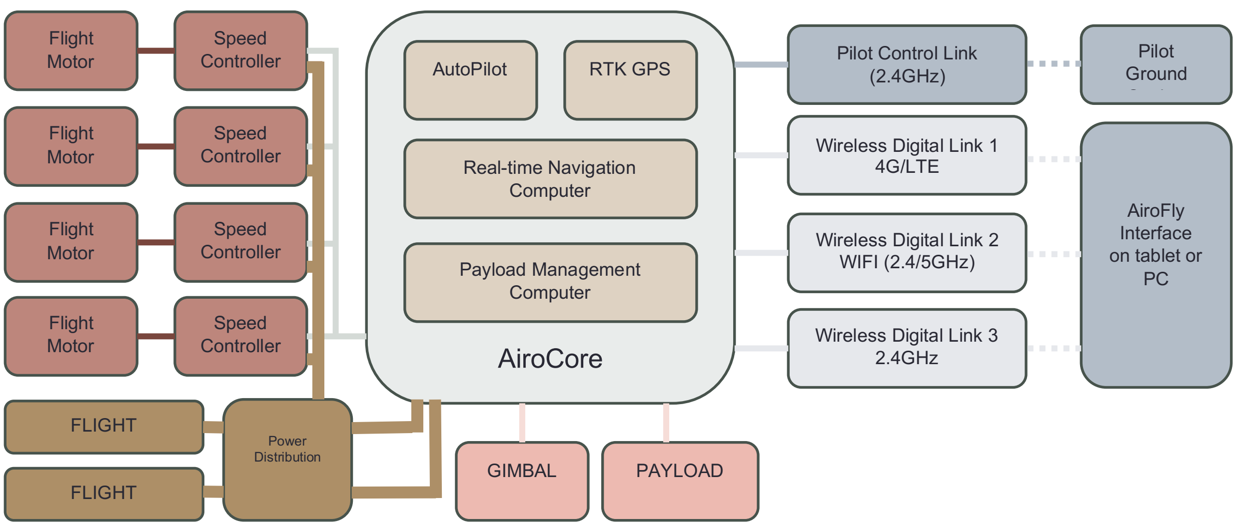

Figure 19: AiroCore block diagram

The main features of the AiroCore (Figure 19) are listed below:

Layered Computing Architecture for increased safety

- Flight Controller (Cube)
- 2 Realtime flight CPU's (one for navigation & flight planning, one for collision avoidance)
- 1 Powerful CPU for interfacing with camera's & running the user interface

Positioning Sensor

- Multi-constellation (GPS, GLONASS, GALILEO, BEIDOU), multi-frequency GNSS receiver
- RTK (centimetre), PPP (decimeter) and WAAS (submeter) positioning modes
- Optionally dual antenna functionality and integration with higher accuracy IMU
- Robust against jammers, spoofing and other forms of (un-)intentional interference

Communication

- 2.4 GHz IP link for visual-line-of-sight flights
- Optional extension with 4G/LTE module
- Optional extension with ADS-B module

Camera Support

- 20MP Sony UMC-R10C (with optional zoom)
- FLIR Thermal camera
- Micasense multispectral camera
- Imec hyperspectral camera
- Up to 6 cameras for FPV flights

Redundant dual-power supply

- Fully redundant power supply
- Separation between critical & non-critical components

On-board Click-And-Fly user interface

- Operated by local pilot or remotely from command centre
- Customizable for specific applications

The specifications of the Airobot Mapper (Figure 17) are listed below:

Flight time: 30-40min
Ground Sample Distance
    20m flight altitude0,24 cm/px
    50m flight altitude0,61 cm/px
    80m flight altitude0,97 cm/px
Environmental
    IP Rating   IP43
    Wind sustainability   35 knots
    Operating Temperature Range   -10°C-45°C
Camera Technology
    Lens   35mm; f/1.8
    Sensor   23,2mm x 15,4mm APC-C size, Exmor APS HD CMOS, 20.1MP
GNSS Technology
    Supported Positioning Modes   standalone, SBAS, RTK, PPK, PPP
    Supported Signals
        GPS: L1,L2,L5
        GLONASS: L1,L2, L3
        Beidou: B1,B2
        Galileo: E1,E5a, E5b, Altboc
        SBAS: EGNOS, WAAS, GAGAN, MSAS, SDCM (L1, L5)
        QZSS: L1, L2, L5
        L-Band: 2 channels
    Realtime RTK
        Horizonal Accuracy   0,6cm + 0,5ppm
        Vertical Accuracy   1cm + 1ppm
    Anti-Jamming Technology Narrowband & wideband interference mitigation, Advanced Scintillation mitigation
    Realtime RTK basestations supported: NTRIP, RTCMv3 compatible basestations
    PPK Processing with AiroCollect software
Size / Weight
    Take-off Weigth   7kg
    Diagonal distance   70 x 70 x49,5cm

AiroCollect Software

The AiroCollect software (Figure 20) can run on in the cloud or on a local server, running Linux, “the AiroBox”. Airobot will provide a rack mountable server, including the required GPU & CPU power to allow for fast data processing. All software is loaded in Dockerized containers (with GPU access) which will be remotely maintained by Airobot. The toolchain is flexible enough to add proprietary components.

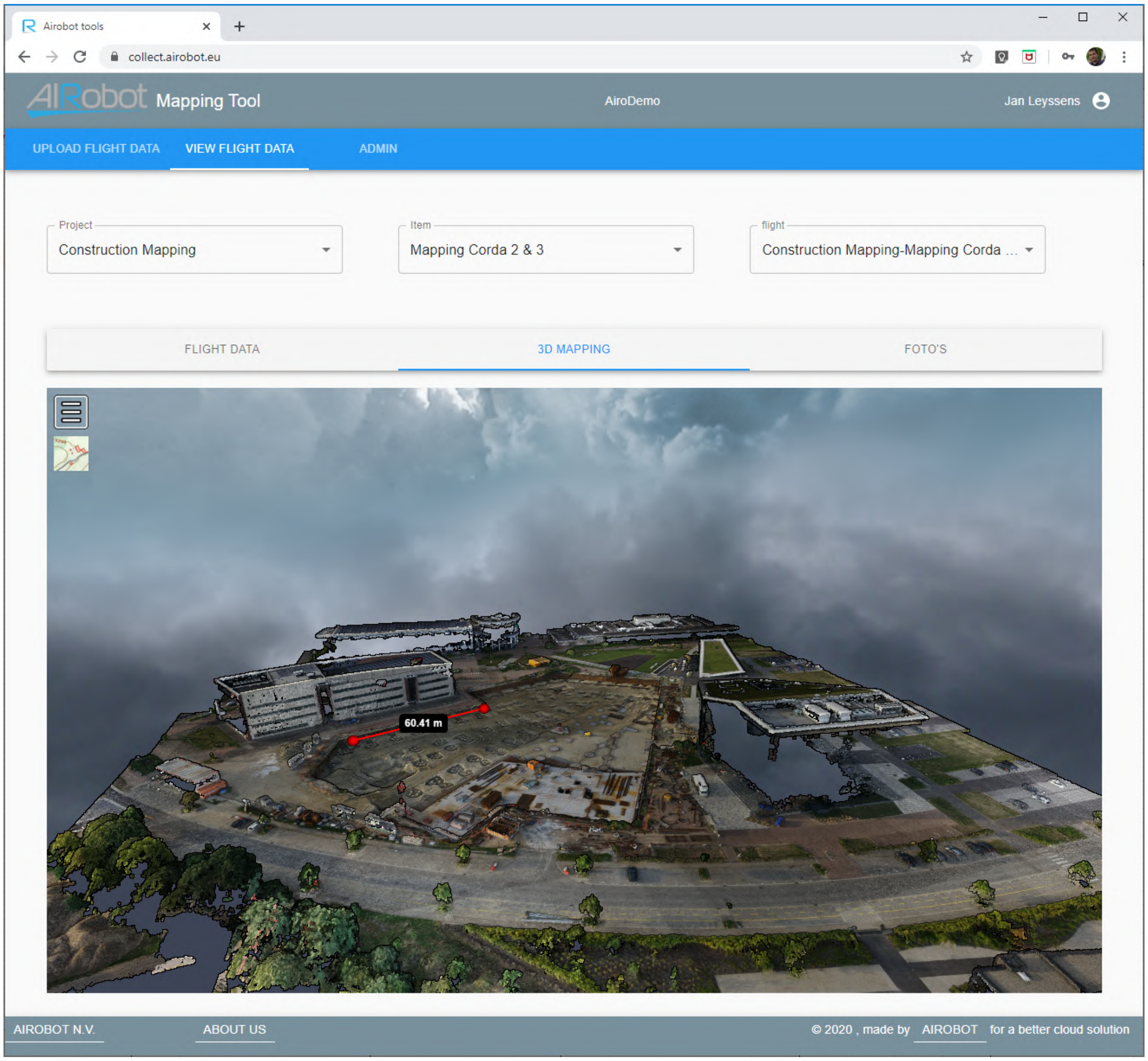

Figure 20: AiroCollect

3.2.2 TUD: Delft University of Technology

The TUD (Delft University of Technology, Delft, The Netherlands) provides a swarm of “small” drones equipped with an event-based camera, the DVS240, and with a collision avoidance system.

The strategy employed by TUD is to develop a plug-and-play (i.e. generic), ROS-based control system to be connected to any drone (Figure 21). This system is composed of the aforementioned event-based camera, connected to an Odroid XU4 running the Ubuntu 16.04 OS and ROS Kinetic environment. Current development makes use of the Parrot Bebop 2 drone running the Paparazzi autopilot.

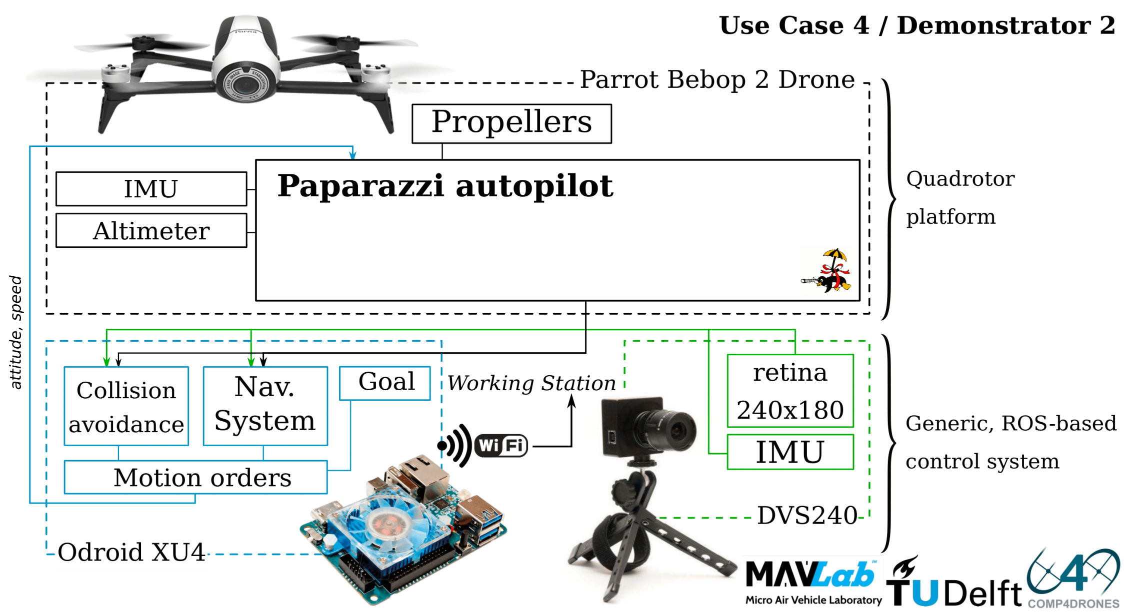

Figure 21: Hardware architecture of the drone.

In Figure 21, Black components depict available hardware and sensing in the drone (slave). Blue components describe the control system embedded on-board the Odroid XU4 electronic board (master), connected to the host station using Wi-Fi protocol. Green components describe the visual-inertial sensing provided by the event-based camera.

3.2.3 DEMCON: DEMCON ADVANCED MECHATRONIC SBV

A generic overview of the technology building blocks, as defined by DEMCON, for mobile robotic/unmanned/autonomous systems can be found in Figure 22.

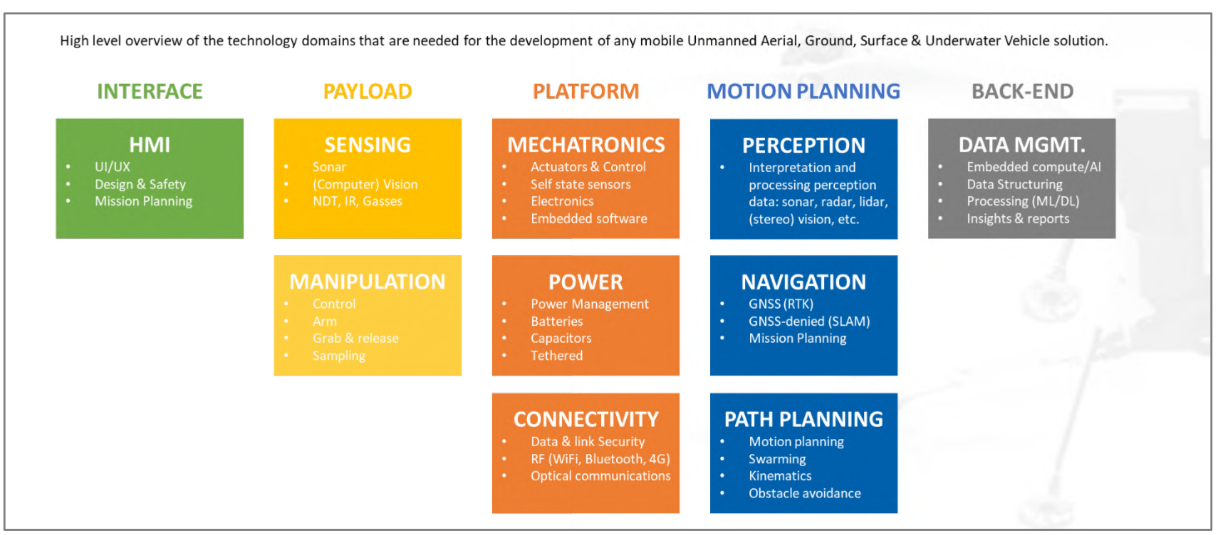

Figure 22: General UAV technology domains

The technology building block colours correlate with the system functionalities in Figure 23. The system functionalities represent all the UAV system user and technical specific system functionalities.

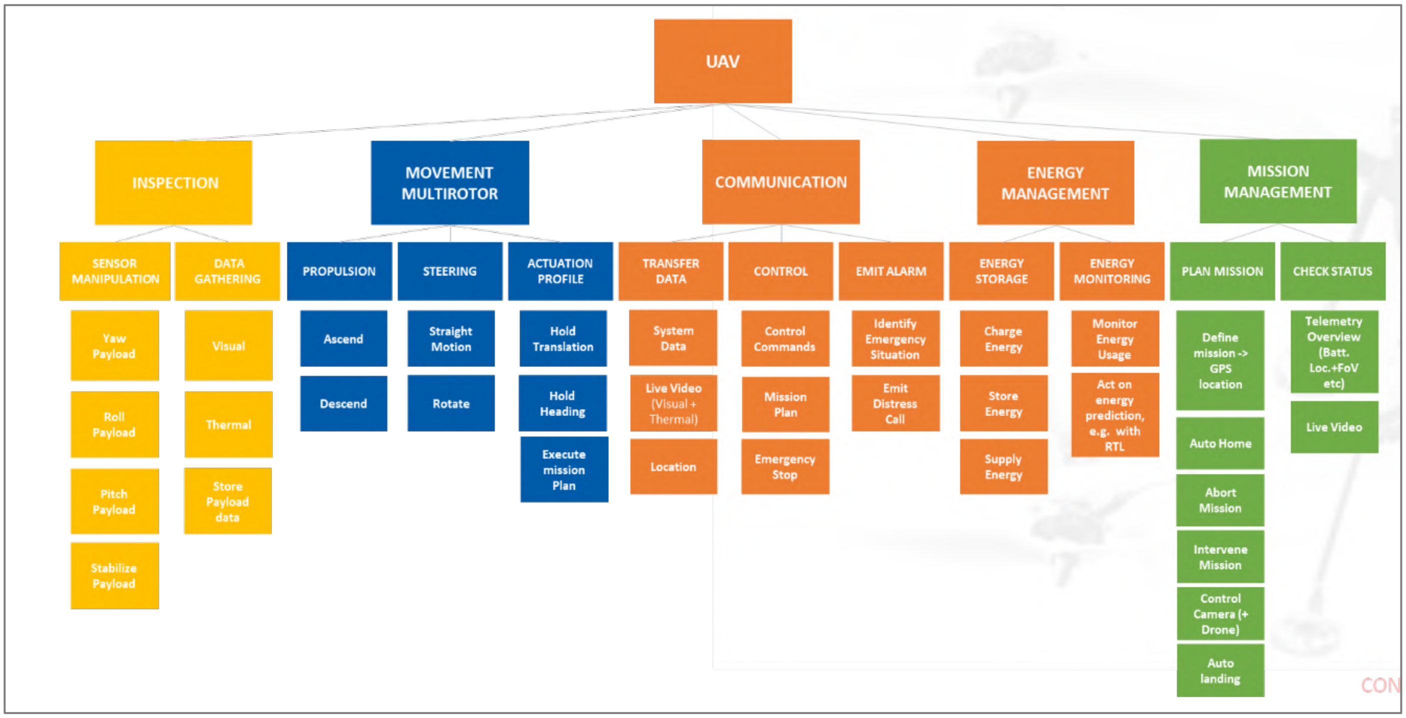

Figure 23: Specific UAV system functionalities

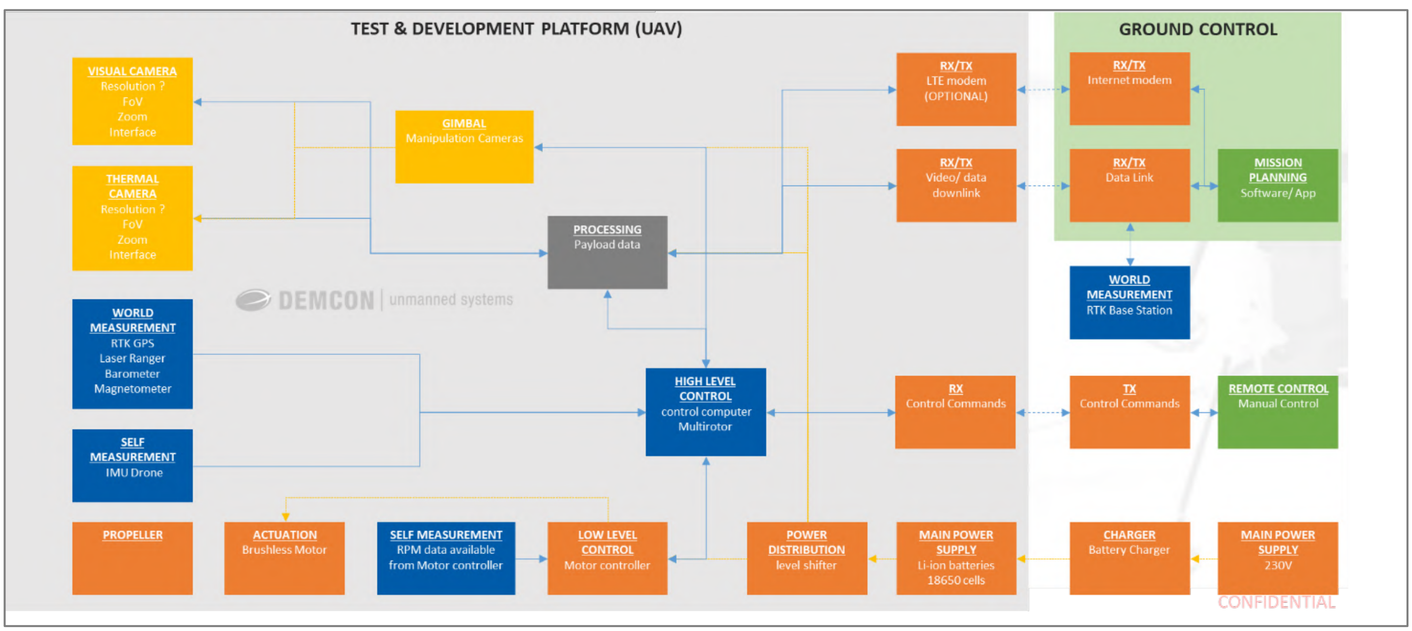

Figure 24: System architecture

Figure 24 defines the UAV technical architecture defining the system functionalities and their relationship to each other.

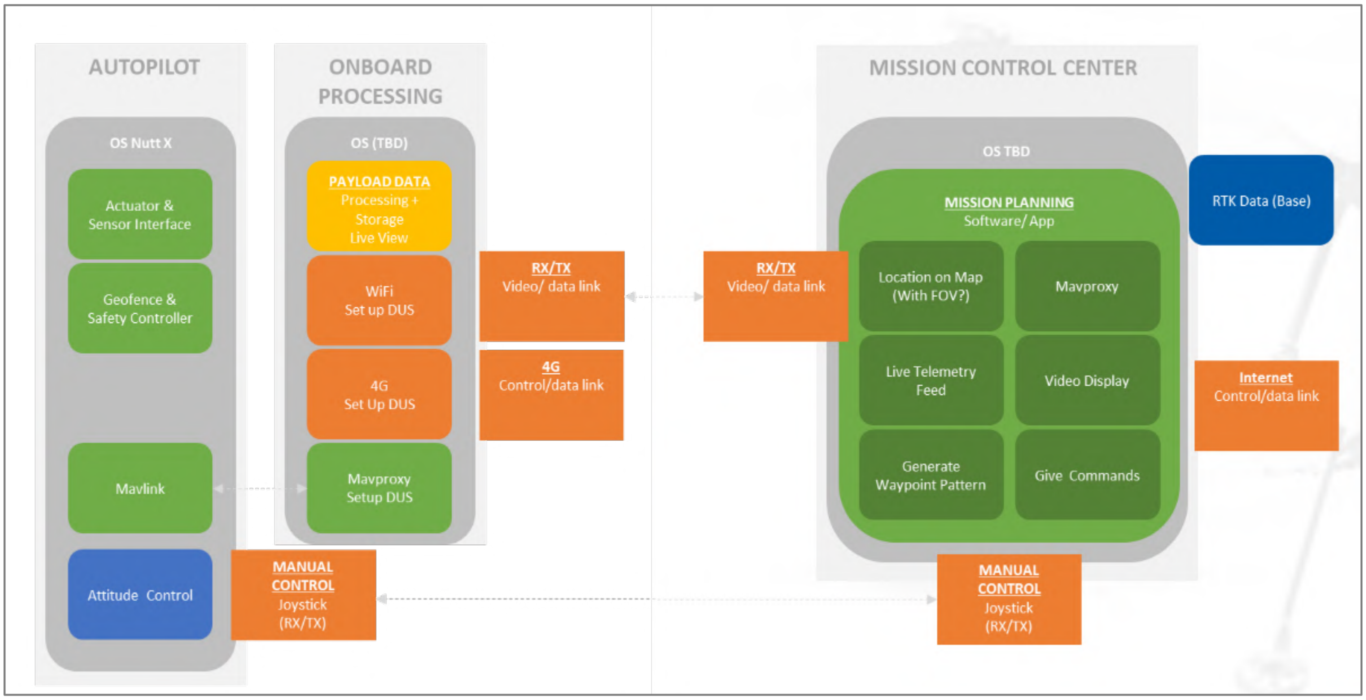

Figure 25: Software architecture

Figure 25 defines the software architecture with the system functionalities and the interfaces for partners to use for interfacing/ integration.

3.2.4 SCALIAN: EZ_Chains

EZ_Chains is an architecture that was first aimed at autonomous UAVs, but has since been extended to autonomous robots. It relies on a centralized knowledge base that allows distributed (embedded) decision making. The architecture is composed of hierarchical components: there is a decision layer to provide plans to the monitoring /execution layer that uses the interface layer to control the robot and its payload.

The modules composing EZ_Chains:

- The **knowledge base** provides a view of the fleet situation and the mission evolution in a SQL database. It also triggers notifications for each fleet/mission event. Through its API, each agent of the fleet (UAV, GCS, C2, etc.) is able to declare critical information, to book shared resources, to send orders or instructions to other agents, etc. It uses the **communication system** to ensure that the state is correctly synchronized among the fleet.
- The **task monitor** is the central node of EZ_Chains. This module sends requests to all the other modules in order to perform actions. The task monitor communicates its planned moves and actions to the fleet by sending transactions to the knowledge base that are transmitted to the fleet thanks to the communication system. The task monitor is also listening to the fleet/mission events triggered by the knowledge base in order to detect conflicts with its initial plan.

- The **task planner** receives request from the task monitor to compute the best plan (that is, the best sequence of actions) in order to achieve a goal (e.g. drop six DARTs). To do its computation, the task planner reads the knowledge base to get the current status of the mission.
- The **navigation monitor** is in charge of the UAV navigation. It complies with the task monitor queries (e.g. take-off, move to, hold position, etc.). This module ensures the safety of the UAV by doing air traffic management, collision detection, and forbidden areas avoidance.

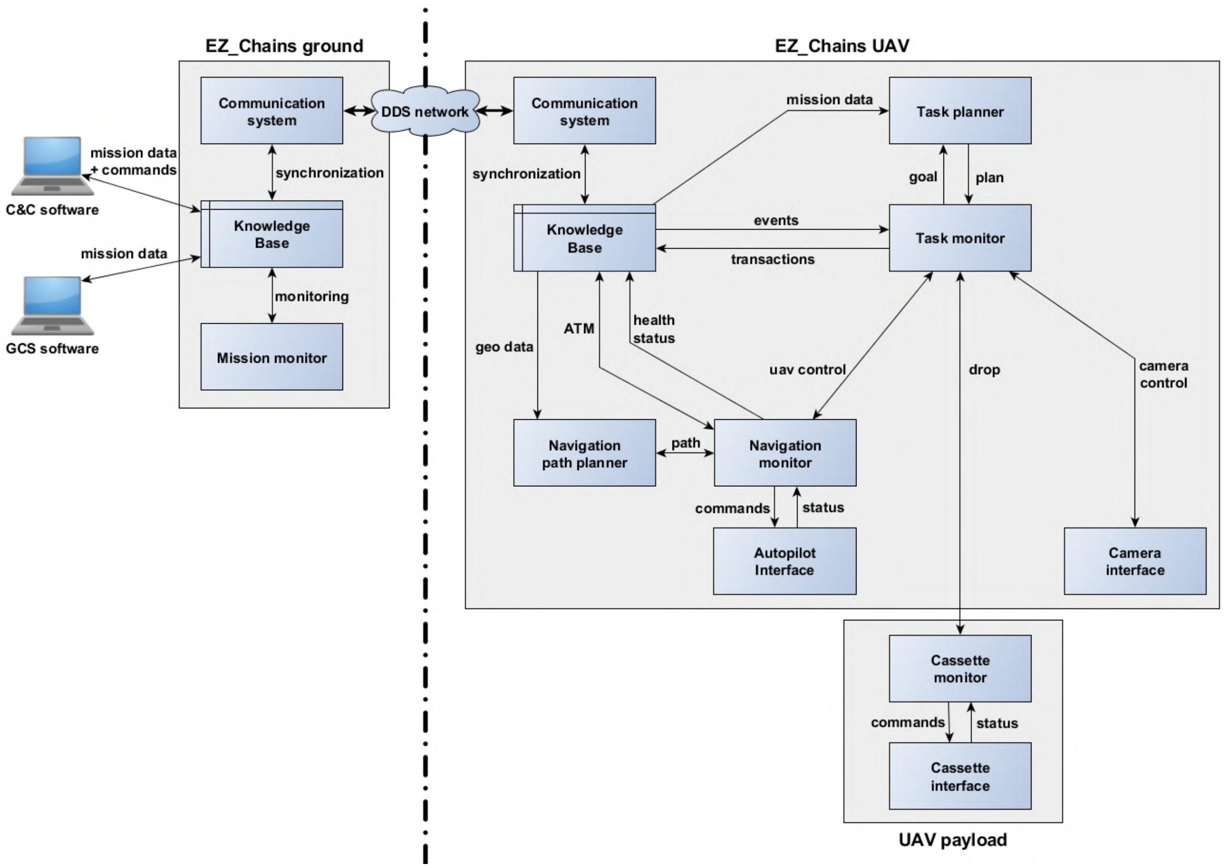

Figure 26: EZ_Chains modules

- The **navigation path planner** is used by the navigation monitor to compute an efficient path to reach a destination, avoiding the forbidden areas, using the corridors if needed and avoiding potential conflicts with the path of other UAVs.
- The **autopilot interface** provides the low-level services to control the UAV behaviour. It receives the instructions from the navigation monitor and reports the UAV status to it.
- In the figure, two payload interfaces are depicted that are related to the mission carried out by the system. There are used to accomplish the Logistics use-case (UC3 – Demo 1), where sensors have to be dropped. Hence there are three sub-modules:

  - The **camera interface** provides the low-level services to control the camera behaviour and its gimbal. It receives the commands from the task monitor.
  - The **cassette monitor** is running on the cassette controller and is connected to the task monitor through a network connection between the cassette and the drone. On a dropper UAV, the cassette provides services related to the dropping of DARTs, but any kind of payload could be handled.
  - The **cassette interface** provides the low-level services to manage the cassette sensors and actuators. It receives the instructions from the cassette monitor and reports the cassette status to it.
- The *ground* version of EZ_Chains, also called *black box* embeds the communication system and the knowledge to allow the GCS and the C2 to define the mission and to interact with the fleet. EZ_Chains ground also embeds a tiny **mission monitor** module doing some checks about the fleet and the mission evolution.

3.3 UAV Sub-systems

In addition to the UAV architecture provided and described by the project partners in the previous section. In this section, a number of UAV sub-systems are described which are the focus of some project partners.

3.3.1 Autonomic Management: FORSCHUNG BURGENLAND GMBH

FB will develop "Autonomic Management" solutions for smart and secure drone-based applications in a vineyard management. This will be based on an extension of existing work with domain specific aspects.

The Generic Autonomic Management Framework (GAMF) architecture, shown in Figure 27, is a Java-based framework used to develop autonomic managers for any target system without having to (re)implement the generic control mechanisms. GAMF provides generic control mechanisms based on the autonomic control loop (MAPE-K) and a set of interfaces to allow the interaction between control mechanism and system specific management components, the system adapters. System adapters include event generators and effectors, which allow interaction of the control mechanism with the target system, as well as metric extractors and policy evaluators, which provide the means for computing a specific response determined by policies to an observed situation modelled by metrics. The information about how a specific system adapter is triggered is held in the system adapters registry.

From a Service Oriented Architecture perspective, Generic Autonomic Management is designed as a component-based Representational State Transfer (REST) service (GAMS) that can be invoked by different SOA-based frameworks without requiring a high adjustment effort. Additionally, given its generic property, each component of the autonomic control loop has abstract interfaces that can be used by a number of application systems. This would reduce the software engineering effort since there is no need to (re)implement the generic control mechanisms for different application systems, only to properly define events, metrics and adaptation policies.

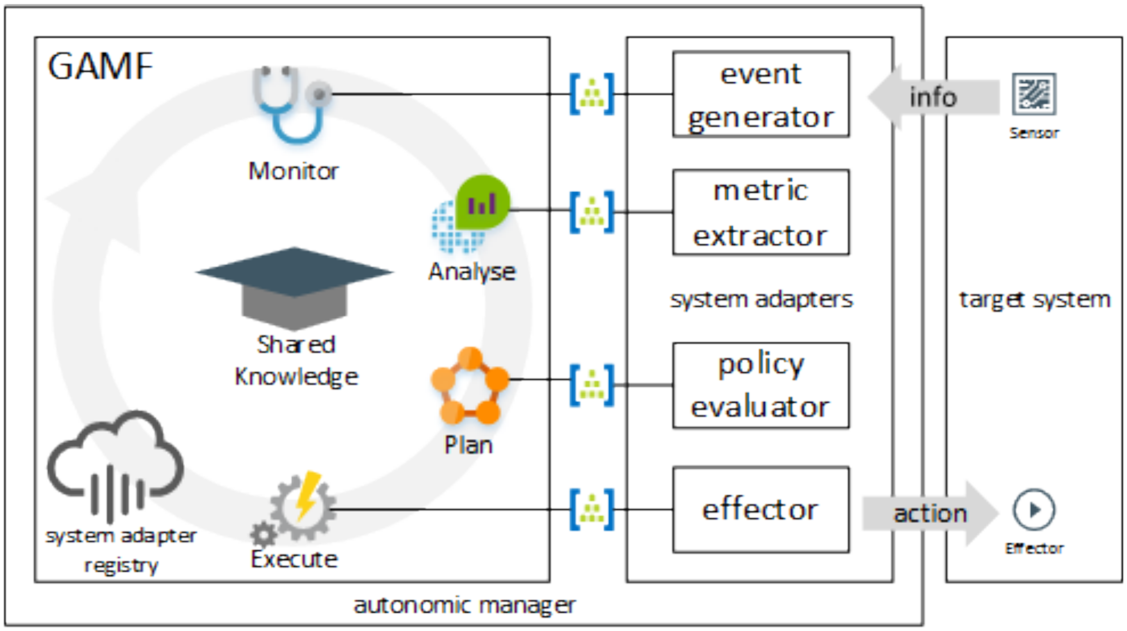

Figure 27: GAMF architecture

Monitor: The Monitor component constantly collects monitoring data from the sensor. The component performs a pre-analysis based on the incoming sensor data and context data stored in the SharedKnowledge. In case there is a significant delta an event is generated.

```
monitor[serviceID]
     getSensorData(sensorData)
     preAnalysis()
     generateEvent()
     updateSharedKnowledge()
```

Analyze: The Analyze component evaluates the events received from the Monitor component with respect to the requirements and context data in the SharedKnowledge. If the requirements cannot be satisfied a change request including a description of the metrics is send to the Plan component.

```
anayze[serviceID]
     getRequired(require)
     getContext(context)
     getEvent(event)
     extractMetric()
     updateSharedKnowledge()
```

Plan: The Plan component is able to understand the metrics received from the Analyze component and to derive adaptation policies.

```
plan[serviceID]
     getMetric(metric)
     addResource()
     releaseResource()
     updateSharedKnowledge()
```

Execute: The Execute component receives the policies from the Plan component and executes the derived action via the GenericAutonomicManagement service.

```
execute[serviceID]
     getPolicy(policy)
     invokeNextAction()
     updateSharedKnowledge()
effectorAdd[serviceID]
effectorRelease[serviceID]
```

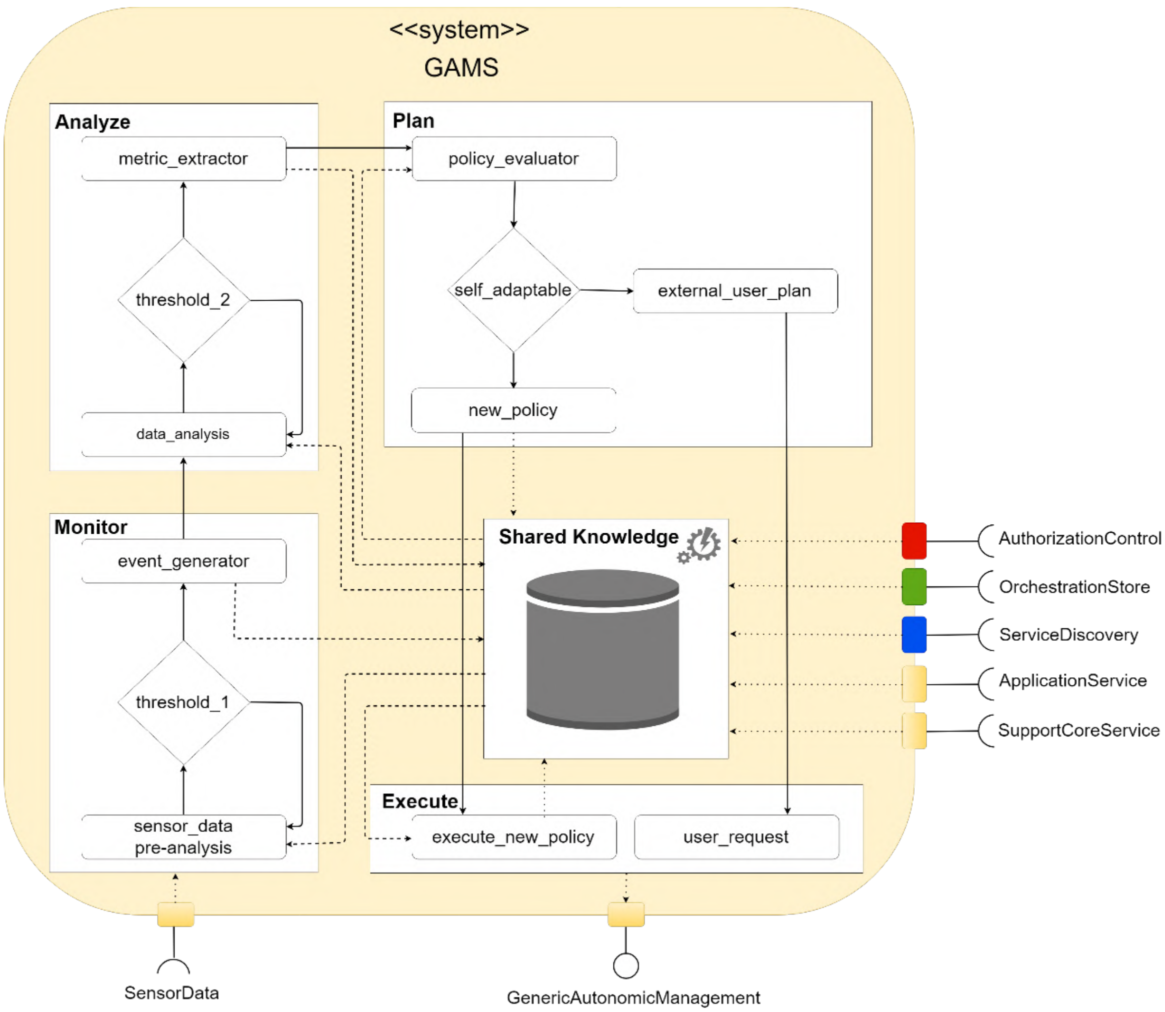

Figure 28: Generic autonomic management as a component-based REST service

In case the system cannot find a suitable adaptation solution (e.g. no additional resource is available), a user intervention is required to handle the issue.

The framework will be validated in the agriculture use case UC5, Demo 2. This will help to build a communication system between the sensors, the drone as mobile sink and the back end in which e.g. the use of expensive ciphers can be decided based on a policy. Modelling such an application will allow users and developers to identify dependencies at an early state.

3.3.2 UAV Communication: ECOLE NATIONALE DE L'AVIATION CIVILE

Being the original author and one of the main contributors, ENAC UAV team uses the Paparazzi system for scientific research[18].

Communication with the autopilot is based on a custom protocol and message definition, called Pprzlink[19]. Libraries exist for airborne and ground segments, in multiple languages (C, OCaml, Python), and for multiple transport protocols (Serial, UDP, Ivy).

On the ground segment, ground control station uses Pprzlink with the Ivy transport. Ivy is a software publish/subscribe bus based on UDP or TCP to exchange text messages[20].

There are four ways to extend Paparazzi functionalities:

- Using Pprzlink with the current ground station tools
- Using Pprzlink independently of the ground station tools
- Adding a dedicated board on the drone and using Pprzlink to communicate directly with the autopilot (usually with the serial transport)
- Adding a module to the autopilot itself

A combination of these options can be used at the same time to achieve specific goals.

Using Pprzlink with the ground station

The easier way to interact with Paparazzi is to create a new agent as part of the ground station. All parameters and configuration files are easily accessible, making it easy to interact with the drone or display new data on the GCS. As example, the Interactive Informatics team of ENAC used it to design novel human-drone interactions for safety pilots and adaptable interactions for pilots with disabilities[21].

Using Pprzlink without the ground station

It is also possible to use Pprzlink on the ground by interacting directly with the datalink. This approach gives less high-level services but makes it simpler to exchange custom messages.

[18] https://hal-enac.archives-ouvertes.fr/hal-01059642/
[19] https://github.com/paparazzi/pprzlink
[20] http://wiki.paparazziuav.org/wiki/Ivy
[21] https://hal-enac.archives-ouvertes.fr/hal-02128390

Adding a dedicated board on the drone

Custom dedicated boards (Raspberry or Arduino for instance) can be integrated in the drone and interact with the autopilot through a local link, typically a serial interface between the dedicated board and the autopilot. The type of interaction is the same than with a ground agent.

Adding a module to the autopilot itself

The modularity of the airborne architecture (see Figure 29) also enables users to write custom modules that will run on the autopilot itself. All sensors data, payload or actuators are then available to this module.

Modules are the building blocks of the airborne architecture. These modules can do various things such as handling a specific sensor connected to the autopilot, enhance navigation capabilities, implement custom stabilization or guidance control loops…

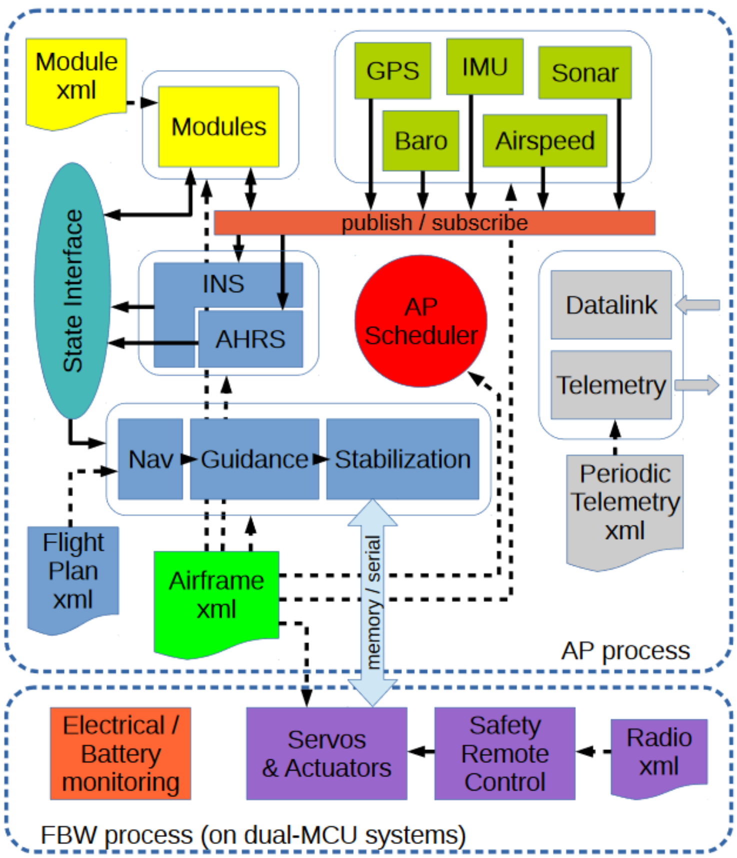

Figure 29: Paparazzi airborne architecture

Paparazzi also has a simulator based on JSBSim. The autopilot can be built for both the hardware target and the simulator target. The simulator then uses the same code that will run on the real hardware. Custom modules that use platform specific capabilities must provide alternative code in order to be built for another target, such as the simulator.

3.3.3 Positioning Systems: ACORDE TECHNOLOGIES SA

Real-time, geo-referenced position and attitude information, and moreover, the specific reference time they refer to, is essential information not only for feeding drone stabilization and navigation algorithms, but also for other aspects of safe drone navigation (e.g., geofencing, U-space), and for mission related purposes.

In **COMP4DRONES**, ACORDE is providing two types of positioning systems. First, ACORDE provides an *integrated geo-referencing system*, capable to provide real-time data (10Hz) on the current geo-referenced position and attitude of the system (or reference body) it is attached to (in a strap-down configuration). Figure 30 sketches the architecture of this system and its main outputs.

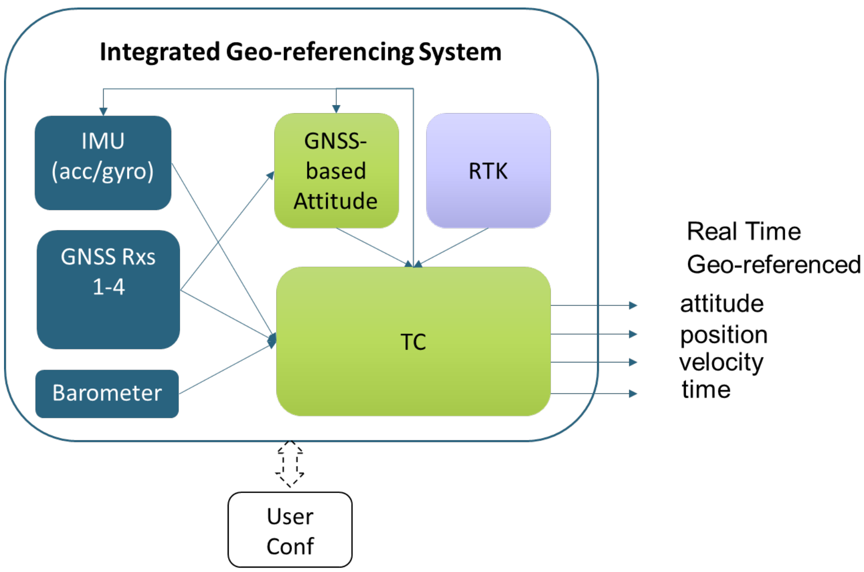

Figure 30: Basic architecture of the integrated Geo-referencing System.

Regardless the different geo-reference formats supported at the output (e.g., local North, East, Down (NED), Earth Centered Earth Fixed (ECEF), geodetic or ellipsoidal height), the basic information offered is position, velocity, time (this triad commonly known as PVT), and attitude. This integrated system is able to offer a resilient, centimetric position and under degree attitude components, thanks to a multi-GNSS, and modular approach. The system provides:

- an integrated solution, where independent raw data sources/sensors (in blue in Figure 30), i.e. several GNSS receivers, a low cost IMU, barometer and temperatures sensors, are integrated, together with the computational resources in charge of executing sensor fusion, navigation data and configuration software.
- a configurable solution which allows, among other things, configuring the number of GNSS receivers used, and the utilization of a Real Time Kinematic (RTK) module (light blue block in Figure 30) for accurate position.

- a more accurate attitude, which eliminates calibration and magnetic interference issues of the magnetometer based solutions, by including a multi-GNSS-based attitude computation algorithm (green block in Figure 30)
- a reliable, higher data rate solution, thanks to a tightly coupling data fusion algorithm (TC green block in Figure 30), based on an Extended Kalman Filter (EKF), able to couple multi-GNSS raw data with the aforementioned GNSS-based attitude estimation, and with low-cost inertial sensors Inertial Measurement Unit (IMU) and pressure and temperature sensors helping on the IMU data calibration, and on the height estimation (barometer) too. When RTK module is enabled, the TC functionality enables the exploitation of this accurate position information, while it covers the gap on eventual gaps on the coverage of RTK corrections.

Notice also from Figure 30 the feedback arrows from the TC block to the IMU (helping on the dynamic re-calibration of raw IMU data), and providing aiding to the GNSS-based Attitude estimation algorithm, which provides a further degree of coupling to the solution. Finally, and additional "User Conf." box in Figure 30 represents an external user configuration too. The most basic and important configurations enabled are the user profile, e.g. drone, land-vehicle (which in turns configures filters and other basic assumptions which depend on the vehicle platform the georeferenced system is strapped down to.

Beyond its own architecture, Figure 31 provides the current vision on how this system can be integrated and exploited, and moreover, how it will be on the outdoor demonstrator of the Construction Use Case (UC2, demo1).

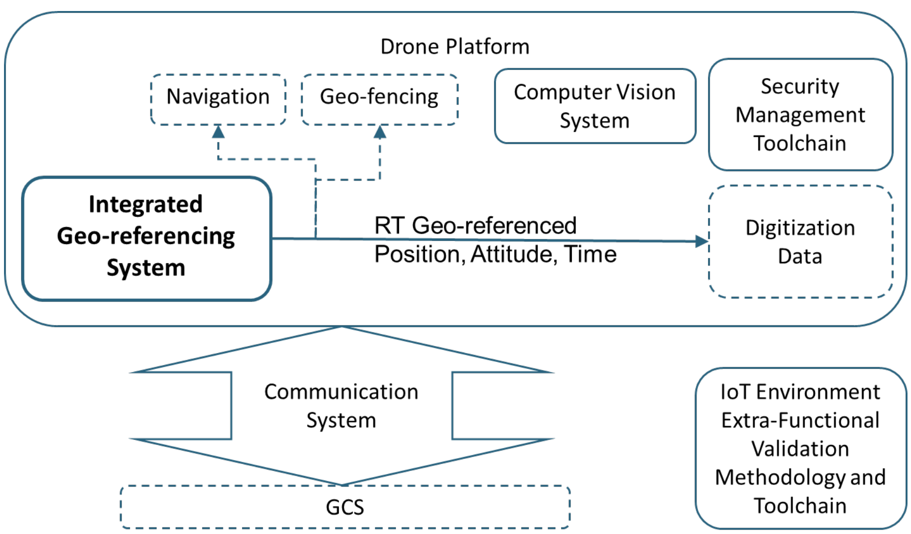

Figure 31: Integrated geo-referencing system with the drone system

The basic idea is that the integrated geo-referenced system is part of the system on-board. Its potential usage is two-fold, as it can employed for:

- Feeding and enabling basic navigations capabilities of the drone, i.e. build an autopilot, or extend its capabilities by providing highly accurate and reliable data (arrow linked to navigation component in Figure 31).
- Enabling additional capabilities related to the safe navigation of the drone. An immediate one is geo-fencing (arrow linked to geo-fencing component in Figure 31). Moreover, given the performance characteristics of the system, it shall allow a more accurate and reliable geo-fencing, e.g. of special intel RTK if the drone platform needs to get close infrastructures, e.g. pylons, challenging navigation data sources of conventional autopilots.
- Providing a specific trace of navigation data, synchronized with an unambiguous geo-reference time reference, to be employed for mission related purposes. This is the case of the UC2, demo1, (arrow linked to data digitalization component in Figure 31), where this trace will be recorded on board and later used for speeding up the digitization process.

Figure 31 represents as boxes with solid lines the components/subsystems of UC2, demo1 explicitly addressed in D1.1 as features and/or subsystems.

Second, In **COMP4DRONES**, ACORDE will also provide an *indoor positioning system (IPS)*, which will be employed on the indoor demonstration of the construction. The main purpose of this system is to provide a real-time, sufficiently accurate position information for enabling a functional, safe navigation of a drone on an indoor structure.

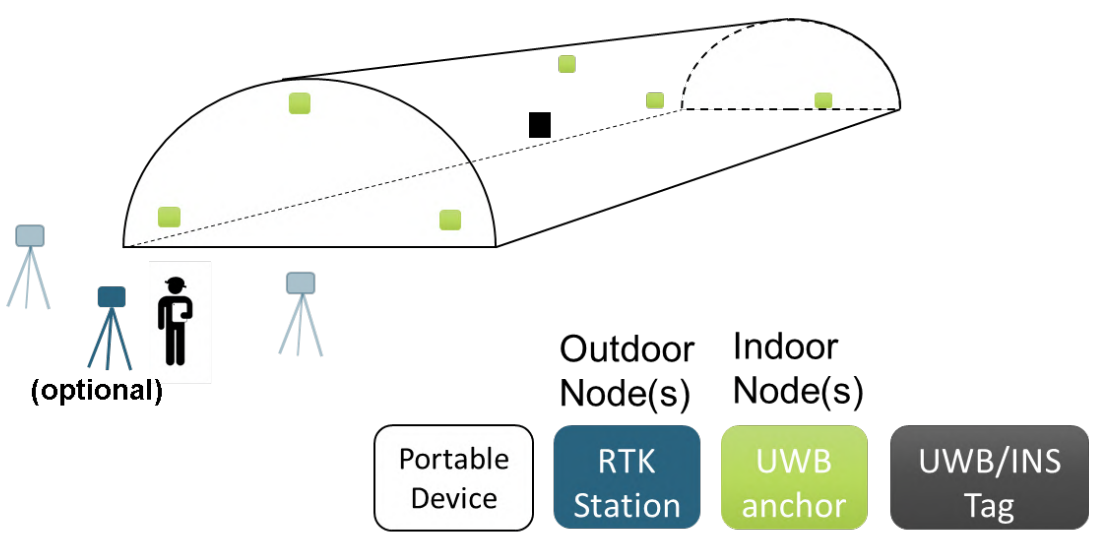

Figure 32: Indoor positioning solution for the construction use case.

Figure 32 shows the basic concept of the IPS posed by ACORDE. Figure 33 shows the generic architecture of the solution. The solution relies on UltraWideBand (UWB) technology. Notice that the use case has some specific requirements on the IPS (3D accuracy, real-time, a long linear structure, position available on the drone). The IPS will be formed by several *anchor nodes* (green nodes) developed by ACORDE and deployed along the infrastructure. The drone will be equipped with a *tag node*, also developed by ACORDE. This special node will be able to process, via specific trilateration algorithms) in real time its geo-reference positions, by relying on the geo-position of the circumvent nodes and the measured ranges (distances) to them. The acquisition and measurement of these data involves a communication tag-anchor, always present in the normal running mode of the system, represented as black bi-directional arrows in Figure 33.

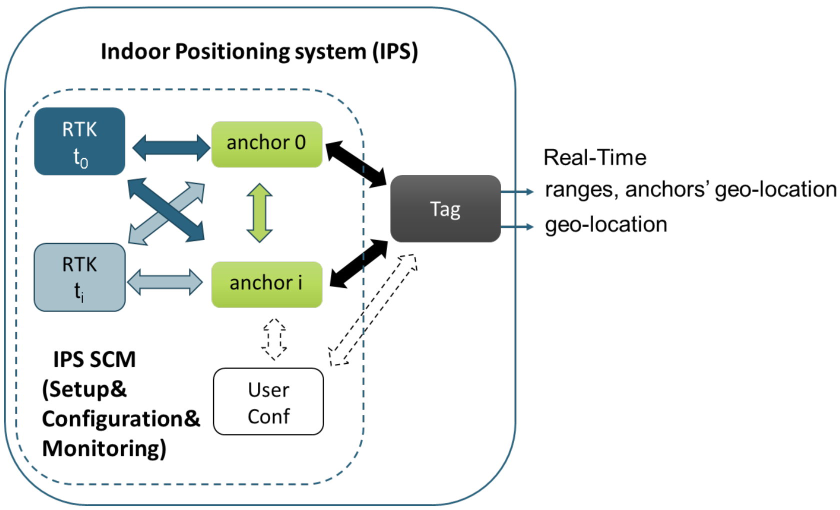

Figure 33: Generic architecture of the IPS in the construction use case.

The solution will enable the user to configure (via a portable device) the anchor position. However, in order to facilitate this setup task (which eventually requires simplicity and little time to minimize interfering construction plans), these anchors can run a self geo-positioning functionality. This functionality will be run, in general, during a preliminary preparation phase (although it can be also run in normal mode after certain periods), and requires a dialog between anchors (reflected as green bi-directional arrows in Figure 33), in such a way that the anchors can compute (or improve) their geo location.

In order to exploit the specific indoor scenario (tunnel), the IPS architecture contemplates the possibility to employ RTK positioning in the nearby of the tunnel portals. The basic idea is to rely on an RTK station with anchoring capabilities (black blue box in Figure 33) and an initial procedure where the station is positioned on 3 or more points such the anchor on the portal nearby can position themselves. This additional RTK/anchor-anchor traffic is represented as blue bidirectional arrows in Figure 33. The additional RTK station re-positioning in this preparatory stage is reflected as lighter blue boxes in Figure 33.

Figure 34 shows current ACORDE vision on how the IPS is integrated on the overall architecture of the Use Case 2, demo 2. The IPS tag is integrated on the drone, providing it at Real Time with the position information, so to serve the Navigation system, and subsidiarity, to a number of functions related to the navigation of the drone, e.g. way-point based piloting, geo-fencing etc. Ranges and anchor geo-positions are provided, so to allow tightly coupled fusion with other image-based sensors provided by the partners that will be eventually exploited on the positioning solution.

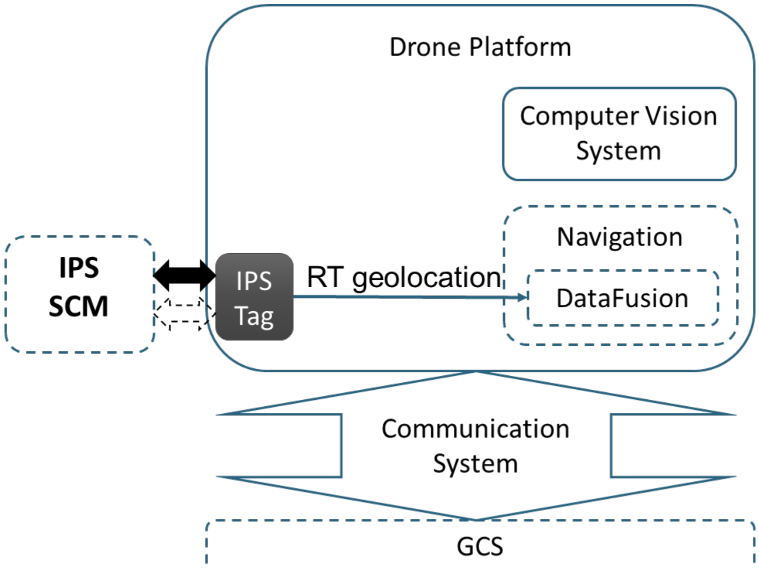

Figure 34: Generic architecture of IPS and drone platform in construction use case.

Figure 34 represents as boxes with solid lines the components/subsystems of UC2, demo1 explicitly addressed in D1.1 as features and/or subsystems.

3.3.4 Communication System: ECOLE NATIONALE SUPERIEURE DE MECANIQUE ET D'AEROTECHNIQUE

ENSMA uses both monolithic and distributed architectures. A monolithic architecture is shown in Figure 35 and distributed architectures are shown in Figure 36 and Figure 37. All of them rely on the MAVLink communication protocol as an interface between a Ground Control Station (GCS) and the autopilot. This GCS may or may not have a GUI.

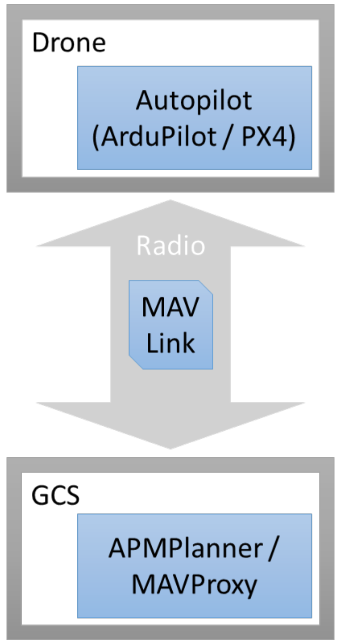

Figure 35: ENSMA's monolithic drone architecture

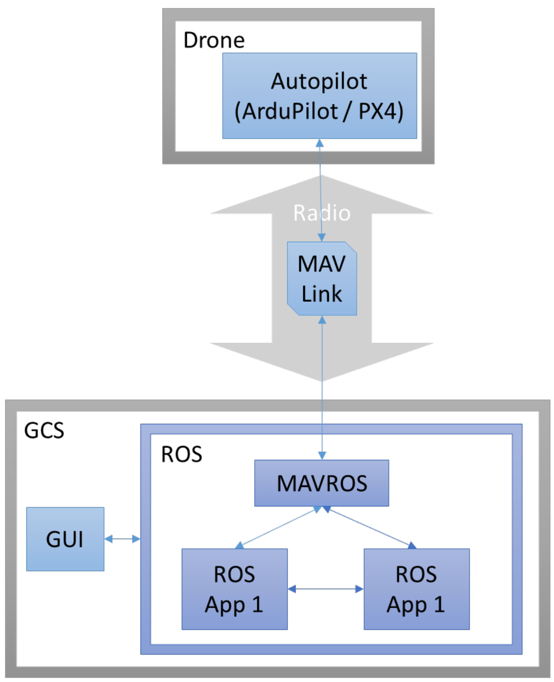

Figure 36: ENSMA's distributed drone architecture

In Figure 35, there is a direct connection between the drone and the GCS. In Figure 36, a distributed architecture allows a system running ROS (Robot Operating System) to connect several applications, such as image interpretation, trajectory optimization, etc. These applications can interact with the drone using MAVROS, a program that translates some messages sent inside ROS into MAVLink messages to the drone, and vice-versa. This architecture is used also for the Software in the Loop (SITL) simulations, in which the autopilot is compiled so that it communicates with simulations of the sensors and actuators of the drone. ROS is then responsible for the communication between the autopilot and the physics simulator Gazebo.

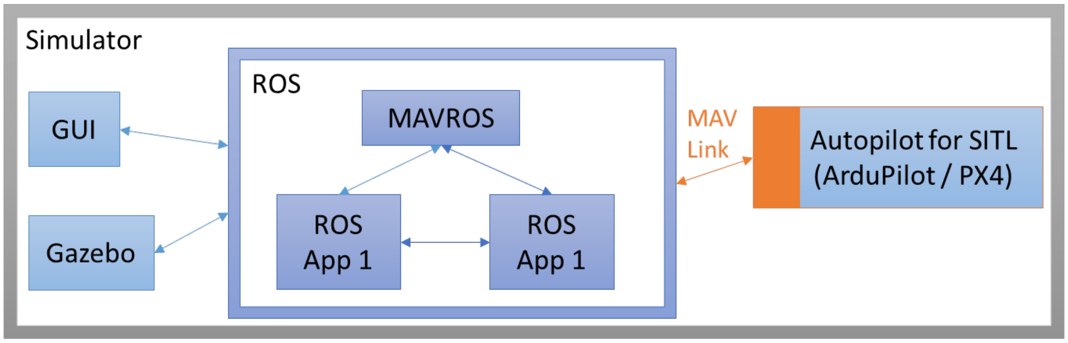

Figure 37: ENSMA's drone simulation

3.3.5 Ground Control Station: ALTRAN TECHNOLOGIES

The initial GCS was intended to manage a closed fleet (fixed maximum number) of agents of one type (UAVs). This architecture aims at being able to monitor any size of fleet with more type of agents (different UAVs, UGVs…) performing different missions. In order to achieve that, it centralizes the data from all the agents that needs monitoring as well data from supporting services and assign them dynamically to different managers.

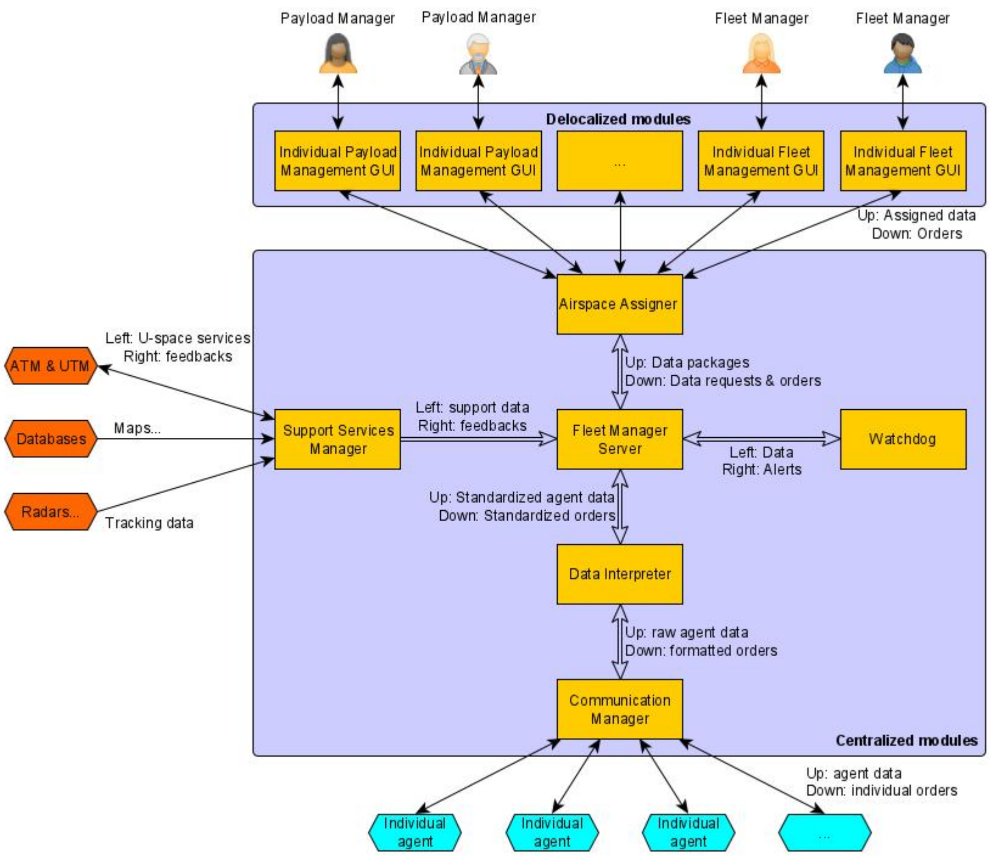

Figure 38: GCS modules

The modules composing the GCS are divided in two groups:

- One that centralizes the common functionalities (collocated in the same physical solution):
  - The **Communication Manager** receives data from the different agents from different communication systems and allocates the managers orders to the corresponding agent through the same communication means. It also manages the alternate communication links if any;
  - The **Data Interpreter** is translating the data exchanged between the GCS and each agent (we do not expect to have standardized communication format in short term);
  - The **Fleet Manager Server** receives all data and requests for data. It ensures smooth and continuous service of data exchange;
  - The **Airspace Assigner** allocates to a manager a volume of the airspace function of the human capability to manage different agent (the agent type impacts it). It also reallocates airspace in case of problem of one manager;
  - The **Support Services Manager** receives data an issue requests for data for the different supporting services that allow a proper monitoring (radar data, ATM orders, U-Space services…);
  - The **Watchdog** provides high level monitoring of the agent regarding risk of collision or excursion outside the allowed airspace for each agent. It generates alerts that are used to increase the manager awareness;
- The other for the modules that are implemented in a single physical solution but can be redounded by many users
  - The **Individual Payload Management GUI** is the interface used by Payload Managers to monitor and control any operation whose payload use justifies increased awareness (ex: delivery, dropping…);
  - The **Individual Fleet Management GUI** is the interface used by Fleet Managers to monitor and control the agents present in the airspace he has been allocated.

3.3.6 UGV: TwinswHeel

TwinswHeel UGV (unmanned ground vehicle) are small logistics robots that circulate autonomously in the city. These UGVs carry heavy loads, for example restocking stores in historic city centers. To move autonomously, the droids follow virtual routes. To establish a route, first we map (SLAM) the environment very precisely, then we define waypoints that will serve as a point of attachment to the future virtual route.

As part of **COMP4DRONES** project, the UGV was coupled to a drone to carry small loads. The UGV and the drone will exchange packages. We present below our macro architecture of the high level soft of TwinswHeel UGV for autonomous shifting and associated remote control. In the project, this architecture as well as the technological bricks will be improved.

Today TwinswHeel high-level software architecture is quite simple. The UGV can receive moving orders from two possible sources: the autonomous mode and remote control. A global view of this architecture is shown in Figure 39.

All the software works on a Linux type OS with ROS middleware. ROS makes it possible to make the links (network) between the various computation nodes by passing the information.

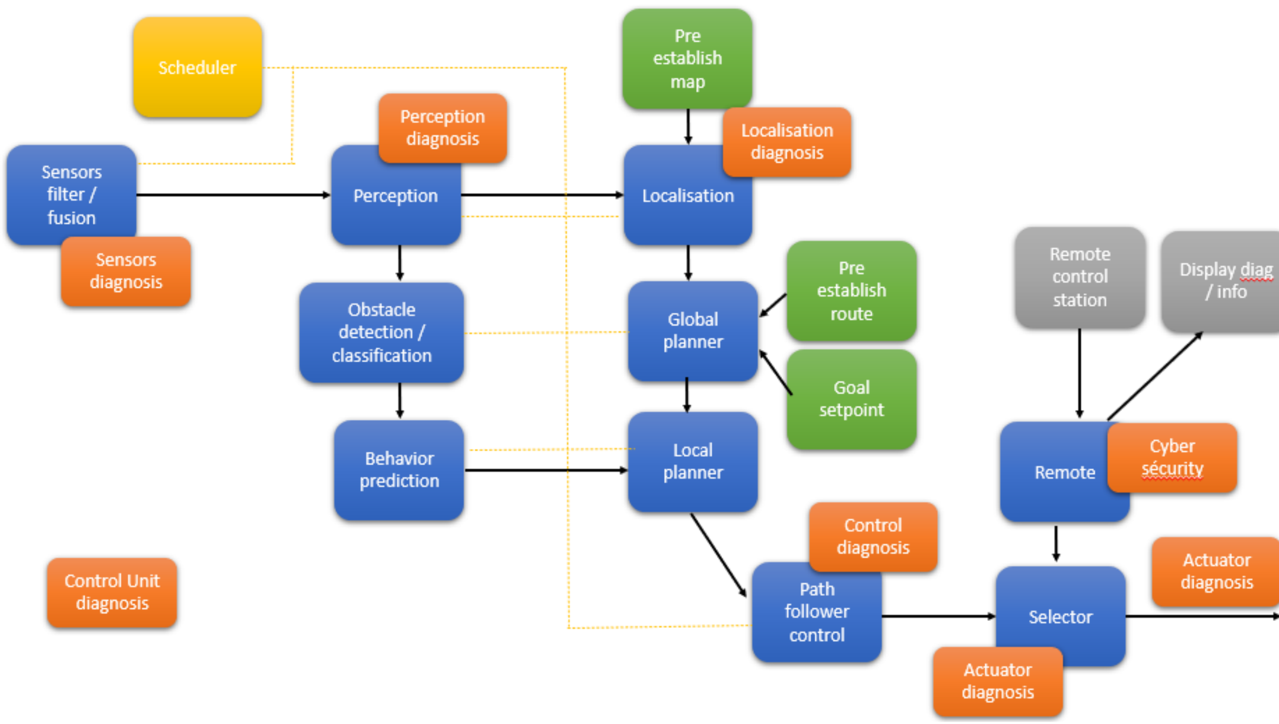

Figure 39:TwinswHeel software architecture

The colours of the blocks in Figure 39 are:

- Blue blocks: functional calculation nodes
- Orange blocks: calculation node for carrying out diagnostics and safety
- Yellow block: schedule the time and prioritize the execution of the blocks
- Green blocks: user inputs in the software (map, route…)
- Gray blocks: the link with the outside world

On the diagram the black arrows show the classic information path between the blocks, but it is all carried by the ROS networks. As a result, the priorities defined by the scheduler and the guarantee of real time with the possibility of killing excessively long processes is not respected. There is no conflict management.

Below is the list of the architecture blocks with a small description

- On the left we find the part specific to reading, filtering and merging the data coming from the different droid sensors

- The perception block will make it possible to create an occupancy grid of land and to distribute the information from the various sensors to the analysis blocks
- Part of the software will run on GPUs / FPGAs for image (video) processing in order to classify objects and scene segmentation. This makes it possible to position the obstacles, to predict their future trajectory and to define the free space.
- Analysis and prediction of the behaviour of moving objects around the droid is essential to minimize the risk of collisions
- From the information from the sensors and by comparing it to a pre-established map, we can localize the droid
- On this map are defined virtual routes and virtual stations which are available in the global planner
- This global planner which defines macroscopic routes is completed by a local planner with the information coming from the detection of obstacles and their predicted future trajectories
- This virtual route enters a controller whose mission is to follow this trajectory to the droid. This controller applies speed setpoints to the actuators
- These instructions can be passed by the user in remote control mode.

To all these functional blocks, a layer of safety with diagnostics that have the authority to stop everything is added. A block of cybersecurity and verification of robustness of the link by wave is also added for the links with the outside world.

4 Project Use Cases and Drone Usages

In this section, we give a brief description for the five use cases that have been identified to validate the proposed framework. These use cases will have different demonstrators (11 demonstrators) that will be used as an input to get the Unified List of Drone Usages.

4.1 Project Use Cases

Demonstration and validation activities are essential to ensure the quality and relevance of innovations. In the following sections, the five use-cases driving the design of the framework are introduced (see Figure 40). Nevertheless, this framework could be used for other related application domains that should use autonomous or remotely piloted vehicles.

4.1.1 Use Cases Overview

COMP4DRONES project achievements will be benchmarked and demonstrated through the below five domain specific use-cases:

- **Transport**: Application of drones to optimize and enhance transport control, operation and infrastructure management activities, such as traffic management (traffic status and incidents), monitoring and maintenance of road conditions.
- **Construction**: Smart Application of drones for the digitalization of the state of a construction process, and analysis of underground constructions status.
- **Logistics:** Logistic using heterogeneous drones' fleet
- **Surveillance & Inspection**: Drone and wheeled robotic systems for inspection, surveillance and rescue operations with enhanced navigation and autonomous abilities.
- **Agriculture**: Smart and Precision Agriculture: From drone to rover

Further and detailed information is provided in the D1.1 deliverable.

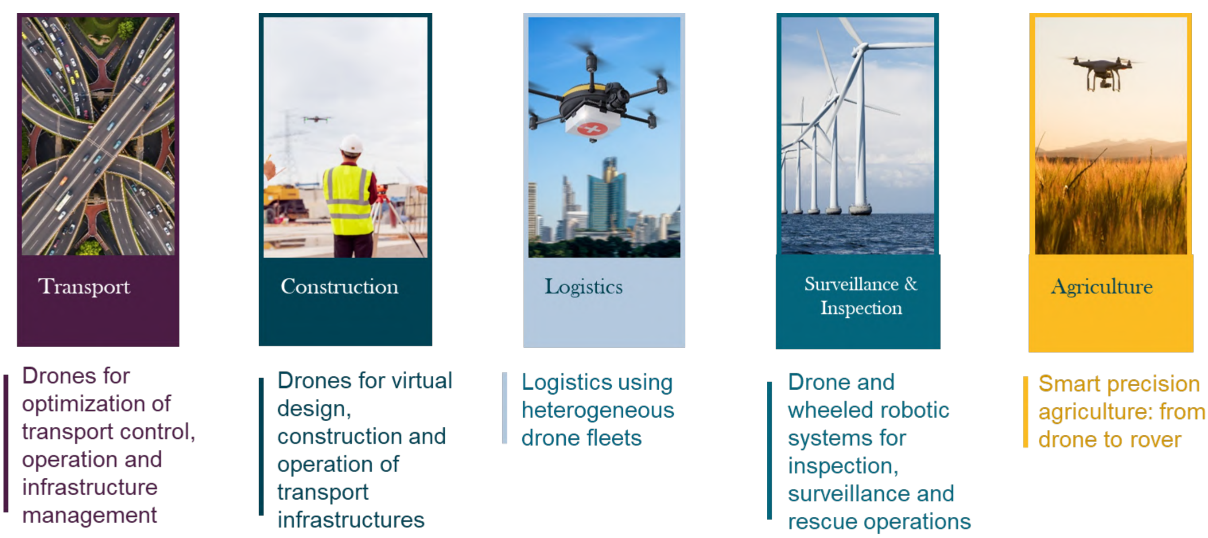

Figure 40: Use-cases driving the design of the framework specification

These use cases and demonstrators have requirements that will be then used as a guide to define the basic elements of the architecture and which methodology and tools are required to develop the demonstrators. These sections introduce the demonstrator objectives, UAV sub-systems, location, etc.

4.1.2 Transport: Optimization of Transport Control, Operation and Management

This use case will demonstrate the technology developed in **COMP4DRONES** in the Transport domain. The aim of this use case is to optimize and enhance transport control, operation and infrastructure management activities, such as traffic management (traffic status and incidents), monitoring and maintenance of road conditions with the use of drones.

Drones can become key players in the monitoring and operation of transport infrastructures, in particular, due to their flexibility to take images/video and easy access to areas that may be congested or difficult to access and even to locate accidents in an early manner.

This Use Case will target the following main objectives:

- Development of drones ' processing tools based on graphic cards for the capture, processing and analysis of images/video generated by aerial and maritime drones.
- Development of secure communication modules to ensure communication between the Control Center, different infrastructure elements and the drone for monitoring and inspection of the infrastructure.
- Integration of Artificial intelligence technologies/DEEP Learning/Machine Learning to analyse the images received by the drones to perform operational and maintenance activities.
- The drones will be integrated with other transport monitoring devices (DAS/DAI) that launch incidents in order to verify these incidents without the need to mobilize human resources.

4.1.2.1 Demonstrator 1: Road Transport Traffic Management & Monitoring and Incident Detection

This demonstrator will focus on the deployment of drones as monitoring devices of the road traffic conditions and the detection and early response to incidents. The drone facilities will incorporate capabilities to request a drone's flight over an area of the infrastructure identified by its operators. Drones will then take flight to verify an incident detected by the system (DAI/DAS), or to inspect a zone in a specific way without associated incidents.

The drones will send the information captured by their on-board modules (primarily video and images) to the transport control center (see Figure 41). The transport control center will integrate the images/video captured by drones as well as by other devices deployed in the infrastructure (such as fiber optics) to visualize what is happening in the infrastructure, and process this information applying the technologies developed in this project to carry out an analysis, launch task and operation plans to obtain parameters of importance for its management: container monitoring/loading, enforcement, asphalt/track inspection, etc.

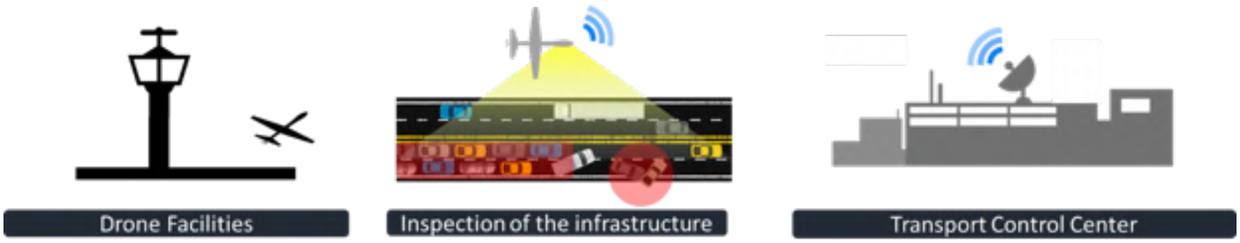

Figure 41: Road transport traffic management & monitoring and incident detection

For this Use Case, Indra will use the Rozas Aerodrome (Castro de Rei, Lugo, Spain) as test facilities (see Figure 42). This aerodrome, located at the northwest of Spain in the Galicia Region, is part of the Civil UAVs Initiative, coordinated by Xunta de Galicia (Galician Local Government) with a contract partially managed by Indra. Indra has moved all its development activities of unmanned aircrafts to this location, which allows the deployment of pilots and experiments, as its airspace is not affected by general restrictions and regulations. Xunta de Galicia will act as facilities provider for Indra in this Use Case, supporting and facilitating the deployment and testing of the technologies and components developed during this project, and providing the required permissions and authorizations needed for performing the activities of this use case.

Figure 42: Indra’s test facilities

For this Use Case different drones will be used: Indra will provide one own-developed aerial drones (Mantis, a fixed-wing light UAV) shown in Figure 43, and other third parties drones will be taken into consideration.

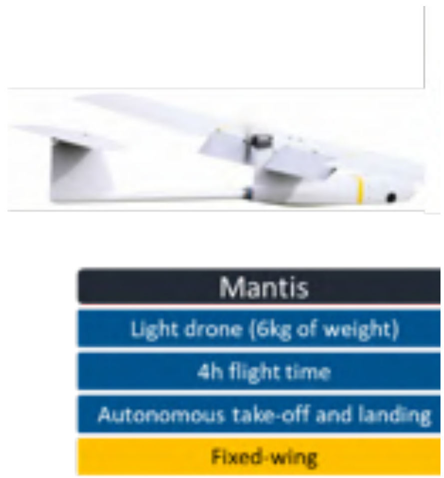

Figure 43: Mantis, a fixed-wing light UAV

4.1.2.2 Demonstrator 2: Port Infrastructure Supervision and Maritime Drone Applications

This demonstrator will focus on the deployment of drones as new sensors for maritime infrastructure maintenance activities and novel applications to support land and sea operations at ports.

This demonstrator will target the following applications:

- Supervision of cargo allocation in yards for a more effective space optimization: Terminals can improve the bay plan and the load/unload cargo operation taking into account the information provided by the drone related to the real current occupancy situation of cargo in the yards.
- Drones as new sensors: The Unmanned Surface Vehicle (USV) can collect water/spills with the development of new modules. An onboard sonar can be installed for inspection of submarine areas which are hard to access.
- Maintenance and communications: the USV can integrate V2I trustworthy and secure communications from infrastructure elements such as Aids to Navigation to the USV, allowing new maintenance applications.
- Other applications: this demonstrator will have the potential to provide solutions to maritime transport safety (first response to emergency situations and navigation risks like fire, vessels collision, drifting boat, oil spill and others, reducing the impact of human losses and environmental disasters), enforcement (detection of infractions and illegal activities of ships) and delivery of goods inside the port (from harbour to ships and vice versa).

Autoridad Portuaria de Vigo is an institution in charge of managing the Port of Vigo's infrastructure, covering a Land Service Area (SA) of 2,572,577 m^2 over five municipalities. Port of Vigo is ranked as the 1st port of fresh fishing in Spain and the 1st port of frozen fishing production in Europe. Autoridad Portuaria de Vigo will support and facilitate the deployment of this demonstrator (see Annex for Xunta letter of support) provide the necessary permissions and infrastructure and authorize INDRA to complete the activities planned in **COMP4DRONES**.For this demonstrator, Indra will provide its own USV maritime drone (see Figure 44).

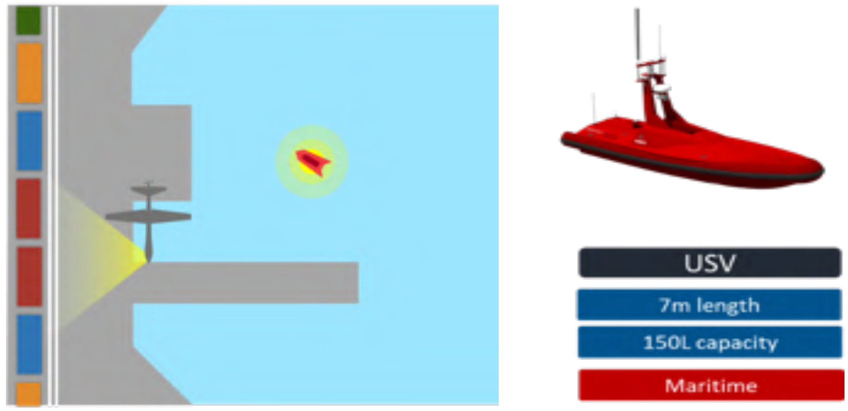

Figure 44: USV maritime drone

4.1.2.3 Demonstrator 3: Monitoring Railway Construction Works and Infrastructure Maintenance Activities

There are four phases of the Rail Baltica project (see Figure 45). Drones can be used in these phases as follow:

a) Design phase: surveying before construction (possibly only for a small number of key areas)
b) Construction phase: surveys, progress reporting, potential for asset tracking
c) Commissioning: design vs as-built validation, detailed monitoring during testing
d) Operational: routine surveys, including vegetation growth, track/ wayside condition monitoring, alignment of overhead lines, etc.

Figure 45: Rail Baltica as part of the North Sea-Baltic core network corridor

There is also incident response, which would apply almost all the way through: something has happened, let's get video of a particular site as quickly as possible? This may be during construction, it may be if there are problems during commissioning, and of course once the railway is operational this can be a response to accidents, to "intruder on track" alerts, inspection following severe weather, and so on. Actually, that last one could apply at any time – for example, during construction, in some circumstances it might be sensible to inspect places before allowing staff back on site.

This demonstrator will focus on the deployment of drones as monitoring devices of the railway infrastructure operation and maintenance activities. It also may include some construction work activities. There will be provided 5G connectivity for all connected solutions and operations.

One of the areas that requires special consideration is what sensors are appropriate, which is something that may change as railway step through these phases. For example, if during the design phase a very detailed survey of a particular location is required, this may have to be a very high-resolution camera, lidar, and done relatively slowly with a rotary UAV, whereas at later stages, a quicker survey using a fixed wing may be appropriate most of the time – once things are operational, demonstrator will typically be looking for changes and trends, rather than absolute precision.

4.1.3 Construction: Virtual Design, Construction, and Operation of Infrastructures

During the construction phase of a Civil Infrastructure, it’s very important to keep a good track of its progress in order to have an adequate control of Costs, Times and Qualities, as well as to be able to certify the state in which the construction process is at a certain moment. Nowadays, the construction process of an infrastructure is monitored through traditional processes, processes that have changed little in recent decades.

The new LIDAR and photogrammetric technologies allow a great digitalization of the state of construction. In addition, these data must allow greater control in all phases of the construction process. (Measurements, Advance Control, Digitalization, Certifications).

By current drone technology, it is possible to ship sensors (Lidar / RGB) that allow the digitization of the state of the construction process, and make all data capture without causing any interference in the development of activities undertaken in the work.

In addition, the use of the aforementioned technology allows to reduce the costs and times of Acquisition of Data in relation to traditional technologies; either by traditional surveying or terrestrial methods.

The Digitization of the state of the construction process will allow generating products that allow approximating the development of construction in a Building Information Model (BIM) Model, a work methodology that will be of mandatory use by 2020 in the European Union for the Construction of Civil Infrastructures.

4.1.3.1 Demonstrator 1: Digitalization of Civil Infrastructure Construction

To achieve the digitalization of a civil infrastructure, the definition and study of the data will be required, to make the best use of them and try to achieve the challenge of creating a procedure to accelerate the extraction of the elements, from a cloud of points to a geometric definition.

The study of the data and the creation of different tools will allow identifying elements related to the geometry and characteristics of the terrain of the construction site, flat surfaces of structures, recognition of fix elements and alignments. The main objective is the automated creation of a database of objects of predefined types, directly out of the captured cloud points, where those objects are automatically recognized, detected and added to the database.

For the development of the tools, the first testing and training flights will be done in the Villanueva de la Cañada airfield, located near to Madrid (see Figure 46). It is an extensive private airfield that allows the training of pilots and experiments, as its airspace is not affected by general restrictions and regulations. It has two main landing areas: 03-21 280m compacted earth and 12-30 170m compacted earth airstrips.

Figure 46: Private airfield that allows the training of pilots and experiments

Another option for the testing and training flights is the Flight Test Centre called ATLAS. ATLAS is located in Villacarrillo, Jaen, Spain (see Figure 47). It is specially designed for light and small UAS operations. It counts with 1.000 Km2 of segregated airspace until 5.000 ft. available jointly with a main runaway of 600 m and auxiliary one of 400 m which allows performing long-range flights even with the current Spanish UAS regulation. Telemetry and primary surveillance radar facilities are also available, along with a suited orography and climatology enabling more than 300 days per year for operations. Furthermore, offices, meeting rooms, hangars, workshops are ready for customers, including full support to operations: management of flight permits for the coordination of flight operations, and interactions with Civil Aviation Authorities in Spain. Then, this is an ideal location for outdoor technology integration and validation, before pilot experiments, and it is planned to be used in this project.

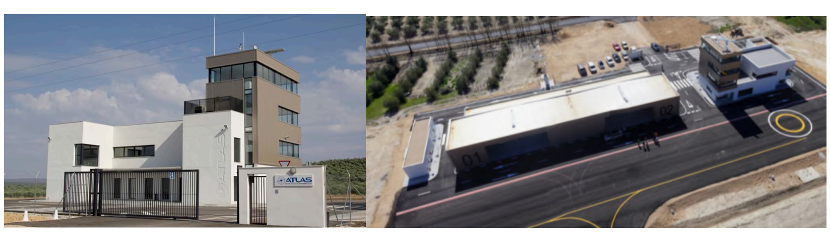

Figure 47: Flight test centre (ATLAS)

Finally, flights in a real construction environment will be done in Acciona`s facilities or works.

For this demonstrator one drone has been initially selected. The drone is based on the Matrice600 platform from DJI (see Figure 48). This is an off-the-shelf multi-rotor platform with 5Kg payload, around 20 minutes of endurance and a very versatile configuration since it has enough space to integrate the different sensors and equipment developed during **COMP4DRONES** project. Moreover, DJI offers an SDK that allows the integration of the multicopter autopilot with ROS (Robot Operating System), facilitating the use of advanced positioning functionalities based on GNSS.

Figure 48: Off-the-shelf multi-rotor platform with 5Kg payload

4.1.3.2 Demonstrator 2: Monitoring Underground Infrastructure Construction Process

This demonstrator will focus on the deployment of drones as new tools for the analysis of the status of the constructive process in underground constructions such as tunnels. The drone platform will be able to obtain data in real-time, keeping the distance to the wall sides and detecting any interfering obstacle inside the tunnel. During the flights, the drone platform will acquire data and, as a result, the system should give high accuracy models.

The information produced will improve the efficiency of the activities of planning, exploration, measurements of the underground environment, mapping of tunnels, generation of complete high-precision models, and production of base models for implementation in BIM. In short, it will be a helpful tool for decision making in hostile environments.

First testing and training flights will be done in an indoor testbed at FADA-CATEC facilities (see Figure 49). This indoor testbed has 15x15x5 volume with the VICON positioning system that can be used as a ground truth to validate the indoor navigation system. This testbed (see below Figure) will be used in the project as part of the integration and validation activities to further validate the technologies before the outdoor and pilot experiments.


Figure 49: FADA-CATEC facilities

For this demonstrator the drone will be based on a small aerostructure (like F550 from DJI) due to the specific requirements of the underground infrastructure. A special drone configuration will be used in order to integrate the advanced indoor navigation functionalities and the sensors required for 3D reconstruction (like for example LIDAR). The autopilot will be based on PixHawk opensource autopilot and an external computer that will integrate the advanced GNSS-free navigation algorithms.

4.1.4 LOGISTICS: Logistic using Heterogeneous Drones' Fleet

All human activities have a part of logistics. For example, (a) the delivery of a spare part or a new sensor for a machine in the forest; (b) the delivery of food from a famous restaurant on the other side of town; (c) during surgery in a hospital, emergency samples tests need to be done in a laboratory a few kilometres away;

Drones are useful for the solutions, as they are not depended on paths in modern urban environment and are able to use higher speed, so making deliveries easier and faster. For some tasks, ground vehicles are better suited, that makes demand for combined UAV and UGV solutions for logistics applications.

4.1.4.1 Demonstrator 1: Deployment of an Autonomous Communication System in hard-to-access areas thanks to a Highly Automated Multi-Vehicles System

Total kicked off its METIS® R&D project[22] in late 2014 to "unlock" hard-to-image in hard-to-access location. The project has developed an innovative 3D high-density (HD) geophysics solution that enhances the quality of subsurface images, lowers costs and HSE exposure while reducing the environmental footprint. By limiting human intervention on the ground, METIS® curbs the risks and environmental impacts through the implementation of key technologies:

- Maximizing the logistics from the air with a unique hybrid airship to replace the helicopter operations

[22] https://www.ep.total.com/fr/innovations/recherche-developpement/metis-un-systeme-integre-dacquisition-geophysique-pour-imager

- Flying swarms of drones to efficiently cover huge surfaces with a state-of-the-art wireless real-time autonomous communication network which could be tied to any type of sensors
- Re-engineering today's components to make the full communication network system eco-friendly with bio-plastic, printed electronics and harmless batteries

The ultimate aim of METIS® is to operate onshore geophysics operations three times faster (and cheaper) than the conventional way with five times fewer personnel (see Figure 50). Nevertheless, the METIS® concept is not restricted to oil prospecting and may be enlarged for many other scientific or civil protection applications:

- Research and rescue of people after natural disasters as floods, avalanches or earthquakes
- Characterization of soil integrity for landfill sites
- Research and control of water resources
- Research and prevention of sinkholes

In December 2017, a proof of concept[23] with one drone delivering around 60 sensors in the tropical forest of "Papua New Guinea" was executed. At the industrial stage, the ultimate system will operate a fleet of 50 drones flying together to deliver up to 100 000 sensors in a foothills/deep forest environment with a minimal impact on the environment. The lesson learnt of Papua New Guinea is that the concept works but that the Authorities does not grant easily the permit-to-fly. Another proof of concept, with several drones operated by one pilot, is necessary to demonstrate that a quick deployment is possible with the agreement of the Authorities.

[23] B. Pagliccia, K. Dalton, C. Walker, K. Elder, R. Jenneskens, "METIS Hits The Ground in Papua New Guinea, a Field-Proof Innovative Method to Revolutionize Onshore Seismic Acquisition," in *EAGE*, 2018

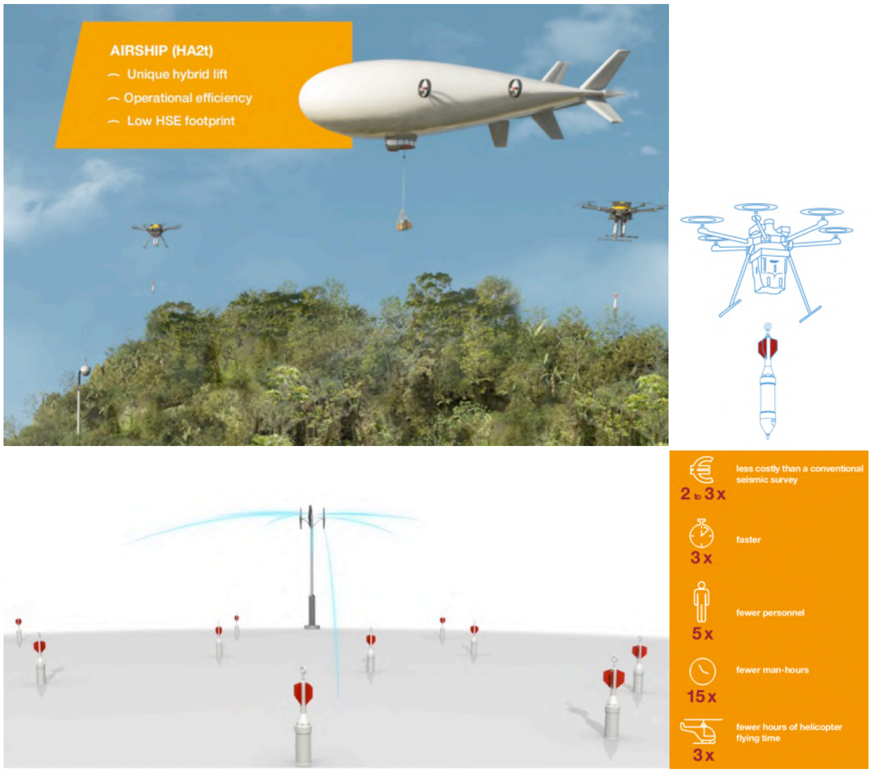

Figure 50: METIS® R&D project

To do so, **COMP4DRONES** project will ease it by enabling technologies for communications inside the fleet of drones, interactions with the Ground Control Station, integration of the fleet in the Air Traffic Management and for the safety clearance associated to the sensor's drop.

Most of these technologies and operations have been concentrated in a simpler civil protection use case that covers several important parts of the future industrial METIS® system: the deployment of an autonomous communication system by a fleet of drones after natural disasters.

The number of casualties after earthquakes and snow avalanches is strongly correlated to the time needed for the rescue teams to locate people. The use case using **COMP4DRONES** project results would be the fast-deployment by a fleet of 5 drones of 4000 sensors over an area of around 10 km^2. Sensors will be equipped with seismic-grade 3C accelerometers enabling the detection and localization of any underground sound source. The area covered is at scale of a small village affected by an earthquake or of a snow avalanche.

Beyond the monitoring done by the sensor, the communication network in place, with its autonomy of more than 20 days, would also be tested to contact any mobile phone of a buried person.

For deploying automatically thousands of objects on a large area, we need to overcome plenty of challenges focused on safety, connectivity, interoperability, and architecture of a complex and reliable system.

4.1.4.2 Demo 2: Logistics in 5G Urban Environment: Clinical Sample Delivery in Hospital Campus

Logistics in urban areas is a very big challenge. The inhabitants of the cities are more and more consumers of home delivery (+10.5% on average in Europe per year) and at the same time want greener cities, easier to live.

Delivery in urban areas can be imagined in three phases:

1. Delivery to warehouse in periphery of the city by conventional means (trucks or trains), or if it is a manufactory, deliver the product directly.
2. Delivery between the warehouse and the destination by drone on areas of low population density (between 5 and 10 km). The drone takes-off and lands on the roof of the buildings of departure / arrival destinations.
3. Delivery from the roof of the building up to the floors or in the buildings near (by rolling in the streets) thanks to UGVs (between 500 m and 1.5 km).

This demonstrator is based on real life situation. Hospital needs a fast and reliable method for transportation of laboratory samples between several points inside relatively large hospital territory with several buildings. Delivery by drones is selected to provide a solution which have to satisfy hospital requirements (special challenge is safety and security requirements, as deliveries are inside the hospital campus).

This should replace a highly expensive pneumatic mail system through which hospital now is doing different medical sample delivery. The demonstrator of hospital parcel delivery will be carried out in Latvia, where LMT thanks to its 5G network and developed components will be able to ensure the safe and secure connection between the operators and the drones and droids. For this demo IMCS will develop a ROS node for the autonomous displacement of drones (recognition, avoidance, online safety monitoring). On their side, ATE and TH will provide a drone and a droid with the software needed to perform these delivery missions in a hospital.

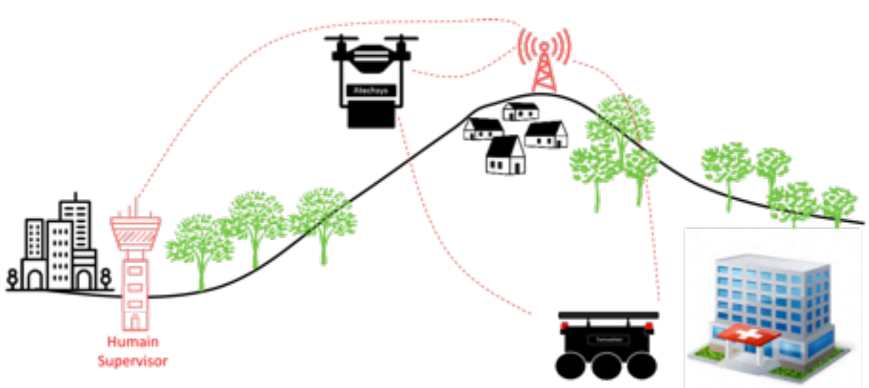

Figure 51: Hospital parcel delivery

Due to strong security and safety requirements in hospital, developed solutions can be looked as a prototype for a much larger class of last mile applications in urban territories.

This demo will allow linking a telephone operator, a software developer, a drone manufacturer and a droid manufacturer in France and Latvia. It will highlight the development of **COMP4DRONES** project in an extremely promising market that is urban logistics (last mile delivery).

4.1.5 Surveillance & Inspection: UAV and UGV for Inspection and Surveillance

The main goal of this use case is the realization of autonomous Unmanned Aerial Vehicles (UAV/Drone) with enhanced sensory abilities by means of sensory systems and novel control strategies augmented by real-time data-analytics algorithms. These enhanced drones can then be safely applied in indoor and outdoor environments in many applications such as industrial inspection, security, surveillance, and in rescue operations (for example in finding targets and mapping indoor or outdoor environments).

Many companies have developed innovative solutions for in-flight diagnostic of the avionics systems including wireless Health and Usage Monitoring Systems (HUMS) and other game-changing systems. Diagnostic of the electromotors is a crucial functionality that not only save the drone but also lower the cost of maintenance. It is therefore fundamental to develop autonomous and adaptive diagnostics to increase the confidence level in autonomous drone, lowering the costs of maintenance and increasing the overall autonomy of the system.

However, to achieve safe control in uncontrolled environments there is still the need for developing efficient computational strategies that are adaptive and that can cope with the limited computational resources of the drones and robots. For this, we will focus on the development of drones and robotic systems in which sensing, perception, planning and control of each component will be determined by a high-level data analytics system that will be able to achieve high-level decision strategies. Novel formal verification approaches will be developed that will be aware of future certification. These formal verification approaches will reduce the time and cost of the verification process by finding defects earlier in the development process.

Novel communication channels which offer high-availability, robotic controllers, and closed-loop algorithms implemented in FPGA-based accelerators will be developed during the execution of this use case. Hardware and software components as well as services toward end user will be developed and qualified. One of the main goals is the cooperation within project partners and open communities to enable the reuse of software components thereby to enable the reduction of costs for customized solutions.

Outcomes of this use case will be readily applied in a variety of situations ranging from infrastructure monitoring, crowd monitoring, autonomous scanning and control of wind turbine structures, to assessment of disaster sites (e.g. after earthquakes) as well as indoor environments when entering inside a damaged structure could be unsafe.

Two distinct demonstrators will be developed within the context of this use case: inspection of off-shore infrastructures, and mapping a disaster site.

4.1.5.1 Demonstrator 1: Inspection of Offshore Turbines Structure with Hyperspectral Technology Carried by Drones.

The goal of this demonstrator is to showcase the benefit of hyperspectral cameras on unmanned aerial vehicles for inspection of off-shore infrastructures (see Figure 52).

Drones are excellent tools to inspect tall structures and difficult to reach areas, like the foundations of offshore wind turbines (see Figure 52). However, to make them useful and cost-effective, automated, inspection tools the collected images need to be processed automatically to detect and classify defects. Additionally, the location of the defects on the structure needs to be known accurately to plan and coordinate maintenance activities.

Figure 52: Inspection of offshore turbines structures

Hyperspectral technology can provide more spectral information to make detection and classification of defects (e.g. corrosion) easier. However, application of the hyperspectral technology on drones has mainly been limited to agriculture applications.

The first goal of this demonstrator is to investigate if hyperspectral technology on drones can also be used for inspections and automatic detection of corrosion and other defects. Secondly, research will be done into Artificial Intelligence and deep learning algorithms to process hyperspectral data for automated feature detection.

The European Union has decided that by 2030, 27% of the energy consumed must be produced by renewable energy from renewable sources. In 2015 there were 40,000 wind turbines installed on land and 3,000 offshore. By 2030 there should be 80,000 turbines on land and 20,000 offshore to meet the target. The steel structures on which these turbines are installed need to be regularly inspected for corrosion problems which is typically done by certified human resources. This is a costly and dangerous activity (see Figure 52).

A drone can gather the required data in less than an hour to enable the same value of inspection. Today, high resolution visual cameras are used for these inspections: the images are captured on-site then experts interpret the images remotely, detect problems and categorize defects. To speed up the inspection process and use the costly time of experts more efficiently, there is a need for automatic defect quantification, monitoring changes over time, and predicting the best time for expensive maintenance.

Importantly, traditional RGB photographs suffer from high rate of false alarm errors and can't reliably detect and categorize the defects, e.g. specific corrosion problems. There is strong evidence that hyperspectral images can provide additional information about the state of the material which can improve the defect detection performance. However, several problems need to be solved before these can be used in practice.

4.1.5.2 Demonstrator 2: Fleet of Multi Robot Navigating and Mapping in an Unknown Environment

The goal of this demonstrator is to showcase the benefit of a fleet of aerial vehicles (drones) and a land robot for mapping a disaster site.

A fleet of drones and a UGV will be deployed in a warehouse-like environment and will autonomously navigate in it, while mapping the entire environment (see Figure 53). AI/ML/DL/NN together with traditional approaches will be used for data acquisition, fusion and processing to perceive the environment. Different novel sensors such as stereo vision cameras, event-based sensors, and lidar will be used to perceive the environment in a most efficient and detailed way. The different sensors modalities will be fused by the sensory fusion modules and novel data-analytics will be validated. The fleet will rely exclusively on on-board processing systems as well as on-board communication systems. For on-board processing system possibilities to use SoC (FPGA+CPU) based modular embedded platform (e.g. Altera Arria or Xilinx Zynq) will be explored with specific focus on optimization and energy efficiency, which are crucial parts for battery powered drones.

Novel close-loop dynamic control and real-time data analytics for sensory fusion will be benchmarked and demonstrated.

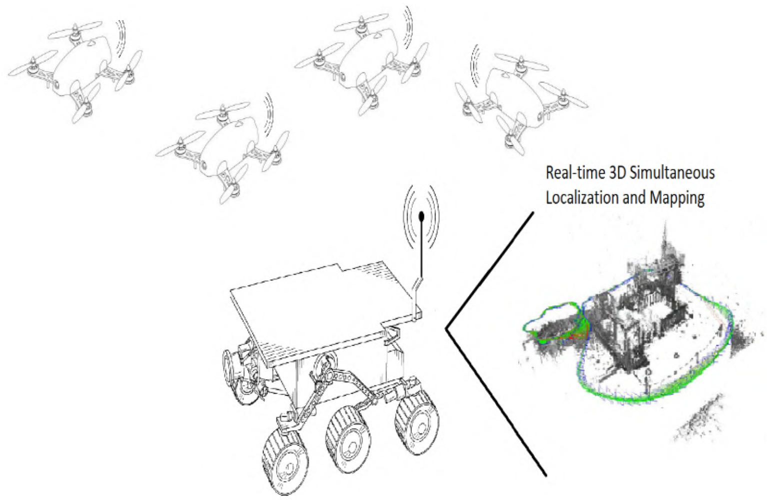

Figure 53: Fleet of multirobot navigating and mapping an unknown environment.

4.1.6 Agriculture: Smart and Precision Agriculture

Agriculture is the science, art, or practice of cultivating the soil, producing crops, and raising livestock as well as the preparation and marketing of the resulting products.

To achieve tangible results in the project **COMP4DRONES**, two demonstrators will be implemented. On the one hand, a focus will be on technology needs for crop monitoring, focusing on health and growth crop management, while on the other a focus will be on specific technology needs of wine cultivation.

On smart agriculture and precision farming topics, **COMP4DRONES** project will enable technologies for real-time monitoring and more accurate analysis purposes and trustworthy interaction between land-bound sensors and drones as gateways.

Both Inspective Missions (i.e. digitized data about leaf chlorophyll used on-the-go to apply fertilizer-N using variable-rate techniques or to decide on soil and crop management strategies), and Precise Spraying is enabled by drone usage. Digital and/or Spectral information, i.e. indices obtained in real time or with short time post-processing, acquired by RGB and Near Infra-Red (NIR) camera, mounted on unmanned aerial systems or vehicle (UAS and UAV) linked to unmanned ground vehicle (UGV) vehicle, in vineyard, horticultural crops and in olive trees determine best management practice (BMP) in field. Data will be used to detect the status of health of fields and plants, (early pests detection using image processing and computational intelligence); compare the data collected periodically with (definition of best soil and crop management strategies); obtain and compare different vegetation indexes (fertilizer distribution management); construct 3D models (optimal water and fertilizers distribution).

COMP4DRONES technologies are meant to:

- Save human effort and improve usability of advanced technologies by non-expert operators: technical set-up, number of missions and post-processing time can be saved by (i) facilitating calibration and usage of drones in combination with agricultural operation machineries in field (ii) improving and augmenting collected information by developing advanced Decision Support System; (iii) conveying to the operators pre-processed data through convenient interfaces (app and/or authorized web-access).

- Reduce the impact on the environment: The deployment of an autonomous rover can reduce the impact on the ground of bigger and heavier tractors. Moreover, advanced and more intelligent models can help both in water efficiency use and in reducing the cost/impact on the environment of herbicides/pesticides. Please note that spot application brings down chemical usage by 35–75%.

The **COMP4DRONES** project will provide the agricultural domain with a basic drone platform which can be configured as a modular system for multiple and generic tasks as well as for specific tasks in the agricultural domain. Development of the drones and components will be supported by a workflow and toolchain environment as well as dependability modelling system.

In both demonstrators of this use-case, the architectures for drone systems-of-systems composition to enable self-adaptability and secure communication will be demonstrated. This relates to the challenges of extending drones capabilities by embedding more features and by setting up a system engineering framework and development workbench.

Figure 54 show how the application of drone systems under the different soil cultivation conditions is achieved.

Figure 54: Wide Crop production multiple tasks demonstrator

In wide crop production (see Figure 54), input from visual inspection technologies is used to control the targeted usage of spraying, irrigation and fertilizers.

In vineyards, the usage of data from local sensory equipment relayed by drones (see Figure 55) offers specific opportunities for smart farming.

4.1.6.1 Demonstrator 1: Crop Monitoring

This demonstrator is mainly focused on crop monitoring, with special emphasis on health and growth crop management.

A wise farmer wants to improve its business by going green, using as less pesticides as possible and wasting as less water as possible. In addition, to be able to properly size the amount of pesticides needs to assess the growth of the crops (for example by determining the volume of the tree crowns) and their status (for example by determining the presence and amount of nutritional deficiencies, other disease or insect infestations). Here follows a short story-board of the scenario:

- [STEP 1] To gather more precise knowledge of the growth, he buys a drone and starts its usage to observe his fields. Image campaign acquisitions can be performed to determine the precise tree crowns and be able to determine exactly how much water is needed for irrigation. This first improvement results into:
  - The possibility of using just the exact amount of water needed, meaning less impact on the planet resources.
  - The reduction of pollution and costs determined by a non-properly sized irrigation when water tankers are adopted. Indeed, he certainly want to minimize useless irrigation missions that have a cost in terms of effort and fuel at least.
  - At this stage the treatment is still distributed to all the crops indistinctively.
- [STEP 2] To become greener, and to be able to intervene promptly and locally on un-healthy crops/plants, he invests on a smarter drone with augmented capabilities, smart enough to determine where actions are needed. This second improvement results into:
  - The possibility of addressing the most import best practice in agriculture performing treatment when is needed only where needed.
  - The reduction of pollution and costs determined by a non-properly sized treatment.
- [STEP 3] He, as a wise farmer, knows that it would be good to save also a bit of his own effort without losing money in hiring someone to do the treatments. Therefore, he buys a rover that under the lead of its master (the image acquisition drone) actuates the treatment as determined in the acquisition campaign. This third improvement results into:
  - The possibility of saving the farmer precious time and effort.
  - The possibility of promptly intervene on nutritional deficiencies, other disease or insect infestations to avoid their worsening/spreading.

4.1.6.2 Demonstrator 2: Wine Production

This demonstrator is designed to assist the winemaker in his work and to minimize the workload and the travel time to remote and poorly connected to the infrastructure vineyards.

Therefore, a drone will fly over the vineyard to collect sensor readings of land bound sensors and visual and multispectral images of the grapevines. This data will be sent to a base station for offline analysis. By fusing the sensor and image data the (health) condition of grapevines and the soil can be monitored and the next steps, like spraying, fertilizing, irrigation, will be suggested (see Figure 55).

Collecting data by flying autonomous over the vineyards, saves considerable time, otherwise the assessment and evaluation of the plants and the soil needs to be done locally.

Trustworthy and reliable communication of the drone with the sensors and base station guarantees that only valid data is retrieved, defective sensors are detected and only authorized partners (drones, sensors, base stations) participate in the communication. As a result, the sensor data cannot be manipulated and retrieved by any foreign drones.

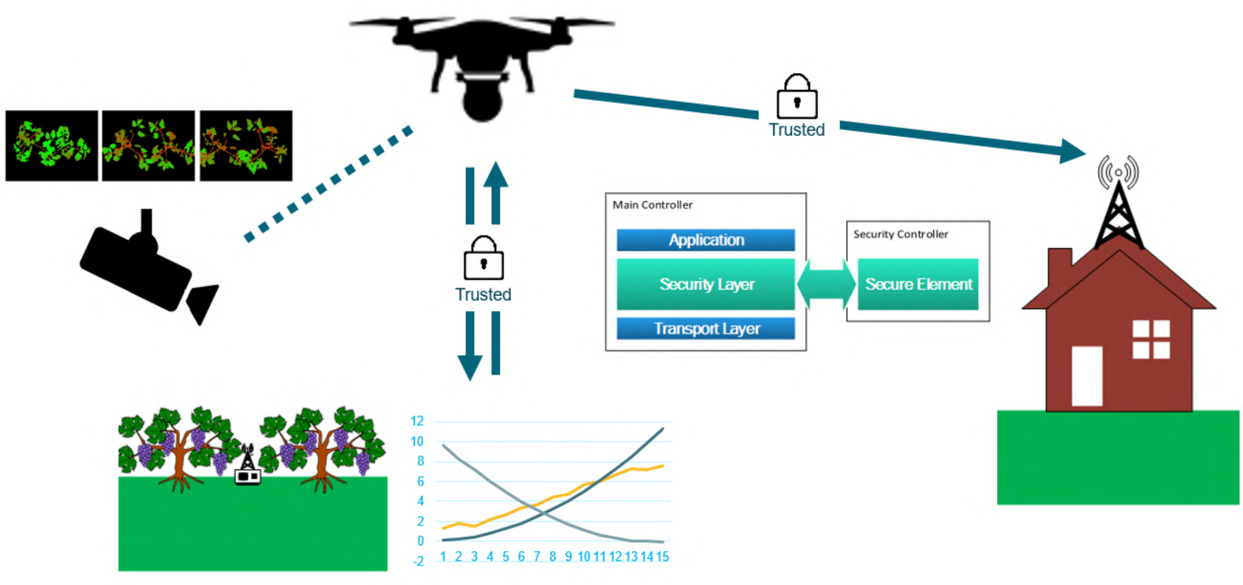

Figure 55: Wine production specific tasks demonstrator

4.2 Unified List of Drone Usages

Based on the demos' description, we have identified the common usage of the drone system which is combined into two categories: flying stages/operations, and mission specific operations.

4.2.1 Flying Stages/Operations[24]

A flight has a number of phases/stages. They are namely: taxiing; take-off; climb; cruise; descent; and landing. If a drone completes these all stages of flight, then it is said to have been completed one flight cycle. In the following, we describe these stages.

[24] https://www.fp7-restarts.eu/index.php/home/root/state-of-the-art/objectives/2012-02-15-11-58-37/71-book-video/parti-principles-of-flight/126-4-phases-of-a-flight.html

- **Taxiing** is the movement of an aircraft on the ground, under its own power, in contrast to towing or push-back where the aircraft is moved by a tug. The aircraft usually moves on wheels, but the term also includes aircraft with skis or floats (for water-based travel). An airplane uses taxiways to taxi from one place on an airport to another; for example, when moving from a hangar to the runway. The term "taxiing" is not used for the accelerating run along a runway prior to take-off, or the decelerating run immediately after landing, which are called the take-off roll and landing rollout, respectively.
- **Take-off** is the phase of flight in which an aerospace vehicle leaves the ground and becomes airborne. For aircraft that take off horizontally, this usually involves starting with a transition from moving along the ground on a runway. For balloons, helicopters and some specialized fixed-wing aircraft (VTOL aircraft such as the Harrier), no runway is needed. Take-off is the opposite of landing.
- **Climb**, in aviation, a climb is the operation of increasing the altitude of an aircraft. It is also the logical phase of a typical flight (the climb phase or climb out) following take-off and preceding the cruise. During the climb phase there is an increase in altitude to a predetermined level.
- **Cruise** is a flight phase that occurs when the aircraft levels after a climb to a set altitude and before it begins to descend. Cruising usually consumes the majority of a flight, and it may include changes in heading (direction of flight) at a constant airspeed and altitude. For most passenger aircraft, the cruise phase consumes most of the aircraft's fuel. This lightens the aircraft and raises the optimum altitude for fuel economy. For traffic control reasons it is usually necessary for an aircraft to stay at the cleared flight level. On long-haul flights, the pilot may ask air traffic control to climb from one flight level to a higher one, in a manoeuvre known as step climb.
- **Gliding** flight is heavier-than-air flight without the use of thrust; the term volplaning also refers to this mode of flight in animals. It is employed by gliding animals and by aircraft such as gliders. This mode of flight involves flying a significant distance horizontally compared to its descent and therefore can be distinguished from a mostly straight downward descent like with a round parachute. Although the human application of gliding flight usually refers to aircraft designed for this purpose, most powered aircraft are capable of gliding without engine power. As with sustained flight, gliding generally requires the application of an airfoil, such as the wings on aircraft or birds, or the gliding membrane of a gliding possum. However, gliding can be achieved with a flat (uncambered) wing, as with a simple paper plane, or even with card-throwing. However, some aircraft with lifting bodies and animals such as the flying snake can achieve gliding flight without any wings by creating a flattened surface underneath.
- A **descent** during air travel is any portion where an aircraft decreases altitude. Descents are an essential component of an approach to landing. Other partial descents might be to avoid traffic, poor flight conditions (turbulence or bad weather), clouds (particularly under visual flight rules), to see something lower, to

enter warmer air (in the case of extreme cold), or to take advantage of wind direction of a different altitude.

- **Landing** is the last part of a flight, where a flying animal, aircraft, or spacecraft returns to the ground. When the flying object returns to water, the process is called alighting, although it is commonly called "landing", "touchdown" or "splashdown" as well. A normal aircraft flight would include several parts of flight including taxi, take-off, climb, cruise, descent and landing.

4.2.2 Mission Specific Operations

Based on the use cases described above, we have identified the specific missions that can be performed by drones. Theses missions are classified into five categories: remote sensing, aerial surveillance, disaster relief, seismic survey, and smart agriculture. In the following, we describe these missions.

4.2.2.1 Remote Sensing

- **Survey and map land**: Surveying or land surveying is the technique, profession, art and science of determining the terrestrial or three-dimensional positions of points and the distances and angles between them. These points are usually on the surface of the Earth, and they are often used to establish maps and boundaries for ownership, locations, such as building corners or the surface location of subsurface features, or other purposes required by government or civil law, such as property sales. Surveyors work with elements of geometry, trigonometry, regression analysis, physics, engineering, metrology, programming languages, and the law. They use equipment, such as total stations, robotic total stations, theodolites, GNSS receivers, retroreflectors, 3D scanners, radios, clinometer, handheld tablets, digital levels, subsurface locators, drones, GIS, and surveying software.
- **Check air quality**: is the air quality within and around buildings and structures. IAQ is known to affect the health, comfort and well-being of building occupants. Poor indoor air quality has been linked to sick building syndrome, reduced productivity and impaired learning in schools. IAQ can be affected by gases (including carbon monoxide, radon, volatile organic compounds), particulates, microbial contaminants (mold, bacteria), or any mass or energy stressor that can induce adverse health conditions.
- **Assess water quality**: Water is essential for human survival, and its quality should be monitored and protected. The safety of water resources is threatened by external factors such as industrial wastes and agricultural fertilizers. Water quality monitoring programs have been developed to preserve water quality and eliminate the contamination of water sources. The quality of water in rivers, ponds, and lakes can be evaluated by monitoring dissolved oxygen (DO), pH, temperature, and electrical conductivity (EC), which are the most commonly used indicators of impairment. Low concentration of dissolved oxygen, undesirable temperature or pH, and inappropriate concentration of salinity lead to poor water quality. Periodic

sampling and analysis allow one to characterize water and identify changes or trends in water quality over time.

- **Gather geological information**: With the help of specific electromagnetic sensors, drones can be used to gather geological information to help geophysicists identify and better approximate the location and presence of minerals, oil, and natural gas.

4.2.2.2 Aerial Surveillance

- **Measurements over locations that are hazardous**: Drones are particularly useful for acquiring imagery or measurements over locations that are hazardous or difficult to reach on foot. In one early example is the measurements of volcanic gases using a quadcopter outfitted with spectrometers and electrochemical sensors within the La Fossa crater (Vulcano, Italy). In another example, octocopters are deployed to monitor methane (CH4) dynamics both above and below the trade wind inversion on Ascension Island in the South Atlantic Ocean, an ideal location for characterizing tropical background methane concentrations. The octocopters operated at high elevations, sampling methane at altitudes up to 2,700 meters above mean sea level.
- **Inspect hard to reach places**: Drones can access cluttered spaces, like where complex pipes are laid inside construction walls, to collect hard to reach information. These features built-in LEDs for darkness visibility and a versatile outer cage which allows it to rebound off of obstructions. It should lower downtime, reduce inspection bills, and improve worker safety. You can use quadcopters, for instance, to count up the number of markers in highway and to make sure guardrail is long enough and correctly placed. For inspecting bridges, drones provide a lot more quality and efficient inspection process. Airlines are experimenting what drone can do to pace up aircraft inspection. The crafts can hover all over the planes, capturing HD videos and photos that the engineers can then analyse instead of manually having to check the airplane.
- **Gather video and imagery**: Wide-area motion imagery (WAMI) is an approach to surveillance, reconnaissance, and intelligence-gathering that employs specialized software and a powerful camera system—usually airborne, and for extended periods of time—to detect and track hundreds of people and vehicles moving out in the open, over a city-sized area, kilometres in diameter. For this reason, WAMI is sometimes referred to as wide-area persistent surveillance (WAPS) or wide-area airborne surveillance (WAAS). A WAMI sensor images the entirety of its coverage area in real time. It also records and archives that imagery in a database for real-time and forensic analysis. WAMI operators can use this live and recorded imagery to spot activity otherwise missed by standard video cameras with narrower fields of view, analyse these activities in context, distinguish threats from normal patterns of behaviour, and perform the work of a larger force.
- **Offshore infrastructure inspections**: Inspecting tall infrastructure like offshore constructions and bridges is currently mostly done via rope access: inspectors

climb on the infrastructure to perform local visual inspections. This is a hazardous and time-consuming process, which can be largely performed remotely with drones. These flying cameras can be used to perform a visual inspection and decide whether a human is needed for detailed follow-up inspections.

- **Traffic management operation (using aerial images)**: In the case of an event, emergency or an incident occurring in the road, the prompt response of the authorities and road operators is of vital importance. When this response involves the usage of drones, it requires the activation of a geofencing area over the incident point locking down the airspace to all flights but authorized drone operations, that will be based on the streaming of HD video in real time from the incident location to the transport control center, video analysis based on artificial vision and embedded vehicle tracking capabilities on the drone.
- **Digitalization of the state of a constructive process:** This mission is to capture data from the affected flight area (i.e. areas under construction, civil works assets, motorways and highways, etc.). This capture is carried out using mass data capture technologies and positioning systems in space. The post-processing in office of the entire set of data collected, is performed through artificial intelligence technologies. It must provide the necessary data to carry out the scan to BIM step, prior to the generation of a georeferenced model of assets construction and civil works.
- **Analysis of underground constructions status**: This mission is for capturing a georeferenced scanner of the progress in the construction of a tunnel developed by conventional means (i.e. explosives, gravel, hammers, etc.). This capture is carried out using drones inside the tunnel, capturing the data set using LiDAR technologies and using positioning / navigation systems developed for autonomous navigation inside the tunnel. In the post-processing, the entire set of collected data will be positioned in the space using software with automatic beacon / sphere recognition systems to subsequently carry out the Scan to BIM step prior to the generation of a georeferenced advance model of tunnel under construction.

4.2.2.3 Disaster Relief

- **Locate and save life**: Rescue comprises responsive operations that usually involve the saving of life, or prevention of injury during an incident or dangerous situation.
- **Deliver medicine/medical sample:** Medical professionals will load a secure drone container with a medical sample or specimen at one of nearby facilities. The drone will fly along a predetermined flight path, monitored by a remote pilot, to a fixed landing pad at main hospital and central pathology lab.
- **Autonomous access in GPS denied cluttered environment**: For the purpose of preparation of human access in disaster relief sites, drones can access unknown spaces. The goal of such drone support is twofold: (1) to explore the unknown space and create a common reference model of the environment, and to transmit this model external to the building; (2) to identify points of interest (e.g. human

victims) and calculate routes for humans to extract those victims, using this reference model. As such areas may be indoors (e.g. large industrial buildings, shops, high buildings) with a complex structure the drones must be able to operate autonomously without reliance on GPS.

- **Deliver parcel, coordination between drone and droid:** To be able to reach the inside facilities in a flight pass between 2 buildings, the droid and the drone have to share the work. The droid will transport the parcel outside the first building, detecting its own surroundings, then guide the drone during its landing phase. Once the drone landed, the droid transfers the parcel to the drone. The drone will fly along a predetermined flight path, monitored by a remote pilot-in-command (RPIC), to a fixed landing pad or another droid.

4.2.2.4 Seismic survey

- **Deliver seismic sensors**: Going in the air to deliver wireless seismic sensors unlocks many hard-to-reach places where it is not worth going to shoot seismic in a traditional ground-based way. Many places in the world will become accessible to seismic imaging for different usage from oil and gas exploration to geothermal or environmental hazards monitoring.
- **Communicate with the delivered seismic sensor:** After the seismic sensor has been dropped, it is essential to verify its good landing and coupling. 3C accelerometers are fitted in the seismic sensor to monitor the free-fall, the landing deceleration and the final attitude of the sensor. The drone is hoovering for a couple of seconds to collect these data wirelessly as well as other information like serial numbers and GPS location.

4.2.2.5 Smart agriculture

- **Crop spraying:** To maintain crop yields, plants require the proper fertilization and protection applications. Smart crop spraying helps save great amount of water, fertilizers, and human effort. Instead of evenly distributing the liquid over the crop, intelligent spraying helps provide the right amount of water and fertilizer to every plant.
- **Presence of water:** UAVs equipped with suitable sensors identify parts of a crop that need more water. In this way it is possible to improve the efficiency of water use, in the right places at the right time and in the right quantity.
- **Accurate Geo Tagging**: Nadiral images acquisitions (i.e. Optical / Thermographic pictures) are tagged with high geographical accuracy (double precision, RTK/PPK techniques), in order to allow other AI components, to easily extract features from the images (as explained in the previous points).
- **Measure the height of crops**: Monitoring crop growth provides timely and reliable spatial information to farmers and decision-makers employed in precision agriculture. Studying growth of crops throughout the growing season is a prerequisite for informed farming, decision-making and estimating yield production. Measuring the evolution of crop height and biomass during the growing

season provides the essential indicators for growth and health and thus provides a means for dedicated irrigation, fertilization and estimation of yield.

- **Check the health of plants**: In the field of precise agriculture, modern sensors and data analysis are used to inform farmers about the plants' health. The monitoring of the condition of the plants and the soil during the entire growing season provides the essential to effectively manage plants, soil, fertilization and irrigation and respond to shortages, diseases or pests in a timely, targeted and local manner.

5 COMP4DRONES Framework

In this section, we describe the overall workflow of the project with a focus on the identification of the **key enabling technologies**, the task of this deliverable, based on the demos' descriptions in D1.1. To do so, we describe, a general structure/architecture for the drone system which is then used by a process to identify the different components of the system. The identified key technologies, their targeted improvements, the methodology to develop such technologies, and the list of tools to support this methodology are described in the next sections.

5.1 Project Workflow

The **COMP4DRONES** framework specifications define what the framework should provide (i.e. components, tools, methodology and workflow) to be a **key technologies** (KET) enabler for drone. Drone manufacturers will oversee the project's technical guidelines. To limit the scope and better target the domains considered in the project, the use cases specifications will be used as inputs. The final specifications should also consider the extensibility and usage of the framework in related domains of application.

Figure 56 shows the overall workflow during the **COMP4DRONES** project. First, the different demonstrators are going to be specified (i.e. scenarios, features, and functional and non-functional requirements). The demos' requirements are then analysed to get a unified list of requirements (WP1). Second, the unified list of requirements is used to identify the key enabling technologies that are going to be developed during the project (WP2). Third, the identified key technologies are characterized and decomposed into the project working packages: the architecture and its generic components (WP3), technologies for safe autonomous decision (WP4), trusted communication technologies (WP5), and tools for design, verification, performance analysis, etc. (WP6). Fourth, the developed technologies are integrated and validated. Finally, the key technologies are evaluated by using them for the development of different demos (WP1).

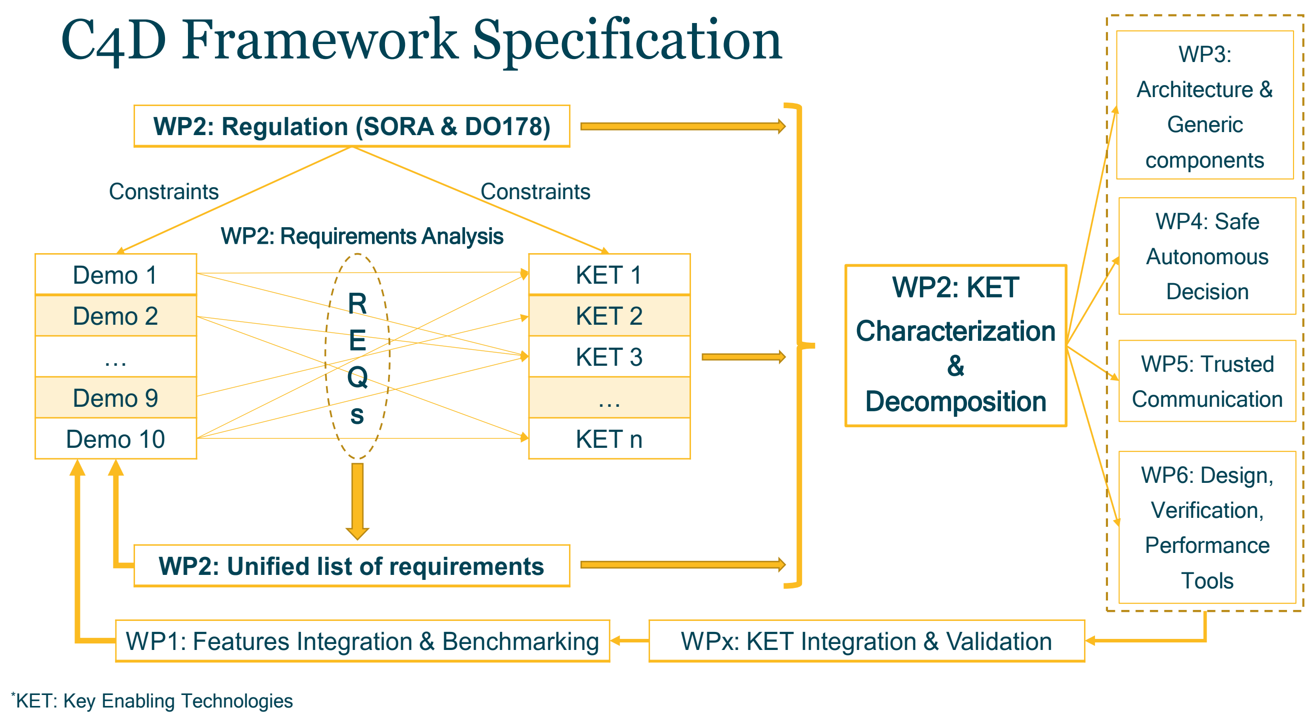

Figure 56: The overall work flow of the COMP4DRONES project

5.2 Process for Identifying Drone System Components

To identify the key enabling technologies for drones, there is a need for a general system structure/architecture for the drone system. The idea behind this general system architecture is to have a well-defined system partitioning for easy development of the key technologies and their integration later on.

A proposed architecture for an UAV is shown on Figure 57. This architecture is based on the current drone systems described in Section 3. This architecture separates the different concerns of the system into three layers: *control*, *flight management*, and *planning*.

1. The *control layer* contains the low-level control modes of the UAV (e.g. take-off, landing, trajectory following, etc.). The control behaviours are realized through actuators in case of they are performing an action or using sensors in the case of perceptional tasks.
2. The *management layer* is responsible for selecting a pre-defined (designed) plan in response to an environment situation propagated from the control layer. It is also responsible for executing the selected plans by sending commands to the control layer to perform tasks such as fly to, scan area, etc. Furthermore, in case of, there is no existing plan to cope with the environment situation, a request is sent to the planning layer to provide a new plan.
3. The *planning layer* is responsible for high level planning. Its main task is to generate/provide the different plans that enable the drone system to satisfy its

requirements and perform its intended missions. This layer is responsible for task planning, motion planning, reasoning and diagnosis mechanisms, and execution monitoring mechanisms, etc.

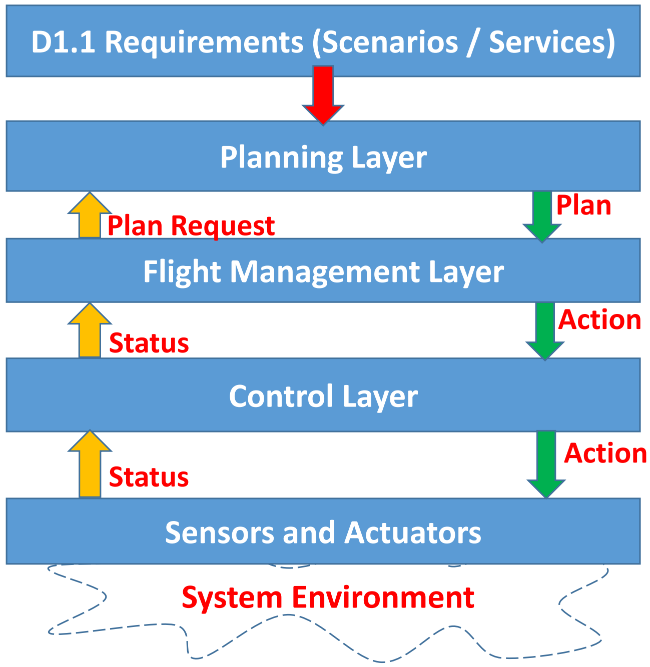

Figure 57: A layered architecture of UAV System

An example instance of the architecture shown in Figure 57 is presented in Figure 58. This instance is taken from a rescues mission where a number of UAV are used to scan an area to find the injured civilians. To achieve this mission, a plan has to be either designed or automatically generated using planning algorithms at the planning layer. The plan consists of a set of tasks such as scan area, transmit data, fly-to destination, etc. These actions are performed sequentially or done in parallel. The sequence of actions (i.e. the plan) are coordinate and executed using the execution engine in management layer. This layer also has a coordination component to enable the collaboration between different UAVs. Finally, the control layer is responsible for executing the control behaviours to realize the tasks. For example, the fly-to task is achieved through the take-off, trajectory following, and landing control behaviours. The behaviours use hardware and software components to execute the different tasks (see Figure 58).

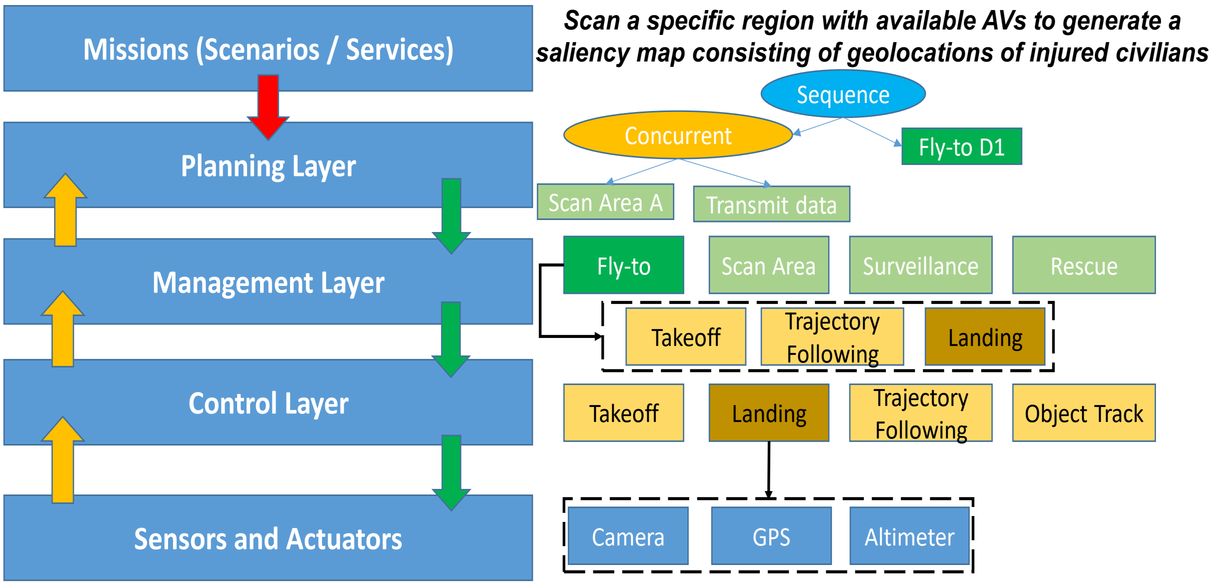

Figure 58: An example of UAV different layers

In the following, we describe how to identify the key technologies that are going to be developed in the project based on the unified set of requirements discussed above.

As shown in Figure 57 (i.e. the UAV architecture) and the instance of UAV architecture in Figure 58. The requirements (missions) are the main part that drive the different elements of the architecture, where the requirements are used to define the plans. These plans consist of a set of tasks which are realized using control behaviours. These control behaviours are executed using hardware and software components as shown in Figure 59. These steps also define/require a number of tools to support the engineers in doing this process.

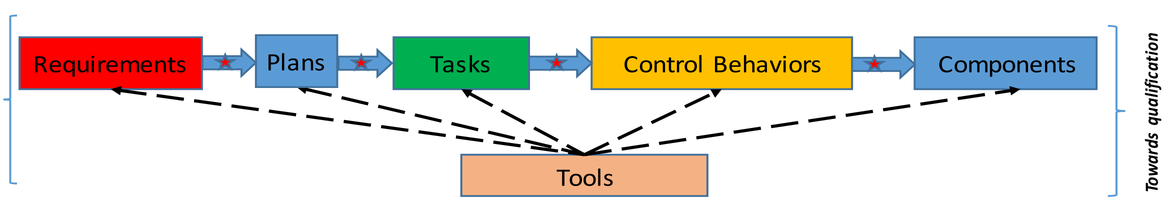

Figure 59: A process for identifying the key technologies

To come up with the drone system components, the unified list of usages discussed in Section 4.2 are used to identify: tasks to satisfy the requirements, control behaviours to perform the tasks, hardware/software components that provide the resources to execute the behaviours, and tools required to create the identified components. A summary for the result of this process is shown in Figure 60. In Figure 60, a number of tools and languages are identified for specifying and validating, requirements, plans, tasks, behaviour, etc. In addition, different subsystems are identified such as landing, localization, navigation, etc. Furthermore, these sub-systems components are either software architecture (e.g. planning algorithms, plan execution, etc.) or UAV hardware components (e.g. Camera, LIDAR, etc.)

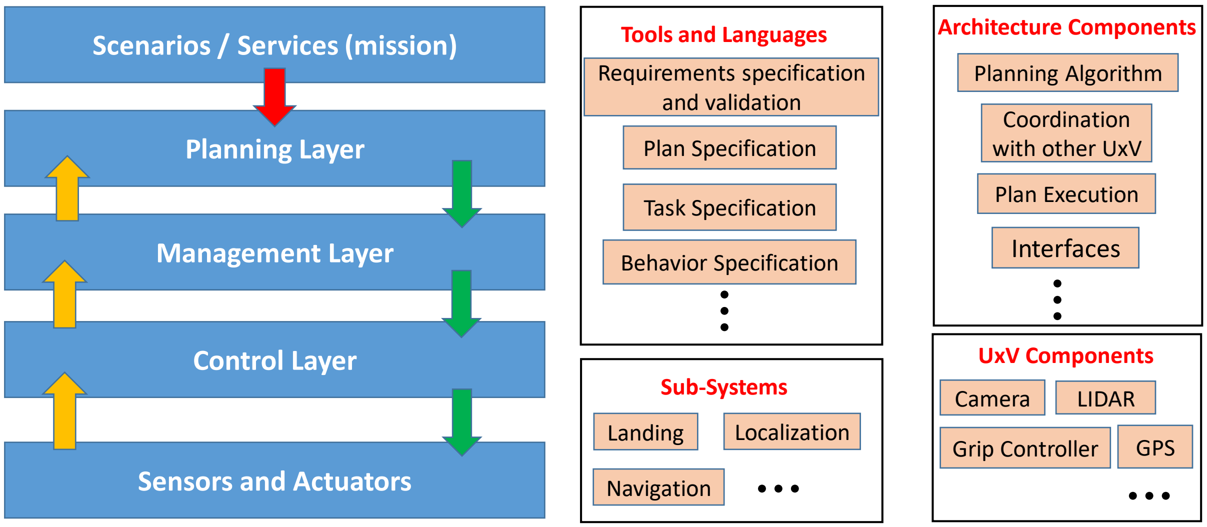

Figure 60: Tools and components to support the UAV system development

6 Key Enabling Technologies for Drones

In the following, we give a brief description of the **different components** that are required to have a fully functioning drone system. These components are divided into two groups: architecture components and UAV components. The architecture generic components are the common/shared elements that can be reused across different drone systems. The UAV specific components are specific to certain application/mission, but also can be used in more than one application. In the following, we give a brief description of the different components that are required to have a fully functioning drone system. These components are divided into four groups: u-space capabilities, system functions, payload, and tools. The system functions are the common/shared elements that can be reused across different drone systems. The payloads are specific to certain application/mission, but also can be used in more than one application.

6.1 Drone Capabilities for U-space[25]

As the range of mission types expands, and U-space services are deployed and enhanced, drones of all types, and the supporting ground infrastructure, will need to have capabilities that evolve accordingly. The capabilities expected to enable U-space services are shown in Figure 61 and are described in the next section.

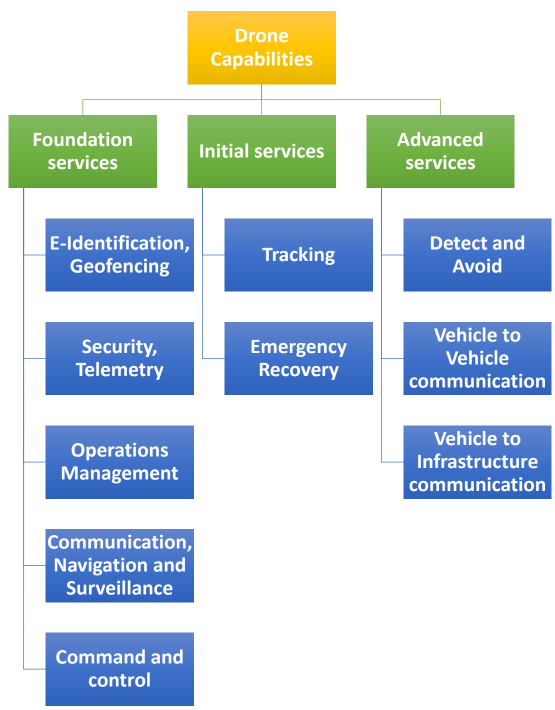

Figure 61: Drone capabilities for U-space

25 https://www.sesarju.eu/sites/default/files/documents/reports/European%20ATM%20Master%20Plan%20Drone%20roadmap.pdf

6.1.1 U1: U-space Foundation Services

E-Identification: E-identification is the ability to identify the drone and its operator in the U-space system

Geofencing: Geofencing is the ability to comply with geographical, altitude and time restrictions defined by the geofencing service. This capability covers the technology, processing and any required communication links, as well as management and use of geofencing information used in the provision of this service.

Security: Security is the ability to protect vehicle and data (interaction with other vehicles and infrastructure) against attacks on information technology and communications systems.

Telemetry: Telemetry is the ability to transmit measurement data from the drone-to-drone operator and/or service provider to meet the demands of relevant services.

Communication, navigation and surveillance: Communication, Navigation and Surveillance is the ability for drones to meet the communication, navigation and surveillance performance requirements for the specific environment in which they will operate. This capability involves the combination of on-board sensors and equipment (e.g. data link, voice radio relay, transponder, laser, GNSS, cellular etc.) as means of achieving the required performance.

Command and control: Command and control is the ability of drones to communicate with their ground control station to manage the conduct of the flight, normally via a specific data link.

Operations management: Operations management is the ability to plan and manage drone missions. This includes access to and use of all aeronautical, meteorological and other relevant information to plan, notify and operate a mission.

6.1.2 U1: U-space Foundation Services / U2: U-space Initial Services

Tracking: Tracking is the ability of the drone to provide flight parameters including at least its position and height.

Emergency recovery: Emergency recovery is the ability of drones to take account of failure modes, such as command and control (C2) link failure, and take measures to ensure the safety of the vehicle, other vehicles and people and property on the ground. This includes identification of possible problems (auto-diagnostic) and all equipment required to manage solutions.

6.1.3 U3: U-space Advanced Services

Vehicle to infrastructure communication (V2I): Vehicle to Infrastructure communication (V2I) is the ability for drones to share information with infrastructure components.

Vehicle to vehicle communication (V2V): Vehicle to Vehicle communication (V2V) is the ability for drones to communicate information to each other. The nature of the information exchanged, and its performance requirements, will depend on the application.

Detect and avoid: Detect and avoid is the ability for drones to detect cooperative and non-cooperative conflicting traffic, or other hazards, and take the appropriate action to comply with the applicable rules of flight. This includes the collision avoidance, situational awareness and "remain well clear functionalities, as well as the other hazards described in chapter 10.2.3 of the ICAO RPAS Manual: terrain and obstacles, hazardous meteorological conditions, ground operations and other airborne hazards.

6.2 System Functions

The drone system functions are the core functions required for the drone to perform its flying stages in safe and efficient manner. The different system functions are shown in Figure 62 and described in the next sections.

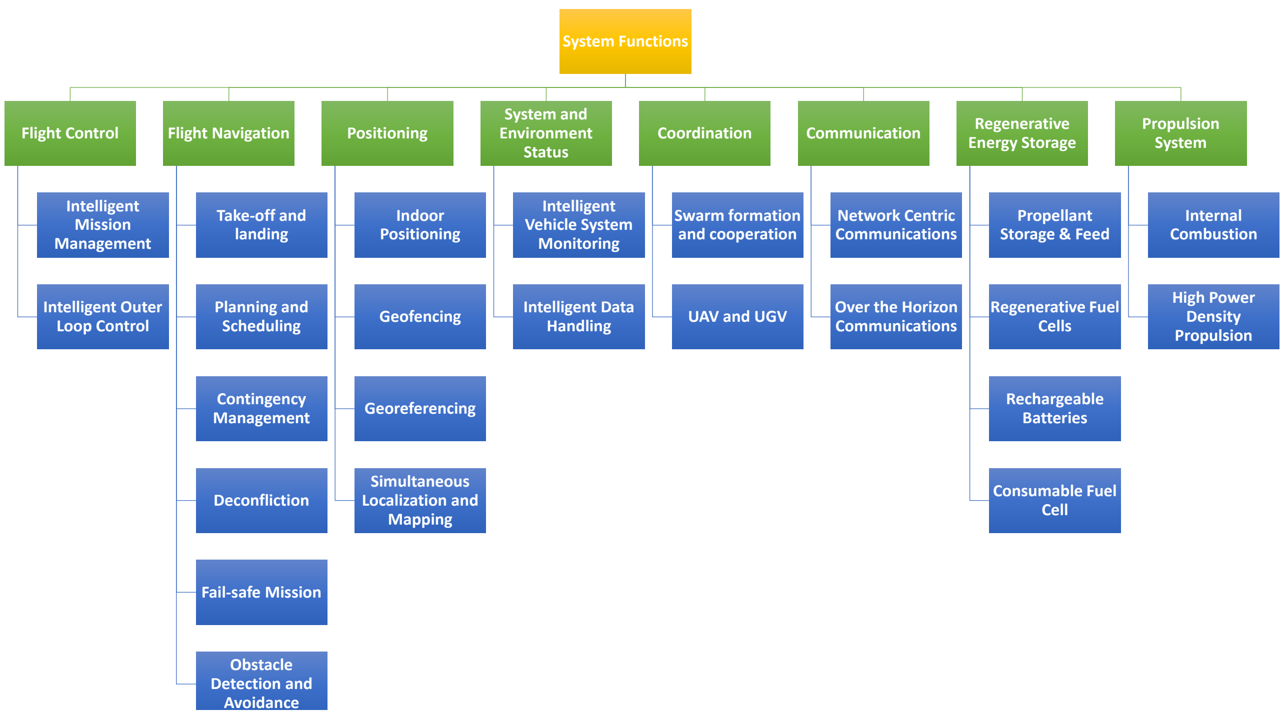

Figure 62: Drone system functions

6.2.1 Flight Control

6.2.1.1 Intelligent Mission Management[26]

Intelligent Mission Management (IMM) refers to onboard and ground-system technologies that provide a desired mixture of autonomous and human-directed UAV operation. It shifts the human role in conducting UAV missions from operators of vehicle and payload systems towards being users of and requesters for observation data products. IMM

[26] https://ti.arc.nasa.gov/m/profile/frank/sullivan.SPIE-04-Final.pdf

increases Level of Autonomy (LOA) for sustained or complex UAV operations. This technology offers several benefits sought by the civil UAV user community including:

1. An ability to operate in environments where unreliable communications make conventional remote operation infeasible
2. An ability to conduct tedious, long duration missions where conventional remote operations would be expensive and excessively strenuous for human operators
3. An ability to optimize use of limited airborne sensing assets and to maintain optimality in changing conditions by modifying mission plans
4. Reduced need for highly trained pilots and payload operators in order to reduce operational costs and increase access to airborne sensing assets
5. Enhanced integration with command and control systems, particularly as mobile elements of automated sensor networks

IMM encompasses a range of specific technology areas. For onboard systems, these include Automated Planning & Scheduling (APS) and Intelligent Outer Loop Control (IOLC) as autonomy-enabling technologies.

6.2.1.2 Outer Loop Control: Intelligent Outer Loop Control[27]

Intelligent Outer-Loop Control (IOLC) provides an on-board capability for autonomous and semi-autonomous operation. A traditional outer-loop control system such as an autopilot or flight management systems (FMS) achieves human-defined navigation and guidance goals, mainly by controlling vehicle flight surfaces. IOLC extends the traditional approach to achieve high level mission goals. For example, whereas an FMS might be tasked with making the aircraft follow a specified route, an IOLC might be tasked with a much broader goal such as repeatedly monitoring a set of ground targets for events of interest and alerting users whenever such events occur. To meet these goals, the system needs to be able to control not only vehicle flight surfaces, but also sensor payload, communications and other subsystems. IOLC entails specific capabilities including:

- Mission planning: The ability to generate a mission plan that meets user defined goals and preferences. This function is carried out by an automated planning and scheduling (APS) component
- Mixed-initiative planning: Depending on operational requirements and user preferences, users may interact with the APS component to help formulate the plan or to select among alternative APS generated plans.
- Monitored execution: Input from system sensors, payload sensors, IVSM and human controlled ground systems may be used to track progress, determine when it is time to advance to the next plan step and determine if anything has occurred that threatens, invalidates or reduces the effectiveness of the plan.
- Payload-directed execution. Sensor payload inputs may be used to fill in details about the plan that could not be determined as part of mission planning. For example, a mission requirement to follow a moving object or shifting contour can

[27] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5621028/

only be met by sensing and acting in a tight loop. Path decisions cannot be incorporated into the mission plan in advance, so the IOLC makes these decisions as the plan is being carried out

6.2.2 Flight Navigation

6.2.2.1 Take-off[28]

Performing a take-off with UAV is significantly less intricate than landing. The main parts consist of getting into air, which depends on whether the aircraft is launched from hand throw, catapult or runway, and climbing to a specified altitude while avoiding any obstacles. In a hand launch or a catapult launch the aircraft starts off airborne and the main challenge in this case is to maintain control of the aircraft despite the fact that the airspeed can be very low at the same time as ensuring that the aircraft does not lose too much altitude. In the case of a runway launch the aircraft will need to gain enough speed to be able become airborne on its own at the same time as keeping itself on the runway. When climbing, aside from the initial increase in the climb angle, where the increased angle of attack results in greater lift, the wing can be considered to have the same lift as when flying in level flight and thus the maximum climb rate is mainly dependent on the available thrust and weight of the aircraft.

6.2.2.2 Landing[22]

In broad terms landing consists of four stages, where the first stage concerns aligning the aircraft with the landing area and position itself for the next stage. The second stage, the approach, descends the aircraft towards the touch down point in a constant glide slope. The third stage, the flare, concerns with the last adjustments before touchdown with the goal of reducing the vertical speed, transition to a desired touchdown attitude and aligning the aircraft in the direction of the aircraft velocity vector. The fourth stage concerns with stopping the aircraft on the ground.

In a belly landing the high friction between the aircraft and the ground will inevitably slow the aircraft to a complete stop in such a short amount of time that there isn't much room for adjustments after touchdown. A runway landing on the other hand is more delicate, taking much longer to slow down and requires much more care after touchdown, making sure that the aircraft stays on the runway and doesn't fall over. Landing should always be done towards the wind and preferably straight into it, if there is side-wind present the aircraft will approach the landing area slightly sideways and should, at last possible moment, align itself in the direction it moves before touch down. The main controllers during the approach and flare are the elevator and the throttle that both have an impact on the angle of attack which in turn also affects the velocity of the aircraft. Larger aircrafts often have flaps that both slow the aircraft down and increase the lift (thus reducing the stall speed) and/or other form of air-brakes. However, UAVs of the sizes relevant for the

[28] https://liu.diva-portal.org/smash/get/diva2:1055556/FULLTEXT01.pdf

EasyPilot usually lack flaps or other air-brakes. Slowing the aircraft down in reasonable time without any form of air-brake, while descending, is by itself often a challenge.

6.2.2.3 Planning and Scheduling[29]

Planning and scheduling are general cross-cutting technologies that takes higher level goals, objectives and constraints and turns these into more detailed plans and schedules that can be executed by humans or machines. The difference between planning and scheduling is that planning involves more choice about which objectives will be achieved, and the actions needed to achieve them, whereas in scheduling, the activities are given, and the principle decisions involve ordering the activities and perhaps assigning resources to the activities. Both planning and scheduling are cross cutting technologies that have wide application to many areas of intelligent systems including both IMM, and ISHM.

For IMM, planning and scheduling technology is useful for automated or interactive mission planning and replanning throughout the course of the mission. It can be applied to long term planning (days, weeks, months) of mission campaigns for fleets of UAVs, to the detailed planning or scheduling of routes and objectives for individual UAVs, or to the detailed actions required for operating sets of instruments on board individual UAVs. Note that automated mission planning and scheduling technology has application both on the ground (to assist humans in the mission planning process) and onboard a UAV to adapt mission plans to rapidly changing events or capabilities. Onboard planning or replanning may be essential if quick responses are needed to changing events (e.g. observation of fires or volcanic eruptions) and there is limited bandwidth or communication with the vehicle.

The automation of planning and scheduling in IMM tasks has a number of potential advantages:

- Quicker response to unexpected events, changing objectives, or degraded capabilities
- Better optimization of mission plans and schedules, yielding cost reductions (fewer flights), better coordination between vehicles, and/or greater productivity from individual vehicles
- Reduction in errors and drudgery over manual human planning and scheduling in large measure, for UAV mission management this technology impacts efficiency and quality of operations, although rapid replanning capabilities and elimination of errors could improve (or be essential to) mission safety.

For ISHM, planning and scheduling is useful in at least two distinct ways: 1) planning and scheduling of maintenance activities for individual UAVs and fleets of UAVs, and 2) onboard replanning to permit continued operation in the face of degraded capabilities. For maintenance activities, the automation of planning and scheduling has the same

[29] https://arxiv.org/abs/1906.00777

advantages listed above for IMM, and largely impacts efficiency and cost of maintenance operations. Condition-based maintenance makes maintenance planning and scheduling more dynamic and more complex, increasing the need for such capabilities. Onboard replanning for degraded capabilities has the potential to improve both mission safety and mission efficiency – for example, changing smoke or ash plumes from a fire or volcanic eruption might dictate rapid changes in the mission both for the safety of the vehicle, and to continue to obtain useful observations.

6.2.2.4 Fail-safe Mission[30]

The ability of a UAV flight system to adapt to system or hardware failures is a key technology for flying UAVs with an acceptable level of safety and perhaps the most critical system for the aircraft is the flight control system (FCS). This technology, generic to any UAV application, provides for high reliability and is one of the foundations for unrestricted access to the air space by UAVs. Initial reports from the FAA regarding UAVs indicate they are looking for “reliability comparable to a piloted aircraft”. The issue of reliability can be addressed from two viewpoints. The first is basic reliability of the onboard systems. The second is the reliability of an on-board pilot in being able to recognize a failure and adapt to the situation. Both of these viewpoints must be considered in assessing the reliability of UAV flight systems. This technology is especially important for long endurance flights in remote areas, where options for recovery are limited. One approach to system reliability is simply to increase the redundancy of flight systems. This comes with both an initial cost and an on-going weight penalty. Another approach would add on-board intelligence to recognize and remedy a failure.

6.2.2.5 Contingency Management[31]

Contingency Management refers to an on-board capability to react to unforeseen events, particularly as needed to minimize the likelihood of human casualties and property damage, and to maximize the likelihood of aircraft and payload survival. More generally, it refers to a broad range of techniques designed to increase the robustness of intelligent systems to uncertainty. This uncertainty can take many forms, including degradation or failure of hardware components (sensors or actuators), lack of precise information about environmental conditions (wind, cloud cover, visibility), unforeseen events (fires, volcanic eruptions, algal blooms), or changing objectives. In the face of such uncertainty, contingency management techniques may be useful or necessary for improving both mission safety, and mission productivity. As an example, if hardware degradation or failure occurs, certain mission operations or activities may be too risky, and it may be necessary to quickly alter or restrict a mission plan. In this case, contingency management directly impacts mission safety. In contrast, if a UAV is tasked with certain science observations, and cloud cover or visibility in certain locations proves worse than expected, contingency management techniques could be used to revise the mission plan

[30] https://www.embention.com/news/fail-safe-and-fts-with-uavs/
[31] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.701.9978&rep=rep1&type=pdf

to concentrate on alternative higher quality observations. In this case, contingency management improves mission value or productivity rather than mission safety.

Contingency management cuts across other high-level functional capabilities relevant to UAVs including Intelligent System Health Management (ISHM) and Intelligent Mission Management (IMM). Contingency management techniques would likely be an integral part of an ISHM system for a UAV that must continue to function in a degraded state. Similarly, contingency management techniques would likely be an integral part of an IMM system that is trying to optimize mission productivity or react quickly to environmental events such as forest fires, volcanic eruptions or tectonic events. We have chosen to treat contingency management as a separate top-level enabling technology because it cuts across many different areas and capabilities relevant to UAVs. In many respects, the extent to which a system can react to and handle contingencies is an indicator of its ability to function autonomously. If a system has little or no ability to deal with contingencies, then human intervention and perhaps continuous supervision could be required if the system is to function in an environment with significant uncertainty. For a UAV, the mission plays a large role in determining the type and amount of uncertainty that will be encountered, and hence the need for this capability. For example, a single UAV performing a systematic ground survey of an area may have less need of this capability than a set of vehicles tasked with recognizing and monitoring certain types of events.

6.2.2.6 Deconfliction[32]

Air Traffic Management (ATM) paradigm in Europe is evolving around the Trajectory Based Operations (TBOs) concept, where air traffic is no longer constrained by artificial boundaries such as airspace sector boundaries, national borders, locations of beacons, etc. Instead, ATM will focus on trajectories together with an adapted airspace design. This new ATM concept of operations implies a possibility to resolve potential conflicts between aircraft trajectories in the strategic trajectory planning phase. This strategic de-conflicting will alleviate the air traffic controller’s tactical conflict resolution workload. More efficient trajectories with minimal number of potential conflicts can be strategically designed from a more global point of view, anticipating downstream effects. Once the aircraft is cleared to fly its reference business trajectory (optimal conflict-free trajectory), the controller’s workload will thereby involve more monitoring and less conflict prediction and resolution. As a consequence, the needs of tactical intervention being reduced, more flights will be accommodated by the controller in a given airspace at a given time.

6.2.2.7 Obstacle Detection and Avoidance

Detect and Avoid (DAA) is a basic functional requirement for aircraft to safely operate. The process of collision avoidance involves sensing the surrounding environment, assessing the potential of colliding with those hazards that were detected and taking corrective action to avoid the hazard when a collision is imminent. The potential hazards that are of concern in collision avoidance are ground (the surface of the earth), airborne

[32] https://www.aopa.org/news-and-media/all-news/2019/may/22/drone-deconfliction-advances

(other vehicles in the airspace), weather, ground obstacles (towers, power lines, ground equipment/vehicles) and surface features (buildings, foliage). Most all of the CA process is performed by the pilot in a piloted aircraft to include the use of the pilot's eyes to visually detect and track the hazards. With the operator of the UAV remotely located, a CA system is foreseen as a critical feature to allow a UAV to operate with an equivalent level of safety to that of a piloted aircraft.

Air collision avoidance is unique in that it not only provides safety for the vehicle and its occupants but it also provides safety for other vehicles and their occupants flying in the air space. As a result, a number of regulatory requirements regarding the ability to perform both aspects of the air collision avoidance safety role are placed on vehicles that are to be operated in the national air space (NAS). Finally, collision avoidance is influenced by a combination of mission requirements, procedures and systems. A collision avoidance system is needed only when mission requirements will expose the vehicle to potential hazards. Procedures alone can be used in conjunction with the air traffic management system to allow a UAV to operate in the NAS, however, these procedures carry a burden that impact routine operations and may severely restrict the UAV's ability to carry out some missions.

6.2.3 Positioning

6.2.3.1 Indoor Positioning[33]

An indoor positioning system (IPS) is a network of devices used to locate people or objects where GPS and other satellite technologies lack precision or fail entirely, such as inside multistory buildings, airports, alleys, parking garages, and underground locations. A large variety of techniques and devices are used to provide indoor positioning ranging from reconfigured devices already deployed such as smartphones, Wi-Fi and Bluetooth antennas, digital cameras, and clocks; to purpose-built installations with relays and beacons strategically placed throughout a defined space. IPS has broad applications in commercial, military, retail, and inventory tracking industries. There are several commercial systems on the market, but no standards for an IPS system. Instead each installation is tailored to spatial dimensions, building materials, accuracy needs, and budget constraints. Lights, radio waves, magnetic fields, acoustic signals, and behavioural analytics are all used in IPS networks. IPS can achieve position accuracy of 2cm, which is on par with RTK enabled GNSS receivers that can achieve 2cm accuracy outdoors.

6.2.3.2 Geofencing

Geofencing is a virtual barrier created using a combination of the GPS (Global Positioning System) network and LRFID (Local Radio Frequency Identifier) connections such as Wi-Fi or Bluetooth beacons. This boundary is dictated by a combination of hardware and software which dictates the parameters of the geofence i.e. a drone app and an

[33] https://en.wikipedia.org/wiki/Indoor_positioning_system

unmanned aircraft. This technology has been available for years with early adaptors using it to monitor cattle with the help of GPS collars programmed with geographic boundaries that would provide alerts when then livestock left the predefined boundaries. Other uses included (and continue to include) the monitoring of fleet vehicles such as armoured security vans, providing early warning if anything out of the ordinary occurs.

More modern uses of geofencing include ‘Smart Home’ functionality such as your heating turning itself off when your phone pings at a certain distance from your house and back on when you’re heading back. Drones use geofencing on a much more focused level, usually to satisfy aviation agency regulations about the use of airspace. Nestled within the default safety features of all modern SUAs, many people will be affected by geofencing without necessarily knowing too much about it. With reports of ‘near misses’ and irresponsible flying on the rise alongside the popularity of consumer drones, it makes complete sense that we’re seeing more strict applications of geofencing and other smart safety features from the big-name manufacturers.

6.2.3.3 Georeferencing[34]

Georeferencing is the process of assigning real-world coordinates to each pixel of the raster. Many times, these coordinates are obtained by doing field surveys - collecting coordinates with a GPS device for few easily identifiable features in the image or map. In some cases, where you are looking to digitize scanned maps, you can obtain the coordinates from the markings on the map image itself. Using these sample coordinates or GCPs (Ground Control Points), the image is warped and made to fit within the chosen coordinate system.

6.2.3.4 Simultaneous Localization and Mapping[35]

Simultaneous Localization and Mapping (SLAM) is the synchronous location awareness and recording of the environment in a map of a computer, device, robot, drone or other autonomous vehicle. SLAM is a key component in self-driving vehicles and other autonomous robots enabling awareness of where they are and the best routes to where they are going. By creating its own maps, SLAM enables quicker, more autonomous and adaptable response than pre-programmed routes.

A number of emitters and sensors work together in sensor fusion with an AI for a single purpose in SLAM. A robot that uses SLAM, for example, employs various types of cameras and sensors such as radar, Lidar, ultrasonic and other technologies to understand its environment. By better understanding its environment, a robot can more effectively map, navigate, avoid obstacles and adjust to changes. Highly accurate GPS modules have reduced the need for SLAM in some applications. High-precision GPS can almost entirely replace SLAM in some outdoor environments. That said, GPS may suffer

[34] https://en.wikipedia.org/wiki/Georeferencing
[35] https://link.springer.com/referenceworkentry/10.1007%2F978-3-540-30301-5_38

reduced performance or outages, and SLAM can fill in the gaps in navigation where more detail is needed and also take over in the case of these difficulties.

6.2.4 System and Environment Status

6.2.4.1 Data Fusion and Processing: Intelligent Data Handling[36]

The need for real-time processing of sensor data on-board a UAV is driven by several factors. Imaging devices in particular can produce many gigabytes of data on a single mission. Because the onboard telemetry systems have limited bandwidth, which must be allocated between the aircraft flight control function and multiple payload elements, it may not be practical to transmit all of the data off the platform. Some degree of higher-level data processing is therefore needed to reduce the volume of data for transmission, enabling both real-time analyses on the ground, as well as to ensure some level of data capture in the event that the platform is lost.

6.2.4.2 Intelligent Vehicle System Monitoring[37]

Intelligent System Health Management (ISHM) is technology designed to assess the "health" of a system and recommend or perform actions to ensure the vehicle remains healthy in the future. ISHM is a broad term encompassing a variety of capabilities. These include:

1. Built-in Self-Test (BIST) to reduce checkout time and ensure in-flight reliability of redundant systems.
2. Component fault detection identification and recovery (FDIR) Traditional low-level rules built into software to identify component failures and to recover automatically.
3. Caution & Warning: System off-nominal detection and first order root cause analysis displayed to operator.
4. System/Vehicle Level FDIR: System off-nominal detection and first order root cause analysis displayed to operator or used to reconfigure vehicle.
5. Data Stored/Transmitted on Demand for On-Ground Decision Support: Selective downlink of data on flight data recorder. Parameterization, clustering or compression of data.
6. Data Stored/Transmitted to Support Logistics & Maintenance (L&M): Operational data stored onboard and transmitted to the operator or maintenance crew.
7. Component Health Determined for L&M: Health status information inferred from sensor readings and transmitted to ground maintenance or used in long duration flights for other purposes.

ISHM technology contributes to safe UAV operation in several ways. ISHM technologies used in-flight can recover automatically from some faults, and recommend actions to operators in the presence of other faults. Note that some ISHM techniques can be used

[36] https://www.tandfonline.com/doi/abs/10.1080/19479832.2010.497343
[37] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110024045.pdf

on the vehicle itself, while others can be used on the ground. ISHM technologies used post-flight can reduce the likelihood of faults during operations by recommending maintenance or replacement of faulty parts. Most ISHM techniques require sensors to provide awareness of vehicle state. These can be structural sensors (e.g. strain gauges), mechanical sensors (e.g. interrogation of gears or fans) or component sensors (e.g. heartbeat from the communication system or status from the payload). Sensors add cost, weight, power usage and avionics bus traffic to vehicles. Storage of sensor data or component level FDIR requires either onboard storage or a communication link, imposing some computational requirements and associated power and avionics bus loads. ISHM systems like C&W and System FDIR require computational resources, either onboard the vehicle or on ground with a communication link in-between. Small vehicles may not have the computational resources for ISHM.

6.2.5 Coordination

6.2.5.1 UAV and UGV[38]

The necessity of using teams of both aerial and terrestrial drones is particularly evident for missions in remote or hostile areas where human operators could be exposed to danger situations. In such conditions, exploration and monitoring missions could safely performed by robots as they can easily and safely gather detailed information on the environment. Multiple mobile drone systems are certainly able to play preprogramed mission by moving around in specific scenarios but, the most interesting challenge, is to provide them a decisional autonomy and the opportunity to cooperate and re-adapt the missions according to real time situations and with little or no human interactions. Teams of drones with different capabilities should be able to perform autonomously high-level missions in which, for example, multiple sites need to be explored and surveyed looking for potential targets.

6.2.5.2 Swarm Formation and Cooperation[39]

The coordination block is the reasoning and decision-making entity, which is responsible for using observations (own and from other UAVs), mission requirements, and system constraints to organize the UAVs. In a nutshell, it needs to compute the trajectories of the UAVs and make decisions on how to allocate tasks to achieve team behaviour. Coordination can mean achieving and sustaining rigid formations or can be task distribution among vehicles in a self-organizing manner. Similarly, it can be done at a local or global level, depending on the mission and capabilities of the vehicles. Scalability and heterogeneity are also desired in a multi-UAV system, since a large number of vehicles with different capabilities are expected. Therefore, the coordination block needs to handle growing numbers of heterogeneous UAVs, tasks, and possibly mission areas. Some specific issues that need to be addressed within this block are:

[38] https://ieeexplore.ieee.org/document/7230963
[39] https://www.sciencedirect.com/science/article/pii/S1877050915010820

- Task allocation: Reasoning and decision making is needed to optimally distribute tasks to individual UAVs or groups of UAVs that can handle uncertain or incomplete information and dynamic missions. Mechanisms to define and adapt tasks to the mission requirements or vehicle capabilities need to be de- signed.
- Path planning: There are several path planning strategies for ground robots and trajectory designs for formations of robots. More task-optimized, communication-aware, three-dimensional path planning methods are desired for multi-UAV systems that can handle scarce energy resources and heterogeneous vehicles.

6.2.6 Communication

6.2.6.1 Network Centric Communications Systems

Net-centric communications is an information-enabled concept of operations that exploits advanced technology to move from an application centric to a data-centric paradigm – that is, to provide users with the ability to access applications and services through Web services – an information environment comprised of interoperable computing and communication components. This approach generates increased situational awareness and mission robustness by networking sensors, decision makers, and researchers to achieve shared awareness, increased speed of command and control, greater mission success and focus.

A net-centric information environment utilizes emerging standards and technologies to optimize information sharing among all users. It results from implementing component architectures in accordance with the open system architecture.

6.2.6.2 Over the Horizon Communications[40]

Over the Horizon Communications (OTH) or more commonly referred to as Beyond Line of Sight (BLOS) communications is a basic function required for UAVs to be operated in the Global airspace. OTH is required for Command and Control (C2), situational awareness, health and status of the vehicle, and real time or near real time vehicle position (latitude, longitude, and elevation above a given point above the surface of the earth at a given moment) through the Global Positioning Satellite (GPS) or the AV's on-board navigation system both for safety and scientific purposes. The additional needs for researchers to have C2 with their instruments, instrument health and status, receive real time data, snap shots, or determine status of onboard data recorders are also required.

6.2.7 Regenerative Energy Storage

6.2.7.1 Lightweight Energy Storage Using Regenerative Fuel Cells[41]

Solar powered UAVs coupled with lightweight energy storage can enable long endurance UAV missions. Closed loop H_2-O_2 regenerative fuel cells (RFC) have the potential to offer higher specific energy (Wh/kg) than state-of-the-art batteries (>400 Wh/kg vs. ~100

[40] https://link.springer.com/chapter/10.1007/978-3-030-16770-7_6
[41] https://ieeexplore.ieee.org/document/811091

Wh/kg), especially for long discharge times. An RFC consists of a fuel cell, electrolyser, reactant tanks, and supporting ancillary equipment. During sunlight hours, the solar array provides power both to the aircraft and to the electrolyser to break down water into hydrogen and oxygen which is stored in tanks. At night, the hydrogen and oxygen are fed to the fuel cell, which produces power to the aircraft in lieu of the solar array. A by-product of the fuel cell reaction is water, which is recovered and stored in a tank to send to the electrolyser to repeat the cycle. The RFC can use either discreet fuel cell and electrolyser stacks or a unitized stack which can operate as both a fuel cell and electrolyser.

Low Volume, High Power Density Solid Oxide Fuel Cells: Low volume, high power density SOFC system operated on hydrogen in fuel consumption and regenerative mode to supply 100-day flight capability.

6.2.7.2 Battery Technology: Long-life Rechargeable Batteries Using Li-S Technology[42]

Li-S batteries offer one of the highest energy densities of secondary (rechargeable) battery systems currently under development. Coupled with solar arrays, they can provide an efficient power system for UAV missions. Li-S batteries are projected to have an achievable specific energy of 600 Wh/kg and an energy density of 700 Wh/l at the cell level. As such, they have the potential to serve as a simple, lightweight system for storage of energy produced via solar arrays during sunlit portions of the mission. The batteries would become the prime power source during eclipse periods. The recharge efficiency of this battery systems is relatively high, >85%, which can affect the solar array size and thermal rejection requirements for the overall system.

6.2.7.3 Consumable Fuel Cell[43]

Because of their high conversion efficiency, fuel cells offer lower specific fuel consumption than internal combustion engines and, therefore, can increase UAV mission endurance when used in an electric propulsion system. Due to the significant investment for automotive applications, H_2-air PEM fuel cell technology is at a higher TRL than either H_2-O_2 PEM or SOFC technology, making it a candidate for near term UAV systems. However, since most of this development has taken place on the commercial side, very little published data is available regarding performance, life, and reliability, making it difficult to assess the state of technology development. Current H_2-air PEM stacks typically operate at ambient (14.7 psi) pressure, requiring either compression for operation at altitude or de-rating of the stack power. Also, the life and reliability of these systems is unknown and would need to be assessed for UAV applications.

6.2.7.4 Propellant Storage & Feed: Storage Using Layered Silicate Clay Non-composites[44]

This technology utilizes the dispersion of layered silicate clays throughout the matrix of a polymer-carbon fiber composite tank. The dimension of the clay platelets is1 nm thick and

[42] https://www.sciencedirect.com/topics/engineering/li-s-battery
[43] https://www.intertek.com/blog/2018-03-06-fuel-cell/
[44] https://pubs.acs.org/doi/abs/10.1021/acs.chemmater.6b02186

100nm to 1m in the lateral direction. The high aspect ratio of the nano-particle contributes to enhanced material properties such as increased strength and barrier performance. The work is unique in that a low loading of the nano-filler (2-5 wt%) results in significant improvements in material performance. There has been limited work utilizing layered silicate nanocomposites in traditional polymer matrix composites. Most work to date has been done by NASA or the Air Force, with outstanding results. Decreased gas permeability and improved mechanical properties of polymer matrix composites are consistently demonstrated. This technology will contribute to UAV capabilities by improving the performance and lifetime of lightweight composite tankage for propellant storage.

6.2.7.5 Cryogenic Storage Using Densified Liquid Hydrogen[45]

Densified liquid hydrogen (DLH2) may be able to provide a 9.3 % increase in propellant density by subcooling to 92.75 Fahrenheit. Results will be a smaller, lighter hydrogen storage tank and associated propellant storage systems. The propellants low vapor pressure (1.1 psia) reduces leakage rates while at altitude and allows the designer use of thinner walled tank materials of construction. A number of secondary impacts such as more volume become available for new equipment (i.e. increased payload) or smaller airframe for reduced drag are possible. Using subcooled (densified) liquid hydrogen would also eliminate propellant boil-off losses during a significant portion of a UAV mission; thereby further improving vehicle performance and mission duration.

6.2.7.6 Hydrogen Feed Systems[46]

To support longer duration aloft, liquid hydrogen offers an energy/mass advantage of 2.8 compared to conventional aviation fuels. The challenge is that the energy/volume is 4.2 times greater and additional techniques are required to safely handle and store hydrogen as a cryogenic liquid (T≈-400 °F) over the flight duration.

6.2.7.7 System H_2 Gas Storage Using Composite Overwrapped Pressure Vessels[47]

Light weight composite overwrapped pressure vessels (COPV) can be utilized to store hydrogen gasses at pressure for the long duration, high-flying UAV's. Technological advances in the design and manufacturing of fiber wrapped pressure vessels are enabling highly-efficient pressure-volume to weight ratios. However, to operate safely and reliably over long durations, lifting methods, damage tolerance and standard repair issues need to be addressed. In the past glass, kevlar, carbon and PBO fibers were utilized to build composite overwrapped pressure vessels. Current thinking is to move away from Kevlar vessels to carbon, PBO or other types of fibers due to the poorly understood process of stress rupture in Kevlar fibers as well as the fact that kevlar is known to be adversely affected by UV radiation. Developments in advancing carbon or other fiber based COPV

[45] https://iopscience.iop.org/article/10.1088/1757-899X/278/1/012013/meta
[46] https://www.sciencedirect.com/science/article/abs/pii/S0360319914023702
[47] https://www.gd-ots.com/missiles-and-rockets/missile-components/pressure-vessels/

technology is therefore a key necessity for achieving light weight long duration pressurized tanks on board UAVs.

6.2.7.8 Lightweight Cryo Insulation Using Polymer Crosslinked Aerogels[48]

Polymer crosslinking provides a means of strengthening the otherwise extremely fragile silica aerogels to create a light weight multifunctional insulation material (support structure as well as insulation, low dielectric, acoustic damping, etc.)

6.2.8 Propulsion System

6.2.8.1 Internal Combustion[49]

Internal combustion engines (ICE) can be used to provide primary propulsion for a number of UAV systems. Currently some versions of UAV systems (Predator, Altus, etc.) use internal combustion engines for propulsive power. The systems currently in operation all run on hydrocarbon-based fuels. However, the range of operation may be expanded to high altitude long endurance (HALE) missions with the use of hydrogen as a propellant. For high altitude operations, internal combustion engines require the use of multiple turbo chargers to supply the required airflow and pressure.

6.2.8.2 High Power Density Propulsion Using High Temperature Superconducting

Current propulsion technology limits the endurance and range of UAVs. The NASA Glenn Research Center's High Power Density Motor (HPDM) development research team has investigated applying its technology to high-altitude, long-endurance remotely operated aircraft (HALE ROA) to enhance vehicle performance. Consequently, a mission analysis of a HALE ROA was conducted to determine if HPDMs are a viable solution for these propulsion challenges. This study shows that HPDM technology could be viable for future aircraft and UAV performing civil missions like hurricane tracking. Based on the assumptions and analysis of this study, these motors will allow aircraft to fly longer while reducing harmful emissions.

6.3 Payload Technologies

The drone system includes a number of payload technologies to support the drone mission specific operations. Such payload includes optical sensors, microwave sensors, in-situ sensors, and external sensors (see Figure 63).

6.3.1 Optical Sensors

6.3.1.1 Active Optical: LIDAR[50]

Active optical remote sensing (also known as lidar), uses an optical source, typically a laser, to sense targets. The targets can be hard objects (terrain, other vehicles, obstacles) or the atmosphere via scattering of light from molecules and aerosols. Hard target

[48] https://www.science.gov/topicpages/p/polymer+crosslinked+aerogels.html
[49] https://en.wikipedia.org/wiki/Internal_combustion_engine
[50] http://www.lidar.com/

measurement is useful for altimetry, geographical information systems, ice sheet/pack changes, vegetation canopy studies, and target designation for payload delivery. Atmospheric parameters that can be measured include aerosol density, trace gas concentration (H_2O, O_3, CO_2, hydrocarbons, pollutants, or chemical weapons), wind, and cloud composition. An advantage of lidar-based techniques is that the spatial and temporal resolution is typically much higher than other sensor methods.

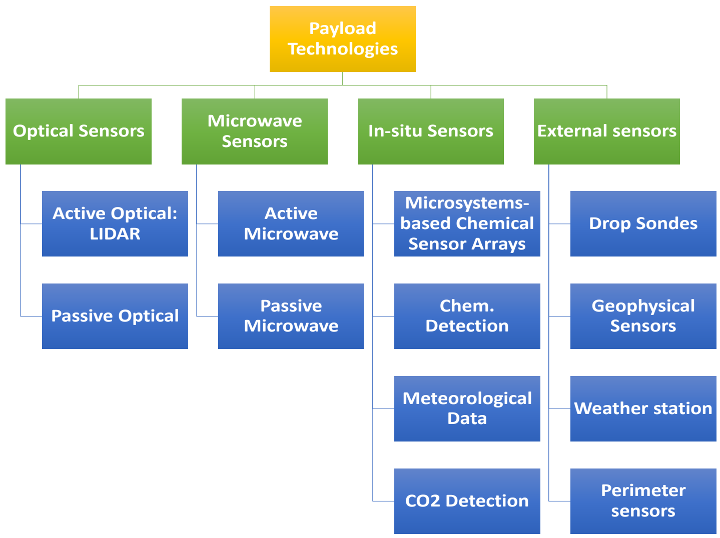

Figure 63: Payload Technologies

6.3.1.2 Passive Optical[51]

Passive optical sensors form the majority of the Earth imaging devices found on satellites and aircraft. They essentially capture reflected or direct solar energy, or emitted infrared radiation, and project them onto photosensitive detectors via some system of imaging optics. Some passive optical sensors are non-imaging, collecting spectral and/or radiometric data from a single point; these are typically used to measure the up-welling radiation from the Earth or down-welling radiation from the Sun, and are often used to optically characterize the intervening atmosphere. Systems of both types are highly appropriate for deployment on UAVs. However, few have been adapted for this application. Some of the technologies involved are necessarily large, making then compatible with only the larger platforms, however several are more clearly candidates for miniaturization. Also relevant to the UAV mission are digital tracking cameras, which are used to document the scenes being recorded by the science instruments.

[51] https://www.nasa.gov/directorates/heo/scan/communications/outreach/funfacts/txt_passive_active.html

6.3.2 Microwave Sensors

6.3.2.1 Active Microwave: SAR, and IFSAR[52]

SAR and IFSAR system are imaging radar that emit microwave radiation and record the echoes returned from the scene under observation. SAR system have wavelengths that vary depending on application from less than a centimetre to greater than 3 meters. To achieve fine resolution in range and azimuth SAR system transmit a chirp waveform (a linear frequency ramp) with bandwidth depending on the desired resolution (1 – 3000 MHz) a collect many pulses in azimuth that are combined through signal processing to achieve the desired resolution. SAR systems may require, again depending on system, large data bandwidth and DC power levels up to the 10 KW range. IFSAR system collect data from two or more antenna that may be on the same platform or for certain applications collected in using repeat passes.

6.3.2.2 Active Microwave: Wind Measurements[53]

Current radar transmitters and receivers/processors required for measurement of clouds and precipitation are too large and power consuming for use in payloads on smaller UAVs. In addition, operation in HUAVs at high altitudes and low temperatures requires special considerations such instrument cooling. New radars employing low power solid state transmitters and low power high-speed digital receivers are being developed but are in their infancy. This development is required for compact, low power systems that will be useful for weather forecasting and climate applications.

6.3.2.3 Passive Microwave: Light Weight, Low Loss, Antenna Technology[54]

The measurement of geophysical parameters important for Earth remote sensing including climate or regional studies often require multiple sensors. These sensors typically include both active (Radar) and Passive (Radiometer) measurements. Microwave measurements have been used successfully for both atmospheric measurements (including rain) and surface imaging. The interaction of liquid water and the sensitivity of the reflections/emissions at microwave frequencies to the state of water (frozen or thawed) make surface imaging at microwave frequencies extremely important for existing and future science missions. An important challenge for these sensors is the spatial resolution required. Cold Land Processes for example may require spatial resolutions of 100's of meters at microwave frequencies, spatial resolution requirements for Soil Moisture measurements (1.4 GHz) of 1 km are also a technology challenge from Low Earth Orbit (LEO). The longer wavelengths of these measurements have limited the available spatial resolution from LEO. SSM/I for example has a spatial resolution of approximately 30 km at 19 GHz. The resolution for spacecraft concepts at lower frequencies (L-band!) have remained a formidable challenge for decades.

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[52] https://www.geospatialworld.net/article/ifsar-mapping-geospatial-intelligence/
[53] http://gsp.humboldt.edu/olm_2016/courses/GSP_216_Online/lesson7-2/other-active.html
[54] https://tel.archives-ouvertes.fr/tel-02051066/file/2018IMTA0075_Nguyen-Hong-Duc.pdf

The use of UAVs for microwave remote sensing may enable incredible improvements in spatial resolution and provide new views of Earth processes albeit on a region scale. However, to enable these improvements UAVs must accommodate these low-loss (for radiometry) antenna systems. These antennas many require integration or at least substantial accommodation of the UAV to provide the desired spatial resolution from a moderate UAV.

6.3.3 In-situ Sensors

6.3.3.1 Microsystems-based Chemical Sensor Arrays[55]

The characterization of chemical species onboard UAV is often done with large and cumbersome equipment. In contrast, there is ongoing development in microfabricated chemical sensor technology that allows measurement of a range of chemical species of possible application to UAV. These microsensors are smaller and less power consumptive than standard instrumentation and can be integrated with hardware and software to form intelligent Microsystems. These microsensors have been developed using base platform technology which can be tailored for the needs of the application. Unlike standard electronic nose technology, which tends to be based on a single sensor type, the approach discussed here uses orthogonal technology, i.e. very different sensor types each of which provide different types of information about the environment, and attempts to minimize cross interference between the sensors. These Microsystems may be deployed to allow more accurate assessment of the immediate environment surrounding the UAV.

For example, UAV systems have previously been deployed in forest fire situations to map out forest fire fronts to aid of ground personnel. Rather than carrying complex, large instrumentation as has been done in the past, it is proposed that a Microsystem based chemical sensor array be integrated into the UAV allowing local characterization of the chemical species. This particular Microsystem array is based on ongoing development to address the needs of the aerospace industry for more accurate and reliable fire detection. Species measured include CO, CO_2, hydrogen/hydrocarbons, and humidity as well as particulates. By recording the local chemical and particulate environment, the UAV can characterize the fire front and aid ground personnel in firefighting activities.

The microsensor systems can be tailored for the application; for other applications a different array may be required. Thus, for atmospheric characterization applications, measurement of CO2 and trace gases may be required, where for environmental safety applications toxic species may be of higher interest. Some of the technology available from NASA GRC and its collaborators, at varying levels of maturity and selectivity, are sensors to detect CO_2, O_2, NOx, H_2S, hydrocarbons, CO, pH, hydrazine, and even nerve gas agent.

[55] https://link.springer.com/chapter/10.1007/978-94-015-7985-8_17

6.3.3.2 Chem. Detection using Laser Diode Spectroscopy[56]

Advanced electro-optical techniques applied to detection of atmospheric chemical species; the measurement is a key element of any atmospheric or meteorological research system deployed on UAVs, has been deployed on ozone layer and cloud/climate studies on conventional aircraft

6.3.3.3 Meteorological Data [Sensors - Met Data (P, T, 3D-winds, turbulence)]

Because there are so many kinds of UAVs, designed and developed world wide for specific application, for our discussion here, let us narrow the focus to basically 3 classes of UAV for science application: small and light-weight such as Aerosonde, medium performance such as the Altus, and high performance such as the Global Hawk. The classification can also be categorized by duration and altitude performance. At the present time, none of these UAV classes are equipped with Met instrumentation to make science quality data. There are nominal thermodynamic measurements for flight operation, which can tolerate a wider error uncertainty than for scientific studies. Take static temperature for example, in general both pressure and temperature are measured to determined air speed and the accuracy can tolerate +- 5 K in static temperature for navigation purpose. For scientific studies, an accuracy to 0.3 K is typically required. Accurate wind field and turbulence require even higher measurement accuracy for velocities, attitudes and the correction for aerodynamic disturbance surrounding the fuselage.

6.3.3.4 CO_2 Detection Using Quantum Cascade Laser[57]

The sensor uses a quantum cascade laser spectrometer in a flight configuration to measure CO_2 to better than 0.05 ppm long term precision and better than 0.1 ppm absolute accuracy—as required for all major atmospheric applications.

6.3.3.5 Trace Gas Detection Using Difference Frequency Generation Lasers[58]

Difference frequency generation (DFG) lasers can be used for advanced in-situ detection of trace gases and their isotopic composition in the mid-infrared and can be combined with cavity enhanced absorption spectroscopy. DFG based sensors are very small, non-cryogenic and allow accurate trace gas detection; these measurements are a key element of atmospheric or meteorological research missions on UAVs.

6.3.3.6 Trace Gas Detection Using Cavity-enhanced Absorption Spectroscopy[59]

Advanced in-situ detection of trace gases and their isotopic composition in the near-infrared using optical feedback, cavity enhanced absorption spectroscopy; very small, non-cryogenic and accurate trace gas detection; these measurements are a key element of atmospheric or meteorological research missions on UAVs.

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56 https://en.wikipedia.org/wiki/Tunable_diode_laser_absorption_spectroscopy
57 https://en.wikipedia.org/wiki/Quantum_cascade_laser
58 http://raicol.com/app/dfg-difference-frequency-generation
59 https://link.springer.com/chapter/10.1007/978-3-642-40003-2_1

6.3.4 External sensors

6.3.4.1 Drop Sondes: Meteorological Sondes[60]

Accurate thermodynamic and kinematic atmospheric profile measurements are probably the most basic type of data needed for any type of meteorological forecasting. Therefore, sensor and sonde (carrier) development has been evolving for many years. Whether sondes are elevated through the atmosphere on balloons, or dropped from a moving platform, the basic technology for sensors is essentially the same. There are four basic measurements needed for forecast model data assimilation, and for assessing the basic atmospheric state. These are: Pressure, temperature, humidity (moisture) and winds. Sondes also being may include sensors for icing, and sea surface temperature sensors.

Temperature, pressure and moisture are generally measured using a thermistor and thin-film polymer package. Temperature and pressure measurements provide the accuracy needed by National Oceanic and Atmospheric Administration (NOAA) forecast model assimilation requirements, and are not a technical challenge. However, humidity measurements have been the subject of some research and debate. A small capacitor or thin-film polymer has limited accuracy and dynamic range for moisture measurements, and there have been several recent comparisons made between water vapor soundings and other water vapor measurement techniques, such as lidar. Winds are now typically measured using GPS receivers, which may be either codeless or true GPS "engines". These receivers are now made into small, low cost chips that are easily incorporated into sondes, although they require power, and the smallest sondes (20 g) may not be able to accommodate GPS, and may instead use radio frequency technology. With GPS winds the descent rate needs consideration because the receiver needs to lock on to the satellite signal quickly in order to start measuring the winds. Calibration of sonde sensors is generally done at the factory with each sonde transmitting this information when it is turned on.

6.3.4.2 Drop Sensors: Geophysical Sensors

Seismic data acquisition[61] is a cornerstone of oil and gas exploration. 3D image of the underground provides a unique tool to the industry for an efficient oil field management. Seismic sensors are deployed on the ground to record soundwave velocities coming from an activated seismic source (like vibrator truck). Number and spatial sampling of these sensors will drive the quality and fidelity of the final image.

Traditionally, seismic sensors are cabled system requiring heavy ground logistic to be put in place. Recent advances bring wireless, real-time technology on the market with enables seismic sensors delivery from the air with swarms of drones.

These seismic sensors are made of geophone and/or 3C accelerometers, a battery, a GPS and a multi-band radio set to transfer the data wirelessly. A specific telemetry is also

[60] https://link.springer.com/article/10.1007/s00704-018-2728-6
[61] http://www.seismo.co.me/Acquisition.htm

transmitted to the UAV just after the drop to check landing quality after the drop (coupling, spatial attitude).

6.3.4.3 Weather Station[62]

In order to ensure a high-level of safety for a UAV system, it is important to take the weather into account. A weather station, for instance near the dronepad, is useful for monitoring the changes in real time. It should allow the UAV system to detect and act when an important change in the forecast appears. For instance, the system could be ordered to try to return to base when it is done and prevent any further take-off if there is still enough time, or if the change is too quick it could be ordered to return to base urgently.

6.3.4.4 Perimeter Sensors, Intrusion Detection[63]

When managing a system with UAVs that operates on a segregated area, it is important to ensure the safety. Any intrusion in the operational area could lead to accidents and misbehaviours. In order to help the system handles those intrusions, it needs detection means. Those can be embedded in the UAV (clearance algorithm), and ground means can greatly help. There is a variety of tools that can provide ground detection: optical barriers, radars, and so on. It is even possible to have dedicated operators that would report any intrusion (from the distance). The nature of the intrusion may dictate the type of sensor to use, indeed intruders can be: humans, vehicles, animals (domestic, cattle, wild life).

Once the system is aware of an intrusion, it can have several behaviours, ranging from setting an exclusion zone around it up to a watchdog approach where an agent of the system (or an operator) has to interact with the intruder to accompany it outside the area for instance.

6.4 Tools

To support the development of drone systems, a number of tools need to be developed. These tools are divided into two groups: tools for service specification and tools for system development (see Figure 64).

[62] https://www.unmannedsystemstechnology.com/category/supplier-directory/electronic-systems/meteorological-stations-weather-measurement/
[63] https://www.sciencedirect.com/topics/computer-science/perimeter-protection

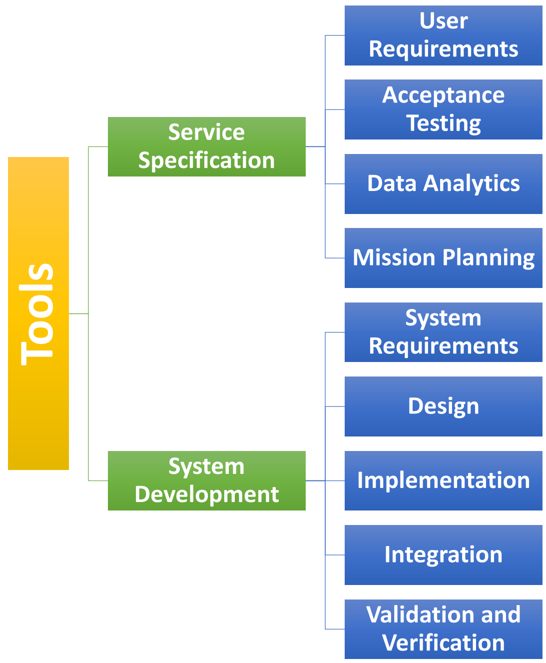


Figure 64: Tools for drone systems

6.4.1 Service Specification

6.4.1.1 User Requirements[64]

User requirements, often referred to as user needs, describe what the user does with the system, such as what activities that users must be able to perform. User requirements are generally documented in a User Requirements Document (URD) using narrative text. User requirements are generally signed off by the user and used as the primary input for creating system requirements.

6.4.1.2 Acceptance Testing[65]

Acceptance testing is a level of software testing where a system is tested for acceptability. The purpose of this test is to evaluate the system's compliance with the business requirements and assess whether it is acceptable for delivery. It is also seen as formal testing with respect to user needs, requirements, and business processes conducted to determine whether or not a system satisfies the acceptance criteria and to enable the user, customers or other authorized entity to determine whether or not to accept the system.

6.4.1.3 Data Analytics[66]

Data analysis is a process of inspecting, cleansing, transforming and modelling data with the goal of discovering useful information, informing conclusion and supporting decision-

[64] https://enfocussolutions.com/business-user-and-system-requirements/
[65] http://softwaretestingfundamentals.com/acceptance-testing/
[66] https://www.droneii.com/drone-data-analytics

making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, and is used in different business, science, and social science domains. In today's business world, data analysis plays a role in making decisions more scientific and helping businesses operate more effectively. Data mining is a particular data analysis technique that focuses on statistical modelling and knowledge discovery for predictive rather than purely descriptive purposes, while business intelligence covers data analysis that relies heavily on aggregation, focusing mainly on business information. In statistical applications, data analysis can be divided into descriptive statistics, exploratory data analysis (EDA), and confirmatory data analysis (CDA). EDA focuses on discovering new features in the data while CDA focuses on confirming or falsifying existing hypotheses. Predictive analytics focuses on application of statistical models for predictive forecasting or classification, while text analytics applies statistical, linguistic, and structural techniques to extract and classify information from textual sources, a species of unstructured data. All of the above are varieties of data analysis.

6.4.1.4 Mission Planning[67]

Mission planner is a ground control station for Plane, Copter and Rover. Mission Planner can be used as a configuration utility or as a dynamic control supplement for autonomous vehicle. Here are just a few things you can do with Mission Planner:

- Load the firmware (the software) into the autopilot board that controls your vehicle.
- Setup, configure, and tune your vehicle for optimum performance.
- Plan, save and load autonomous missions into you autopilot with simple point-and-click way-point entry on Google or other maps.
- Download and analyse mission logs created by your autopilot.
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- With appropriate telemetry hardware a person can:
    - Monitor the vehicle's status while in operation.
    - Record telemetry logs which contain much more information the on-board autopilot logs.
    - View and analyse the telemetry logs.
    - Operate the vehicle in FPV (first person view).

6.4.2 HW/SW System Development Cycle

6.4.2.1 System Requirements[68]

System requirements are the building blocks developers use to build the system. These are the traditional "shall" statements that describe what the system "shall do." System requirements are classified as either functional or supplemental requirements. A

[67] https://ardupilot.org/planner/
[68] https://enfocussolutions.com/business-user-and-system-requirements/

functional requirement specifies something that a user needs to perform their work. For example, a system may be required to enter and print cost estimates; this is a functional requirement. Supplemental or non-functional requirements specify all the remaining requirements not covered by the functional requirements. The term supplemental requirements are usually used instead of non-functional requirements; who wants to be termed non-functional? Supplemental requirements are sometimes called quality of service requirements. The plan for implementing functional requirements is detailed in the system design. The plan for implementing supplemental requirements is detailed in the system architecture. The list below shows various types of supplemental requirements.

6.4.2.2 Design[69]

The purpose of the System Design process is to provide sufficient detailed data and information about the system and its system elements to enable the implementation consistent with architectural entities as defined in models and views of the system architecture. Elements of a System are:

- Architecture - This is the conceptual model that defines the structure, behaviour and more views of a system. We can use flowcharts to represent and illustrate the architecture.
- Modules - This are components that handle one specific tasks in a system. A combination of the modules makes up the system.
- Components - This provides a particular function or group of related functions. They are made up of modules.
- Interfaces - This is the shared boundary across which the components of the system exchange information and relate.
- Data - This is the management of the information and data flow.

6.4.2.3 Implementation[70]

System Implementation uses the structure created during architectural design and the results of system analysis to construct system elements that meet the stakeholder requirements and system requirements developed in the early life cycle phases. These system elements are then integrated to form intermediate aggregates and finally the complete system-of-interest (SoI).

Implementation is the process that actually yields the lowest-level system elements in the system hierarchy (system breakdown structure). System elements are made, bought, or reused. Production involves the hardware fabrication processes of forming, removing, joining, and finishing, the software realization processes of coding and testing, or the operational procedures development processes for operators' roles. If implementation involves a production process, a manufacturing system which uses the established technical and management processes may be required.

[69] https://en.wikipedia.org/wiki/Software_design
[70] https://en.wikipedia.org/wiki/Product_software_implementation_method

The purpose of the implementation process is to design and create (or fabricate) a system element conforming to that element's design properties and/or requirements. The element is constructed employing appropriate technologies and industry practices. This process bridges the system definition processes and the integration process. Figure 1 portrays how the outputs of system definition relate to system implementation, which produces the implemented (system) elements required to produce aggregates and the SoI.

6.4.2.4 Integration[71]

System integration is defined in engineering as the process of bringing together the component sub-systems into one system (an aggregation of subsystems cooperating so that the system is able to deliver the overarching functionality) and ensuring that the subsystems function together as a system, and in information technology as the process of linking together different computing systems and software applications physically or functionally, to act as a coordinated whole.

The system integrator integrates discrete systems utilizing a variety of techniques such as computer networking, enterprise application integration, business process management or manual programming. System integration involves integrating existing, often disparate systems in such a way "that focuses on increasing value to the customer" (e.g., improved product quality and performance) while at the same time providing value to the company (e.g., reducing operational costs and improving response time). In the modern world connected by Internet, the role of system integration engineers is important: more and more systems are designed to connect, both within the system under construction and to systems that are already deployed.

6.4.2.5 Validation and Verification[72]

Verification and Validation (V&V) is the process of checking that a software system meets specifications and that it fulfils its intended purpose. It may also be referred to as software quality control. It is normally the responsibility of software testers as part of the software development lifecycle. In simple terms, software verification is: "Assuming we should build X, does our software achieve its goals without any bugs or gaps?" On the other hand, software validation is: "Was X what we should have built? Does X meet the high-level requirements?"

Verification and validation are not the same things, although they are often confused:

- Verification: Are we building the product, right?
- Validation: Are we building the right product?

"Building the product right" checks that the specifications are correctly implemented by the system while "building the right product" refers back to the user's needs. In some

[71] https://en.wikipedia.org/wiki/System_integration
[72] https://en.wikipedia.org/wiki/Verification_and_validation

contexts, it is required to have written requirements for both as well as formal procedures or protocols for determining compliance.

Building the product right implies the use of the Requirements Specification as input for the next phase of the development process, the design process, the output of which is the Design Specification. Then, it also implies the use of the Design Specification to feed the construction process. Every time the output of a process correctly implements its input specification, the software product is one step closer to final verification. If the output of a process is incorrect, the developers are not building the product the stakeholders want correctly. This kind of verification is called "artifact or specification verification".

Building the right product implies creating a Requirements Specification that contains the needs and goals of the stakeholders of the software product. If such artifact is incomplete or wrong, the developers will not be able to build the product the stakeholders want. This is a form of "artifact or specification validation".

7 Project Contributions

In the following sections, we describe the expected contributions of the **COMP4DRONES** project in relation to the identified key enabling technologies. The contributions are classified into four groups:

- Integrated modular reference architecture
- Safe autonomous decisions
- Trusted communication
- Minimizing the design and verification

7.1 Integrated Modular Reference Architecture

The main goal of this work is to provide reference architecture of a flexible embedded platform. This latter will enable an easy and efficient customization of drones (UAV, rover, etc.) to meet application domain requirements. The software architecture of the embedded platform will be hardware-independent and at basis of modular components which can be plugged-in. A methodological guide of the reference architecture will also be proposed.

This work includes the following specific contributions:

- *Pre-Certified SOM*: First steps into design and development of safety functions in drone technology from other more mature sectors with long lasting experience in safety regulations for the design of HW/SW will be done.
- *Modular SoC based embedded platform for sensor data acquisition, fusion and processing*: Modular SoC based embedded platform will enable: (a) novel implementation of involved SLAM algorithms; (b) distribution of algorithms across heterogeneous processing paradigms; and (c) novel approaches to sensing and processing pipelines.
- *Sensor information algorithms*: The performance of the algorithms will be increased, which will reduce latency and increase throughput. In addition, robustness of the controller with respect to environmental disturbances and increased resiliency will be improved. This improvement will be based on increased robustness of the video processing with respect to HDR while keeping the processing means and extent of video processing "unchanged" thanks to the tone mapping that virtually brings the "same image format" as in usual processing.
- *Trusted communication sub-architecture*: The trusted communication sub-architecture provides a trusted, reliable and efficient communication infrastructure for secured drone operations. Threats from “hacking” and “cyber-terrorism” are taken into account during design of system components.
- *Control components that implement potential barriers*: A control loop that implements a "potential field" that prevents the drone to access certain areas by evaluating its position, geofences and potential obstacles in the environment.

- *Multi-agent swarm control*: A multi-agent control system to manage multiple drones in a swarm.
- *Indoor positioning*: An indoor positioning will be developed. It relies on a novel model for auto-deployment, error estimation and ranging calculation as well as a low-cost design suitable for large scenarios. It provides: (a) a flexible, easy to deploy, low-cost solution; (b) high rate and accurate position on long indoor scenario.
- *Multi-antenna GNSS/INS based navigation*: A set of upgrades with respect to the initial baseline system consists of: (a) improved filtering; (b) advanced ambiguity resolution; (c) multi-constellation benefits; (d) updated baseline estimation and fusion; (d) lower cost. These enhancements directly depend on the enhanced HW/SW platform, where updated GNSS receiver COTs and License free RTOS will: (a) enable the use of Galileo constellation; (b) provide anti-jamming and anti-spoofing featured; (c) release from license fees.
- *Highly embedded customizable platform for SLAM technique*: A customizable platform will be developed, which have (a) hot-plug switching for modular sensors payload and automatically algorithm adjustment given the communication protocol; (b) orientation capabilities through geomagnetic field mapping with similar or higher accuracy to GPS when in GPS-loss navigation and improved precision when GPS is active; (c) improved algorithms for real-time data analytics, and data compression.
- *Onboard compute platform design methodology*: Improvements to the Onboard Compute Platform are expected in terms of more computational power present on board; a wider set of services and complex algorithms runnable on board; an easy to use deployment methodology for the definition of application-specific accelerated services.
- *Efficient digital implementation of controllers*: Efficient implementation to increase performance of the controller, with reduced response time, and robustness of the controller with respect to environmental disturbances and increased resiliency.
- *Onboard compute platform design paradigm*: Extended computational power by leveraging on heterogeneous co-processing units that shall enable advanced and flexible on-board computation.
- *TSN queue mapper*: On the drone, it is expected that communications between different components could be supported by a TSN Network (Time-Sensitive Network). TSN is a group of IEEE Standards that targets support of deterministic communications over standard Ethernet. Several traffic Queues can be defined to support different levels of TSN support (determinism, controlled latency, best efforts, etc.). This software is in charge of setting up the TSN queues and the routing rules so that Traffic with specific QoS requirements can be handled as expected in the TSN network (on-board).
- *Reference architecture modelling and code generation*: A support will be provided to (a) the modelling of the compositional and integrated drone embedded reference

architecture; (b) the generation of well-formed and semantically-correct ROS code from this architecture.

- *Smart and predictive energy management system*: The energy management system wants to tackle the optimal control problem by giving particular emphasis to the computational aspect, the critical point of these methods, providing a comparison between the application of different algorithms.
- *AI drone system modules*: The module aims to compare different architectures by verifying the computational aspect of the algorithms respect to detection performance.
- *Modular vehicle software architecture*: Apply modular vehicle software architecture to paparazzi architecture and modules and provide the outcomes to the community through a public repository.
- *Computer vision components for drones*: The component will provide automatic algorithms for the autodetection/geo-referencing of road elements from a cloud of points captured from a LIDAR camera. The improvement will focus on the recognition of scenarios and work elements through artificial intelligence and deep analysis that will provide an orthophoto of the terrain to accelerate the constructive process of a civil infrastructure.
- *PX4 and Mavlink extensions for autonomous drone battery management*: The goal is to create MAVLink extensions via messages specialized for autonomous drone battery management. These extension modules will cover the communication messages prepared for MAVLink library auto generation process. The messages will be subsequently implemented to PX4.
- *Droneport SW architecture*: The Droneport SW architecture is currently in concept stage. The expected improvement is to develop software component and test together with DP hardware system in the intended environment.
- Droneport HW architecture: The Droneport HW architecture is currently in concept stage. The expected improvement is to design functional prototype and test it in the intended environment.

A more detailed description of these contributions and their related state of the art will be described in deliverable D3.1.

7.2 Safe Autonomous Decisions

The main contribution of safe autonomous decisions is to design and develop a safe and reconfigurable control and navigation subsystems with the capability to autopilot a drone with enhanced perception capacities. The drone sensory system will be augmented with perception techniques, such as sensory fusion to reduce uncertainty, and dynamic sensing to adapt resource expenditure based on situations. This will contribute to a tighter integration among sensory systems and control systems that support the central control engine of the drone during individual or cooperative missions.

To enable safe flight in complex environments, this work aims to extend the navigation system with dynamic control features capable of adjusting and fine-tuning the movement of drones. Indeed, equipped with sophisticated sensors and trusted communication means, drones could detect changes in the environment during the execution of the mission. The aggregation of collected data and their analysis in real time makes it possible to take appropriate decisions to react to unpredicted changes in the environment.

This work will focus on (1) sensory systems, (2) aggregation of collected data, (3) safety and dynamic control, (4) state monitoring of navigation, (5) decision strategies based on control theory, (6) artificial intelligence algorithms for enhancing sensory information, as well as smart resource management.

Specific contributions include:

- Design of control system strategies for autonomous drone stabilization during flight mission.
- Development of tightly integrated perception and control loops for obstacle avoidance and autonomous path planning based on real-world situations.
- Design of supporting modules for the central flight-control system. These modules will be designed to support control strategies in face of the limited computational resources for real-world conditions and in real-time.
- Enable easy and smart configurability of the control and navigation subsystem, using novel AI techniques for resource savings (shortest and safer path).
- Development of safety mechanisms to ensure cautious decision-making behaviour at runtime, including AI safety monitoring, adaptation, alerts and control transfer.
- Develop deep neural network-based algorithms for classification and control, benchmark these novel algorithms against common control theory counterparts.
- Benchmark novel low-latency sensors such as event-based cameras as well as spiking neural networks for low-power and low-latency applications, characterize and gauge them against standard sensors and standard deep learning techniques.
- Implementation of the control and navigation subsystem, on top of reliable, real-time and high-performance hardware (including FPGAs).
- Integrate new sensor payloads based on hyperspectral technology for industrial inspections and research AI algorithms to automatically detect and classify defects.
- Software components based on AI for hijacking/spoofing detection and reaction. These systems will be based on sensory data (geographical position, geomagnetic D-SLAM, GPS, and mission polygons, etc.) as well as on command received from the platform.
- Software based safety rules and drone's sensors information checkers. These will guarantee the rules to be respected. If safety rules are violated the software manager evaluates the action that the drone must perform in order to go back in a safety situation. The safety rules are defined by a risk assessment.

A more detailed description of these contributions and their related state of the art will be described in deliverable D4.1.

7.3 Trusted communication

Trusted communication refers to ensuring robust and efficient drone communications even in presence of malicious attackers and taking into considerations intrinsic platform constraints. In contrast with existing approaches that integrate minimal security, security-by-design will be achieved.

Efficient communication requires adequate communication stacks (from the physical layer upwards) and middleware. It also requires the capability to use concurrently multiple communication links or various radio technologies, as these are available. Meanwhile, communication manageability will allow for remote monitoring and control of drones' communications means. This will allow to further reinforce communication link availability in the fields of reconfigurability and performance (latency and throughput).

The cybersecurity part of this work will achieve the fulfilment of classical 'integrity' and 'availability' security properties. Cybersecurity mechanisms will protect the drone-to-drone and drone-to-infrastructure communications against malicious actions. Drone takeover, peer impersonation attacks will be prevented. Lightweight reactive security mechanisms will complement preventive security ones and will allow to detect and mitigate ongoing attacks. Finally, the security framework will offer a monitoring and control subsystem that will allow it to be finally tuned, especially in order to answer safety requirements.

The work will focus on (1) communication stacks and middleware (2) permanent availability of an efficient communication medium (3) security management, and (4) reactive security. It includes the following specific contributions:

- *Distributed intrusion detection system with in-drone machine learning*: A lightweight anomaly-based intrusion detection system (IDS) for drones will be provided. It will work on network traffic patterns and on carried data plausibility, for both drone to drone and drone to ground central station links. When possible, the IDS will extract information on the detected attacks to notify the experts and might propose some countermeasures if the feature is made available.
- *Security management toolchain for drone monitoring and control*: A mechanism and a visualization interface to ensure that the drone is free of known vulnerabilities will be contributed. In this mechanism, the drone periodically sends information to a remote node, which processes it, extracts conclusions and shows them in a comprehensive manner.
- *Mechanisms to mitigate security issues with impact on the safety of drones*: To mitigate security issues, an integrated long-range communication link by which the unmanned vehicles can be identified and monitored.
- *Detection of navigation system failures due to signal hijacking or system malfunction*: An embedded, software module will be designed. It will rely on commands received from the platform, geographical position derived from geomagnetic D-SLAM, GPS position and mission polygon to detect possible GPS signal hijacking/spoofing.

- *A lightweight cryptography and IDS system on drones' communication*: A lightweight cryptography component that provides differnt modules will be proposed. Once a data has to be send need to be encrypted by the encryption module. Once a data has been received need to be decrypted by the decryption module in order to be read. If someone try to delivered dangerous information to the system is blocked by the IDS module based on topology check.
- *Hardware security component and corresponding APIs for applications to support exchange of data*: The hardware component shall be a separate chip, which for security-reasons is physically separated from the main application mircocontroller of the drone. Therefore the hardware component provides a commonly used I2C or SPI interface to connected to the main microcontroller. Furthermore, the corresponding SW-API shall provide a set of corresponding C-based libraries to be called by the main application microcontroller and will be primarily used to support security-relevant operations.
- *Navigation system with anti-jamming and anti-spoofing features*: The georeferenced position and attitude system will be enabled to support anti-jamming and anti-spoofing capabilities. This will enable more integrity and reliability of data on different scenarios, e.g. unintended jamming, and also malicious jamming or spoofing attacks.
- *Embedded router with multiple radio interfaces capabilities*: Communication capabilities from a drone to a pilot, to the cloud, and/or other drones in an efficient and reliable way will be provided. By aggregating the capacity of multiple radio interfaces, this component is able to increase the available bandwidth for applications. By using multiple radio interfaces, it offers the capability to switch the traffic from one interface to the other as soon as a disconnection or a drop of performance is detected.
- *Robust and enriched communication among beacons, and among beacons and drone, enabling an improved indoor positioning*: Custom tag and anchor platform will be developed. In addition, a specific effort will be done for a more robust and enriched communication. The goal is to successfully tackle a scenario with possible obstacles and also to offer enriched accuracy. The customization of the communication protocol for the data exchanged both among anchors and anchor-tag will be tackled. Specific extensions for the auto-positioning of the anchors, and for a better positioning of the tag will be done. Specific work related to the antenna configuration/integration on the drone platform will be also done.
- *Path manager and scheduler*: Develop a path manager to monitor connection availability and quality of the different base communication channels. These channels can be BT-LE, IEEE 802.11 and other channels for local communication. Compared to standard MPTCP, this path manager will use information from lower layers of the communication stack to improve discovery of useful channels.
- *Link state API*: Develop an API to communicate connection quality and availability as well as available unused resources (such as unused links) to support on-board applications, with prioritized communication, that by applications on the drone. Develop APIs to transfer information from the state of the multi-radio communication system to het lightweight communication system and the multi-path network

communication. Current MPTCP implementations do not make this information available to other software services in a simple way.

A more detailed description of these contributions and their related state of the art will be described in deliverable D5.1.

7.4 Minimizing the design and verification

It is widely accepted that the design of certifiable embedded systems for drone navigation requires the use of adequate design frameworks and techniques, providing the necessary mechanisms for ensuring system quality (modelling, development, requirements traceability, performances analysis, verification, validation and/or qualification tools).

The objective of this work is to define and set-up a system engineering framework and development workbench adapted to drone applications. This platform covers both facets of the V cycle, including modelling, optimization, code generation, performance analysis, verification and validation, etc. The proposed workflow integrating the design, performance analysis and verification tools will support incremental certification through separation of concerns and enabling reuse of qualified components. The work includes the following specific contributions to existing tools:

- *Digital stakeholder acceptance test bench*: The test bench is to (a) allow cities, politicians, associations to evaluate the insertion of drone into the airspace; (b) allow drone operator to refine their high level requirements; (c) ensure the capture and validation of all the requirements necessary to obtain the acceptance of all the stakeholders.
- *E-Handbook for safety, security and privacy*: The aim is to guarantee that permit to fly is obtained, and ensure that the development ensures safety, security and privacy at minimum cost. Designers and architects are guided through an interactive environment (wizard like) towards the results.
- *DOF Test Bench*: Planned developments for the HITL simulation platform are the followings: (a) development of a disturbance and a failure generator; (b) development of scripts emulating a radio control; (c) integration and testing of innovative functions developed by ARMADA project; (d) adaptation to others Flight Controls (Software/Hardware).
- Develop workflows for the drone domain.
- *Simcenter Amesim*: The following list is to be adapted as the project advances: (a) Provide functionality to generate a mission profile (altitude and speed definition for different flight phases); (b) develop component for coaxial propeller performance; (c) improve fidelity of aerodynamics sub-model for UAV applications; (d) improve (with dedicated developments or through methodologies) the integration with other tools for environment simulation, sensors simulation and flight simulators; (d) industrialize demonstrators to help users understand the software capabilities and provide a starting point for UAV system simulation analysis.

- MoSaRT: Two enhancements will be provided. The first one is the adaptation of the modelling language to support drones' specificities in term of temporal behaviour. The second enhancement will be related the enrichment of the repository by adding adequate contexts and model transformations toward external appropriate analysis tools.
- Accelerators programming model for onboard compute platform: Tools will enable from the application developer perspective offloading computations to hardware accelerators should be no more complex than programming a GPU with OpenCL or OpenMP for accessing application-specific hardware accelerators mapped on FPGA programmable logic. The tool will improve the overall accessibility of such special-purpose processing systems using well know programming model interfaces.
- *AirMPL-Simulator (Unmanned Aerial Vehicle Motion Planning Simulator)*: The main goal is to develop a tool that interfaces Gazebo/ROS and Matlab environments to open-source libraries for solving path planning problems. The tool will allow to simulate the behaviour of the path planning algorithm in a realistic simulation by considering drone dynamics.
- *SAGE Verification Suite (SAGE-VS)*: The following improvements will be implemented: a) Extending ReqV and ReqT to more expressive logics (e.g. Signal Temporal Logic) and improvement of natural language processing capabilities; b) improve performance for MLPs and provide verification algorithms for CNNs.
- *Multi-Dataflow Composer (MDC)*: An extension to an already existing acceleration template will be provided. This template is basically an FPGA overlay composed of pre-implemented easily programmable components where application specific computing tasks (i.e. image enhancing, filtering, transformation, cryptography, etc.) can be delegated to custom IPs. The acceleration infrastructure is meant to be coupled to an OS running on GP processors capable of dispatching the tasks and managing housekeeping. MDC tool is meant to be used to create the custom IP within the accelerator to relief designers from the burden of specifying the accelerators bitstream. Automatic wrapping functionalities will be added to MDC to guarantee the possibility of packing suitable IPs for the given template.
- *ESL eSW Design Environment*: The ESL eSW design environment will be used for further analysis and improvements of the multi-GNSS based attitude estimation algorithms. This includes, the assessment on the impact of using machine learning parts on the algorithm, where so far, a more heuristic approach has been used. This development is expected to serve to refine and improve Octave (Matlab compatible) scripts already used for analysing the outputs. Moreover, there is a specific interest in improving the analysis of raw traces of both inputs and outputs, most of them dumped as text files in custom formats. The goal is to get more user-friendly, graphical and useful visualization, optionally updated at simulation time.
- *Indoor positioning system model & analysis framework (IPS MAF)*: A development of the IPS MAF from scratch will be provided, on top of a basic development

framework relying on Eclipse, SystemC and Octave. Eventually, other third-party tools/libraries for visualization and deployment description could be incorporated.

- *IoT environment extra-functional validation methodology and toolchain*: Thanks to this tool, it will be possible to perform a continuous runtime verification of drones. This tool will avoid the need of manual inspection of logs and therefore, it will provide a more agile platform to detect and react to unexpected events (e.g., security breaches, communication issues, system malfunction).
- *Papyrus*: Papyrus tool will be improved from two sides. First, the tool will be enhanced to enable the modelling of a drone software component, which is then fully implemented or an existing legacy code is re-used. The component is then tested and put in a repository to be used for a system development. Second, to enable the easy and fast development of a drone system, the tool will be improved to enable the integration of reusable components from the repository through the modelling and (semi-)automatic integration.
- *PhiSim*: An existing control and planning algorithms used in the automotive industry will be adapted to be used for drones: (a) the simulation platform will be improved to take into account different aerodynamics (drag, thrust) as well as propulsion properties (inertia) for a given drone and allow us to get a realistic behaviour in the simulation; (b) position, attitude controllers will be implemented in this platform as well as obstacle avoidance and navigation algorithms; (c) thanks to ROS, testing different controllers would be possible with minimal modifications. Efforts would be made to make the system modular.
- *Paparazzi*: The objective for this tool is to improve the validation of code modifications with an automated testing procedure. It includes specific compilation, running various static analyses tools and automated simulation. A specific effort will be made to deploy a simulation framework that can be used from other partners to simulate multi-UAV operations with a realistic flight model in order to validate external packages. The objective is to reduce by two the time required to prepare a test case simulation for validation.
- *MoMuT*: The existing base tool will be used to develop and explore new features for security protocol testing. This will possibly include combining it with (binary) program analysis, providing a framework for assuring specific security aspects for drone communication.
- *ThreatGet*: Currently there is no domain specific threat database and knowledge for the drone domain. In addition to that ThreatGet is currently not able to support a compositional threat analysis. The goal is to develop a domain specific database to enable tailored security analysis and to work on compositional security analysis.
- *Workflow Engine*: To develop workflows for the drone domain.
- *Design tools for drone mechanical parts and subsystems development*: The goal is to define and facilitate methodology for design process of the drone components and accessories such as battery system suitable for autonomous exchange. The developed methodology will be used during design and development of open

library of mechanical and electromechanical components. This library will be available for other partners and for public use.

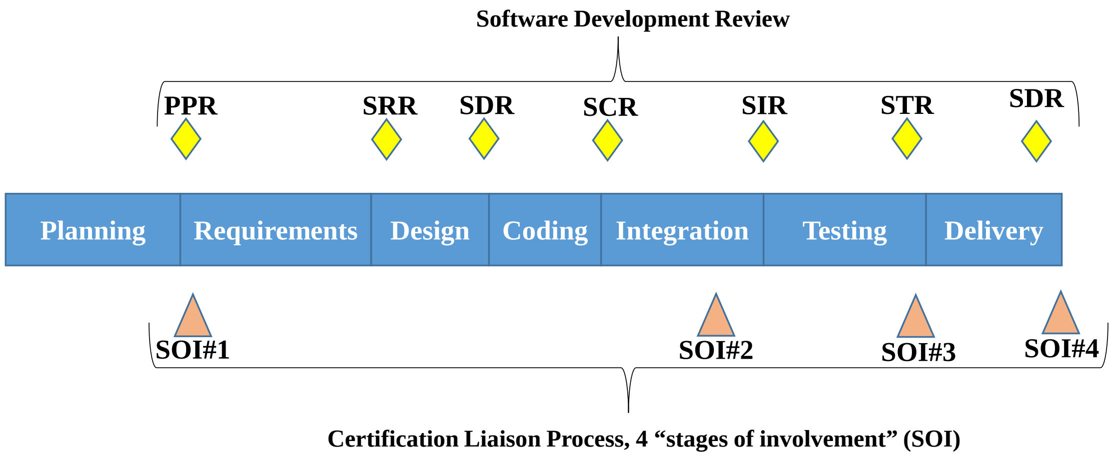
- *ROS/Gazebo modules for autonomous drone battery management simulation and validation*: The goal is to develop the ROS/Gazebo extensions for simulation of air traffic and mission control in vicinity of Droneport. These extensions cover the using of droneports as a charging station and their traffic management.
- *HEPSYCODE*: The tool and its methodology will be improved to guarantee: (a) mixed-criticality requirements fulfillment, with particular emphasis on system partitioning, failure/error isolation, timing scheduling, and inter- and intra-task interferences management, improving the design space exploration activity during the whole project; (b) reduced simulation time and simulator overheads (at least 15% on average simulation time), considering hierarchical scheduling policies; (c) a correct characterization of hypervisors through benchmarking activities
- *Framework and toolkit for validation of APIs for collection of connection metadata of multi-path communication system*: A functionality for more testing and logging of test results for documentation will be added.
- *Framework and toolkit for validation of robustness of path management for multi-path communication system*: A functionality for more testing and logging of test results for documentation will be added.
- *S3D*: The Single-Source, System Design Framework will be extended to the modelling of Cyber-Physical Systems of Systems (CPSoS) so that it is possible to model, analyse and explore different architectural mappings for complete missions. From the CPSoS model, SiL, MiL and HiL models will be automatically produced. The final implementation will be also automatically generated.
- *SoSim*: S3D-VIPPE will be extended to the simulation and performance analysis of Cyber-Physical Systems of Systems (CPSoS) so that it is possible to simulate, analyse and explore different architectural mappings for complete missions in a short time.

A more detailed description of the background technologies put by the partners into the project, the improvements to be made to it and the requirements to be satisfied will be described in Deliverable D6.1.

8 The Methodology

To develop a drone software and to enable its certification, a process that can be followed is the development lifecycle described in the DO-178 standard which is show in Figure 65. The process recommends a waterfall model where each phase of the development process is finished completely before proceeding to the next phase. In addition, there are four stages of involvement for the certification liaison process (see Figure 65). In addition to these stages of involvement, there a software development review after each phase of the development process. The key problem of this process is that errors that are detected late in the development process lead to of much re-work that is costly and leads to many delays in delivery of the software.

To overcome the problem of late detection of errors and its high cost, Airbus has proposed the use of agile software development to shorten the time for software development through either incremental or functional process as shown in Figure 66. In these processes, the development is performed rapidly in an incremental way.



PPR: Project Planning Review
SRR: Software Requirements Review
SDR: Software Design Review
SCR: Software Coding Review
SIR: Software Integration Review
STR: Software Testing Review
SDR: Software Delivery Review
SOI#: Stages of Involvements

Figure 65: DO-178C software development lifecycle[73]

[73] RTCA / EUROCAE. ―Software Considerations in Airborne Systems and Equipment Certification‖, DO178C/ED-12C, (2011).

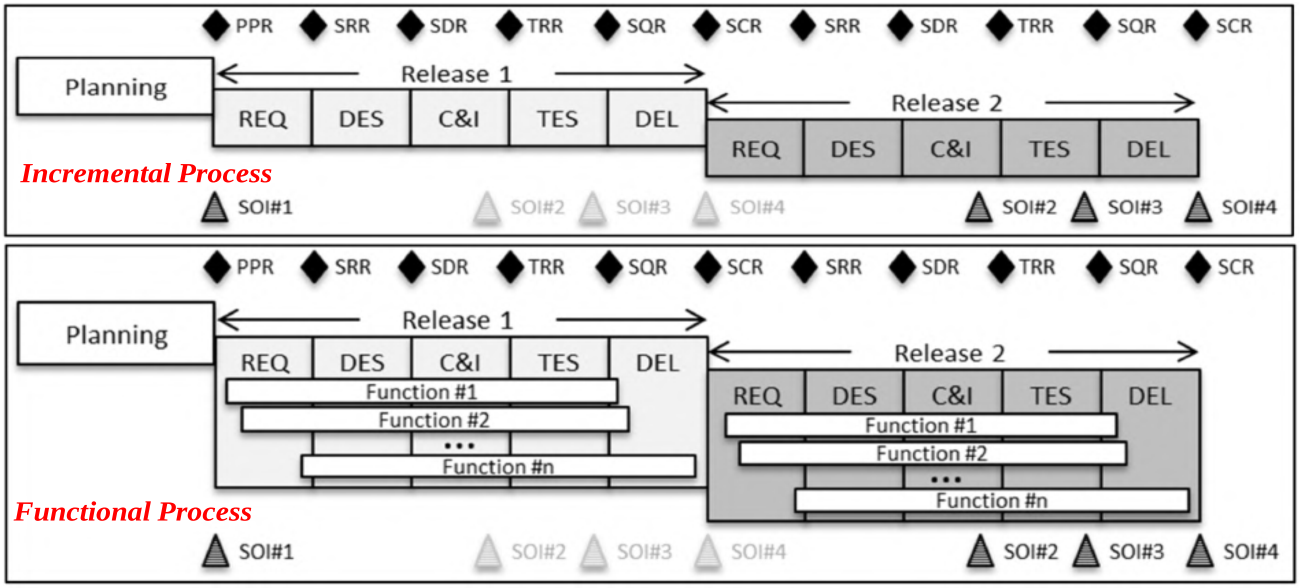


Figure 66: Airbus agile development process[74]

Based on the Airbus agile process, in **COMP4DRONES** project, a reuse-based agile development process is going to be followed as shown in Figure 67. In this process, after the planning phase and requirements identification, a repository that contains hardware and software components is checked to identify components that exist and can be used to satisfy the requirements. In case a component exists, the development process starts from the integration phase. Otherwise, the full development cycle needs to be followed from design to delivery (see Figure 67). The main idea of this process is to speed up the development process through reusing the existing components that supports the identified requirements.

[74] John Marsden, André Windisch, Rob Mayo, Jürgen Grossi, Julien Villermin, et al.. ED-12C/DO-178C vs. Agile Manifesto – A Solution to Agile Development of Certifiable Avionics Systems. ERTS 2018, Jan 2018, Toulouse, France.

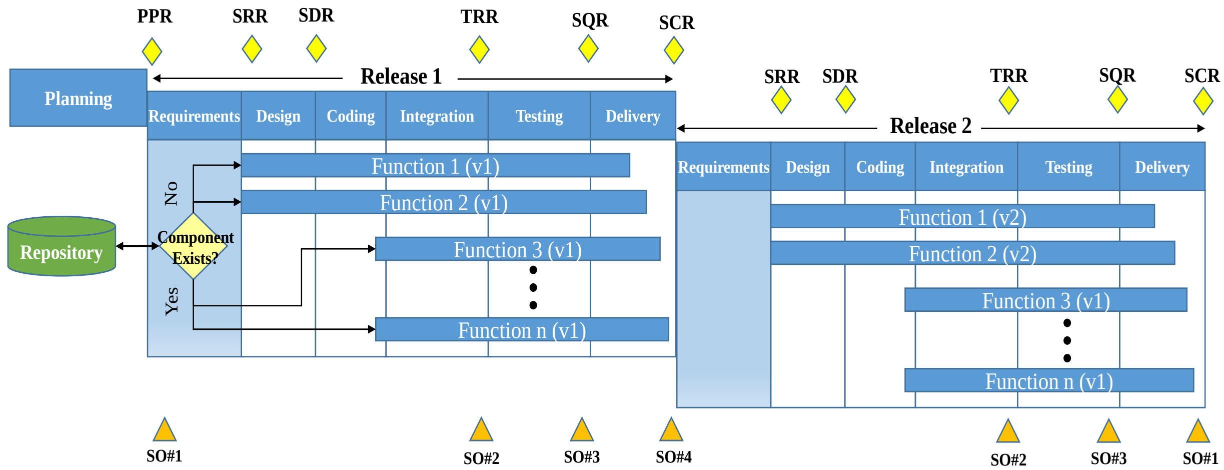


Figure 67: Reuse-based agile development process

Following this reuse-based agile process, the workflow for developing a drone system can be divided into two main phases: development and integration as shown in Figure 68. In this workflow, the drone system is decomposed into sub-systems which are later divided into components. These components are either reused or fully developed from scratch. After having all required components developed or made ready for integration, the integration phase starts where the components are group and integrated together to form a sub-system. These sub-systems are then integrated to have the fully functioning system.

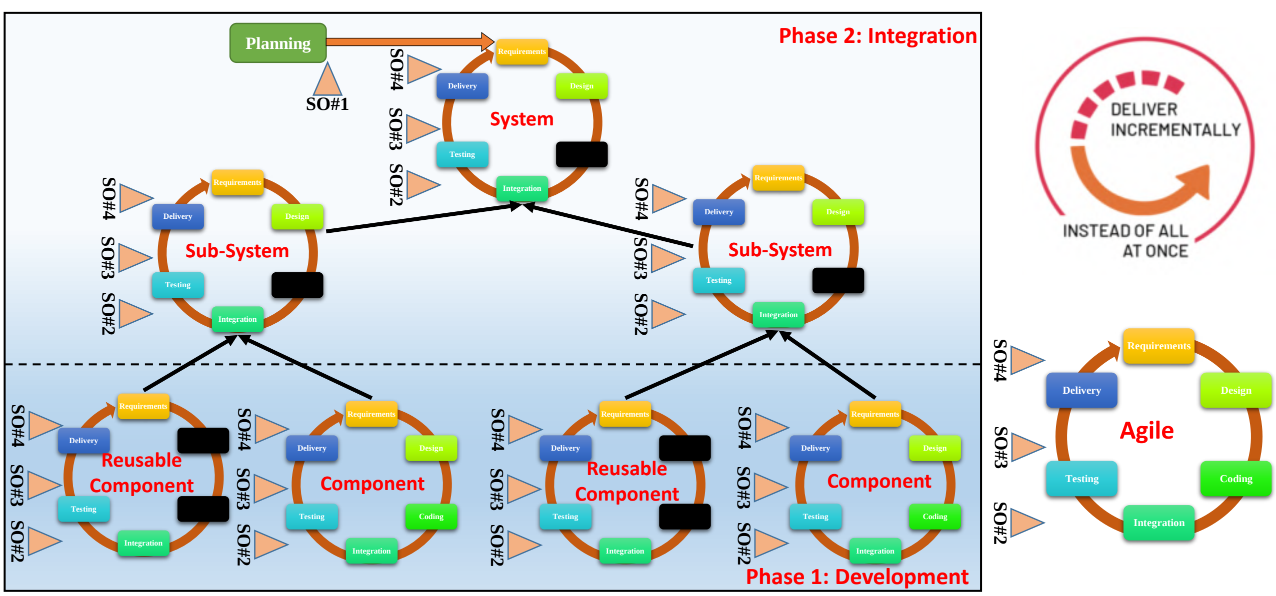


Figure 68: Reuse-based agile development process workflow

A more detailed description of project methodology and a review of existing methodologies will be described in deliverable D2.2.

9 Conclusion

In this deliverable, first, we have introduced challenges for developing drone systems, and a set of key concepts that are needed to define a framework for drone systems. These concepts include U-Space, and SORA (Specific Operations Risk Assessment). U-Space is a set of new services and specific procedures designed to support safe, efficient, and secure access to airspace for large numbers of drones. The Specific Operations Risk Assessment (SORA) provides guidance to both the competent authority and the applicant as to what is required for a national aviation authority (NAA) authorization required to fly an Unmanned Aircraft System (UAS) in a given operational environment.

Second, the current state of the drone systems has been discussed. This includes the drone itself, the ground control station, and the communication between them. The drone (UAV) is composed by three main parts: (a) the platform includes the structure, engines, servomotors, landing gear, etc. (b) the avionics is formed by all the electronic systems that allow the UAV's autonomous flight: the communications link, the flight controller or the navigation system; (c) the payload is made up of one or several sensors needed to carry out the UAV's mission. The most common payloads are cameras, but there can exist some different such as radars, LiDARs, environmental sensors, etc.

Third, a brief summary of the project demonstrators has been presented. The demonstrators are in five domains: transport, construction, inspection and surveillance, and smart and precision agriculture. These demos are then used to identify the common usages of drones. The usage is classified into: fly stages (e.g. take-off, cruise, etc.), and mission specific operations (e.g. check crop health, inspect offshore infrastructures, etc.).

Forth, we described the overall workflow the project with a focus on the identification of the key enabling technologies, the task of this deliverable, based on the demos' descriptions. To do so, we described a general architecture for the drone system which is then used by a process to identify the different components/ technologies of the system.

Fifth, based on the common usages, we identify the key technologies of **COMP4DRONES** framework that need to be developed to enable the common usages. These technologies include U-space capabilities (e.g. geofencing, security, and telemetry, etc.), system functions (e.g. flight control, positioning, coordination, etc.), payloads (camera, LIDAR, etc.), and tools (system design, data analytics, mission planning, etc.).

Sixth, the project contributions to improve the existing technologies to enable easy customization of drones and their safe operation have been described. The improvements are divided into four groups: integrated modular reference architecture, safe autonomous decisions, trusted communication, minimization of the system design and verification.

Finally, a general methodology for drone systems development has been presented that will be elaborated in other deliverables.