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D4.1 – Methodological guide on sensory systems and data aggregation for drone's platforms

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Definitions, Acronyms and Abbreviations

Acronym/Definition	Title
Actor	Participant in an action or process. This can be a person or a group of persons representing an organisation (see also stakeholder definition).
Aggregation	The formation of a number of things into a cluster
Data	Facts and statistics collected together for reference or analysis. The quantities, characters, or symbols on which operations are performed by a computer, being stored and transmitted in the form of electrical signals and recorded on magnetic, optical, or mechanical recording media.
Drone	A remote-controlled pilotless aircraft or missile
HORUS	An integrated management platform, enables tunnel operation, automates processes, contributes to reducing the risk of incidents and speeds up management, offering drivers safety and service quality.
Methodology	A system of methods used in a particular area of study or activity
Platform	A standard for the hardware of a computer system, determining what kinds of software it can run.
RPAS	Remotely piloted aircraft system.
Sensor	A device which detects or measures a physical property and records, indicates, or otherwise responds to it
System	A set of things working together as parts of a mechanism or an interconnecting network.
U-space	U-space is a set of new services relying on a high level of digitalization and automation of functions and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones.
UAS	Unmanned Aircraft System
UAV	An unmanned aerial vehicle (an aircraft piloted by remote control or onboard computers)
3D	Three-Dimensional
ADT	Air Data Terminal
AHRS	Attitude Heading and Reference System
AI	Artificial Intelligence
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Service
ANSP	Air Navigation Service Provider (ATC)
AR	Augmented Reality
ATC	Air Traffic Control
AXI	Advanced eXtensible Interface
BeiDou	Chinese Navigation Satellite System (BDS)
BIM	Building Infrastructure Model
BLE	Bluetooth Low Energy
BSD	Berkeley Software Distribution
C4D	**COMP4DRONES** (short name of the project)
C4I	Computers, Communications, Command and Control, Intelligence
CAD	Computer-Aided Design
CAN	Controller Area Network
CCD	Charge-Coupled
CDT	Control Data Terminal
CMOS	Complementary Metal–Oxide–Semiconductor
CMPD	Centro de Misión de Proceso de Datos

COTS	Commercial-Off-The-Shelf
CPS	Cyber-Physical System
CSI	Camera Serial Interface
DL	Deep Learning
DMA	Direct Memory Access
DP	Droneport
DRL	Deep Reinforcement Learning
DVS	Dynamic Vision Sensor
EKF	Extended Kalman Filter
EM	Electro-Magnetic
EO	Electro-Optical
ESDF	Euclidean Signed Distance Fields
EU	European Union
FMU	Functional Mock-Up Interface for Model-Exchange & Co-Simulation
FoC	Frequency of Occurence
FoV	Field of View
FPGA	Field Programmable Gate Array
FPS	Frames Per Second
GALILEO	European Global Navigation Satellite System
GCS	Ground Control Station
GDT	Ground Data Terminal
GLONASS	GLObal NAvigation Satellite System
GNC	Guidance, Navigation & Control
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
HD	High-Definition
HDR	High Dynamic Range
HIL	Hardware In Loop
HMI	Human Machine Interface
HW	Hardware
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
IPS	Indoor Positioning System
IR	Infra-Red
JSON	JavaScript Object Notation
KET	Key Enabling Technologies
LiDAR	Light Detection And Ranging
MEMS	Microelectromechanical systems
MIL	Model In Loop
ML	Machine Learning
MPU	Micro-Processing Unit
MQTT	Message Queuing Telemetry Transport
MTBF	Mean Time Between Failures
NATO	North Atlantic Treaty Organization
NMEA	National Marine Electronics Association
NN	Neural Network
OS-NMA	Open Service Navigation Message Authentication

PID	Proportional–Integral–Derivative controller
RADAR	Radio Detection and Ranging
REST	Representational state transfer
RGS	Royal Geographical Society
RINEX	Receiver Independent Exchange Format
RMS	Root-Mean-Square
ROS	Robot Operating System
RPA	Remotely Piloted Aircraft (Drone)
RPAS	Remotely Piloted Aircraft System
RSSI	Received Signal Strength Indication
RTCM	Radio Technical Commission for Maritime
SAR	Synthetic Aperture Radar
SDK	Software Development Kit
SESAR	Single European Sky ATM Research
SIL	Software In Loop
SIS	Signal In Space
SLAM	Simultaneous Localization And Mapping
SOA / SoA	Service-Oriented Architecture
SoC	System on Chip
SPI	Serial Peripheral Interface
STANAG	Standardization Agreement NATO
SW	Software
TBD	To Be Determined
TF	Transform
ToF	Time-of-Flight
TRL	Technology Readiness Level
TSDF	Truncated Signed Distance Fields
UA	Unmanned Aircraft
UART	Universal Asynchronous Receiver-Transmitter
UAS	Unmanned Aircraft System ('drone')
UAV	Unmanned Aerial Vehicle
UC	Use Case
UCS	UAV Control System
UDP	User Datagram Protocol
UGS	Unattended Ground Sensor
UGV	Unmanned Ground Vehicle
USB	Universal Serial Bus
USP	Unmanned Service Provider
USS	UAS Service Suppliers
USV	Unmanned Surface Vehicle
UTM	U-space Traffic Management
UWB	Ultra-Wideband
V2I	Vehicle to Infrastructure communication
VDT	Vehicle Data Terminal
VGA	Video Graphics Array
VHF	Very High Frequency
VLOS	Visual Line of Sight
VOR	VHF Omnidirectional Radio Range
Wi-Fi	Wireless Fidelity
WP	Work Package

Executive Summary

Drones/ Unmanned Aerial Vehicles can perform air operations that manned aircraft struggle with, and 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. SESAR joint undertaking identified that issue has a high impact on European innovation, which demands research and development investments and incentives for the convergence of shared technologies and markets as a remedy. Actions creating globally harmonized, commercially exploitable yet widely accessible research and development ecosystems should be publicly performed.

This document introduces a methodological guide on sensory systems and data aggregation for drone platforms. It contains a reference architecture definition, which is further explored in case studies on respective drone systems. Furthermore, a list of key technologies supporting the state-of-the-art and future drone designs and operations is introduced. The presented drone component portfolio provides an intuitive and methodological guide on respective drone system elements. Details on respective components contain, among others, the degree of technological innovation, readiness levels, interface specifications and references to applicable standards.

1 Document Structure

This document is composed of chapters closely related to the drone sensory systems and data aggregation for drone platform´s. The introductory part contains description of case studies and respective demonstrators along with the definition of a reference architecture. Furthermore, a list of key technologies supporting the state-of-the-art and future drone designs and operations is introduced. The component portfolio chapter provides the reader with an intuitive and methodological overview of respective drone technology elements distributed into three main component bins, namely the U-space, System Functions and Payload technologies. Further details on respective technologies, their envisioned utilization, readiness level and degree of innovation are shown in respective component descriptions. Beyond the previously stated details, the listing also contains interface specifications and reference to applicable standards.

2 Introduction

The constantly increasing utilization of drones, spanning a range of diverse industrial applications, stimulates a natural request for novel lightweight components build around proven and emerging technologies in structural design, aerodynamics, flight mechanics, control systems, navigation solutions, sensors and communication.

A user centered natural classification of drone components and their respective technologies evolves around envisioned use cases (UC) in transportation, construction, logistics, surveillance & inspection and agriculture. The drone utilization in transportation has the potential to enrich the road, harbor and railroad operations. The construction industry is already gaining profit from drone-based monitoring in realization of civil infrastructure and underground constructions. A carefully explored use cases evolving around a substantial business opportunity include the utilization of drone systems in logistics, surveillance & inspection and agriculture. The novel drone engagement contains tasks of sensor insertion in difficult terrain or delivery of medical supplies within 5G backed environment, hyper-spectral imaging of off-shore drilling platforms, exploration and mapping of unknown environments or smart farming. These are just few freshly identified deployment niches boosting the need for an increased involvement in drone components research and development.

The drone platforms of tomorrow will not only serve the purpose of providing value to end users and customers in manually controlled operations, but will integrate higher advanced system functions derived from state-of-the-art Artificial Intelligence and Machine Learning techniques enabling strategic mission planning and autonomous decision making. Machine Learning techniques already found their utilization in the field of Sense & Avoid solutions enabling basic on-board situational awareness, which is inevitable in autonomous drone operations. However, the transition from a safe single drone operation to a fully developed diverse multi-actor Unmanned Traffic Management (UTM) Cyber-Physical System (CPS) requires an efficient integration of advanced communication, navigation and surveillance technologies which, among further disciplines like advanced E-identification, Geofencing, Drone Tracking, Emergency Drone Recovery and Command & Control, form the project relevant Key Emerging Technologies portfolio. The key difference between today´s operations and future UTM is clearly in the perceived level of operational autonomy. State-of-the-art autonomous Cyber-Physical Systems which emphasize strategic mission planning may benefit from emerging artificial intelligence technologies in cooperative and non-cooperative multi-agent systems. A reliable framework for enabling safe hybrid operations of manually controlled and autonomous drones, supported by respective drone sensor technologies and data aggregation algorithms, will enable drones to become an integral part of everyday's life and to be beneficial to the whole society. Chapter 2 “Autonomous drones” introduces relevant case studies along with applicable drone demonstrators. This introductory part is followed by the definition of reference architecture and a general model of standard components. Chapter 3 “Sensory systems and data aggregation for sensor fusion” extends standard components with a guide on respective principal sensor systems, data aggregation from sensor network and sensor fusion techniques providing optimal state estimates. Chapter 4 introduces “Key technologies” supporting drone operations. These technologies are clustered based on their control/feedback mechanisms into U-space functions, flight control, payload technologies and supporting design tools. Chapter 5 contains an information rich methodologically balanced guide on “Components portfolio” which provides a detailed insight into applicable sensory systems and associated data aggregation and sensor fusion.

3 Autonomous Drones

3.1 Case studies and demonstrators

The list of case studies with associated demonstrator and lifecycle phases considered in **COMP4DRONES** project are shown inTable 1. Respective use cases are further described in more detail in following subchapters.

Figure 1 COMP4DRONES Use cases

Case study (applies to)		Demonstrator (specific field)		Task / Lifecycle Phase
UC1	Transport	1.1	Road	Operation
		1.2	Harbor	Operation (USV)
		1.3	Railroad	Life cycle
UC2	Construction	2.1	Civil infrastructure	Realization
		2.2	Underground infrastructure	Realization
UC3	Logistics	3.1	Hard to access areas	Sensors deployment
		3.2	5G urban environment	Delivery of hospital parcels
UC4	Surveillance & Inspection	4.1	Off-shore wind turbines	Hyperspectral sensing
		4.2	Unknown environments	Exploration and mapping (UAV + UGV)
UC5	Agriculture	5.1	Smart Farming	Remote sensing, treatment (UAV + UGV)
		5.2	Wine yard	Remote sensing, collection of data sensed by fixed sensor

Table 1 List of Use Cases for COMP4DRONES project

3.1.1 UC1 Transport

In the Transport use case, the drones themselves are envisioned to be utilized as monitoring platforms for the road traffic and infrastructure conditions surveillance. Hence their main applications feature:

- Detection and early response to incidents.
- Road infrastructure inspection.

The envisioned drone operations will include the capability to request a drone's flight over an infrastructure of interest, with the transport control center integrating respective images/video captured by the drone to visualize the infrastructure related surroundings and to process associated information.

3.1.2 UC2 Construction

The goal of UC2 is to develop the technology required to carry out any type of operation that allows the digitization of the state of the constructive process of a transport infrastructure. This allows cost and time reduction of data acquisition in relation to traditional technologies, either by traditional surveying or terrestrial methods. The digitization of this process will allow to generate products that allow an approximation in the development of construction of BIM (Building Infrastructure Model) Model. The goal of the Construction Use Case is to utilize the drone as monitoring device for the road traffic and infrastructure conditions.

3.1.3 UC3 Logistics

Use case UC3 consists of demonstrators for the deployment of an Autonomous Communication System in hard-to-access areas and supporting logistics in 5G urban environment. The Use Case will account for selecting and managing a heterogeneous fleet of autonomous vehicles. It will promote communication infrastructure with redundant, secure, robust, dissimilar and deterministic abilities; and navigation and sensing at the landing or dropping zone with a high positioning accuracy and a guarantee of absence of objects, people or animals. The logistics context will be exercised through the drones being used as monitoring devices for road traffic and infrastructure conditions.

3.1.4 UC4 Surveillance & Inspection

The main goal of UC 4 is the realization of an autonomous UAV with enhanced sensory capabilities and novel control strategies augmented by a real-time data-analytics algorithms. The main applications of the drone will be within an indoor or, optionally, outdoor environments, accounting for industrial inspections and rescue operations. The Use Case will aim towards the development of efficient computational strategies, dealing with limited computational resources, perception, planning and control to be determined by high-level data-analytics systems and high-availability communication channels and closed-loop algorithms implemented in FPGA (Field Programmable Gate Array) based accelerators. Beyond that, the Use Case will emphasize the objective of multi robot navigating and mapping in an unknown environment.

3.1.5 UC5 Agriculture

The UC5 is aimed to demonstrate the future of smart agriculture and precision farming technologies. The envisioned application accounts for real-time crop monitoring, with a special emphasis on health and growth management. Future farming will be supported by an accurate data analysis, allowing for a reduced footprint on the environment. A trustworthy interaction between land-bound sensors and drones as gateways will come from the drone to UGV (Unmanned Ground Vehicle) communication setup.

3.2 Reference architecture

A classical image of a drone system baseline architecture contains the drone platform itself, a dedicated mission payload and a human operated handheld control station. However, an autonomy augmented drone framework goes well beyond this classical layout and accounts for an advanced ground control station element enabling control and coordination of a fleet of drones capable of vehicle-to-vehicle communication designed to meet the requirements of future U-space operations. The autonomy augmented drone architecture, as described above, is introduced in Figure 2 Furthermore, Figure 3 shows a block diagram with a reference system level architecture containing Missions (scenario/services), Planning layer, Management layer, Control layer, sensors and actuators blocks. A practical example related to the system architecture diagram is introduced in the associated graph in igure 3.. The graph starts with the Sequence definition originating in the Mission Layer and propagates further to the trajectory planning block indicating drone´s flight. Subsequently, the Management layer processes the Fly-To request while enabling the actual Landing command. The request propagates further as a command to the Control Layer, triggering the landing control law. This law uses information from the Camera, GNSS (Global Navigation Satellite System) and Altimeter based navigation solution and triggers actuator commands using control allocation algorithm. Beyond others, the Management layer processes shared situational information from a fleet of drones, enabling a proper system reaction in meeting the global mission goals.

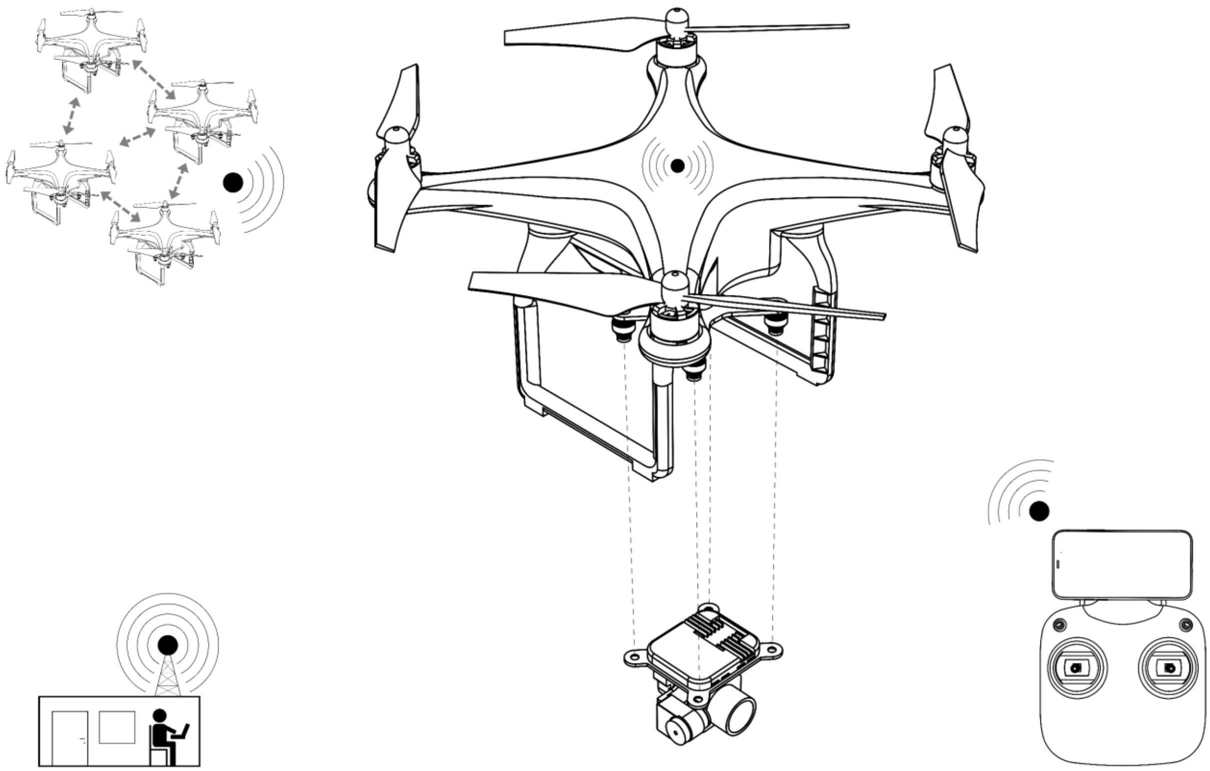

Figure 2 Main drone system components

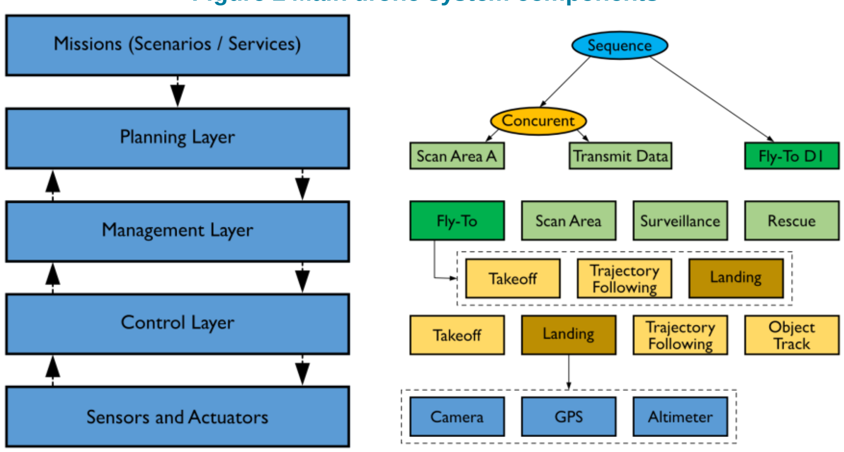

Figure 3 Reference system architecture

3.3 General model of standard components

Standard drone components, as found on a general UAS model, are divided into two main groups, accounting for the aerial vehicle and the ground station. The aerial vehicle is further structured into the drone platform itself, the digital avionics suite and the mission requirements driven payload. The industry standard solution for the avionics is further structured into the navigation, communication, flight controller and respective sensors. The ground station architecture is composed of systems taking care of communication, mission monitoring, launch and recovery. The ground station is operated by a dedicated trained operator. Figure 2.4 shows the general model of UAS components.

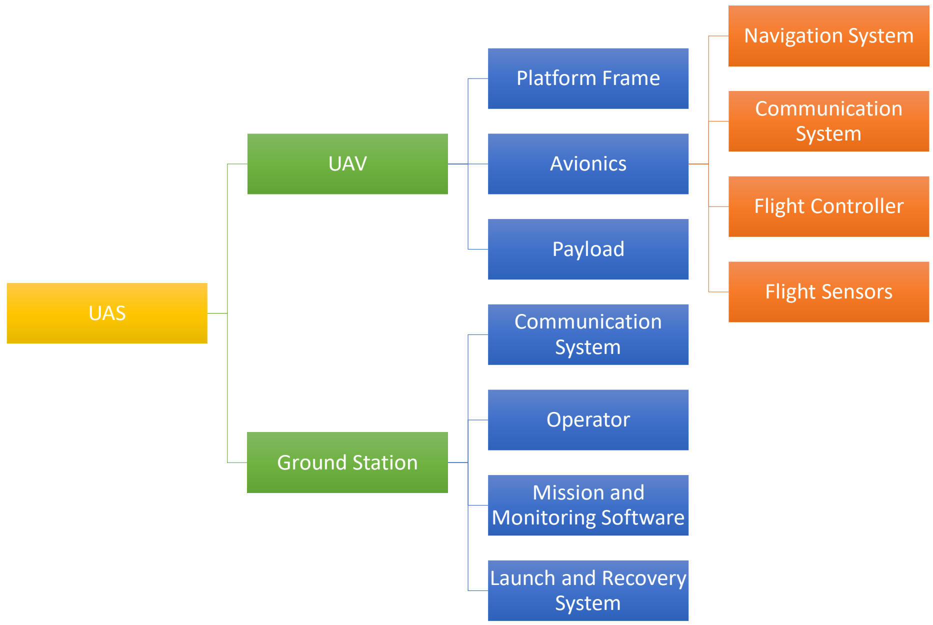

Figure 4 General model of standard UAS components

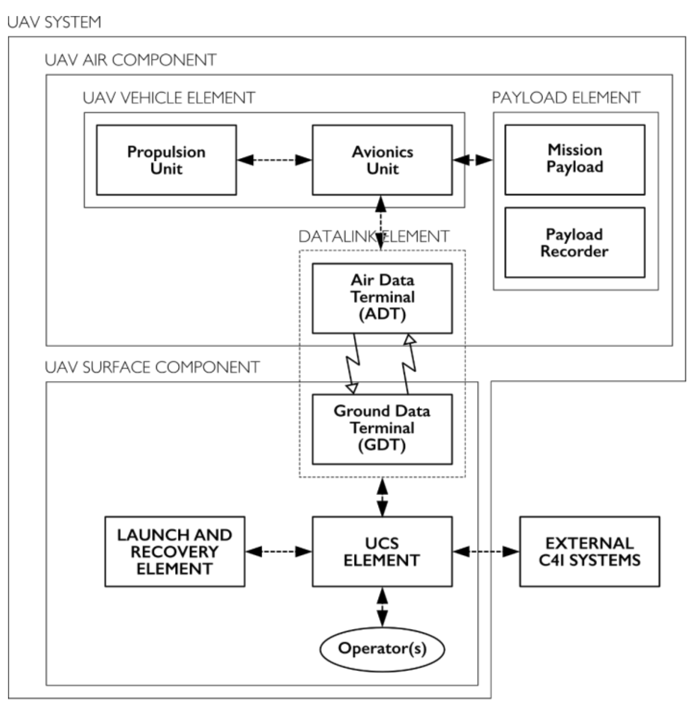

Figure 5 Functional components of an Unmanned Aerial System

Figure 5 shows the similar structure that is found in STANAG 4586 Edition 3 [1]. The STANAG 4586 Edition 3 specifies the Unmanned Aerial System as following:

- The air vehicle element consists of the airframe, propulsion and the avionics required for air vehicle and flight management.
- The payload element is comprised of payload packages. These can be sensor systems and associated recording devices that are installed on the UAV, or they can consist of stores, e.g., and associated control/feedback mechanisms, or both.
- The data link element consists of the vehicle carried Air Data Terminal (ADT) and the Ground Data Terminal (GDT) which may be located on the surface, sub-surface or on aerial platforms.

- The control of an UAS is achieved through the UAV Control System (UCS) UCS and respective data link elements. Although shown as part of the UAS surface component, the UCS and the associated data link terminal can be located on any platform, (e.g., another air platform). The UCS element incorporates the functionality to generate, load and execute the UAV mission and to disseminate useable information data products to various C4I (Computers, Communications, Command and Control, Intelligence) systems. The command and control and respective payload functions may be accomplished on separate, independent data links.
- The launch and recovery element incorporate the functionality required to launch and recover the air vehicle(s).

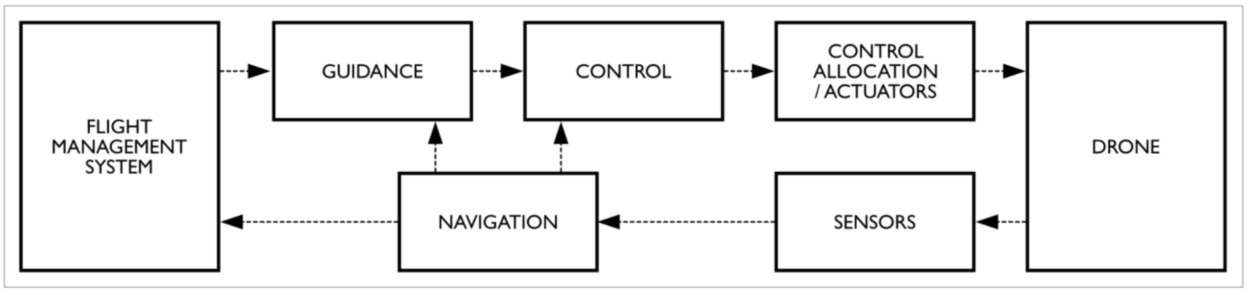

Figure 6 Guidance, Navigation and Control framework

Figure 6 shows a general scheme of the Guidance, Navigation and Control (GNC) framework associated with the drone platform's automatic/autonomous operations. Beyond the GNC, the framework contains Flight Management System block, control allocation on respective actuators/servos and a sensor network installed onboard of the drone platform. Guidance refers to the definition of a desired path of travel from starting point to the destination, along with associated changes in velocity, acceleration and drone attitude. Navigation refers to drone state determination (location, attitude, velocity, acceleration) at any given time. The Control itself refers to the manipulation of forces and moments by steering, to execute guidance commands while preserving drone's stability. The basic GNC framework of a single drone can be further upgraded to the augmented autonomy state by including a vehicle-to-vehicle communication and an advanced ground control station control and coordination role in drone fleet management. Information arriving from cooperating drones and control stations are processed in the Flight Management System block and influence further the actual GNC solution.

4 Sensory systems and data aggregation for sensor fusion

Sensor is a device which detects or measures a physical property and records, indicates, or otherwise responds to it. Drone sensors used in UAS (Unmanned Aircraft System), UGS (Unattended Ground Sensor), USS (UAS Service Suppliers) typically account for proprioceptive and exteroceptive sensors. Proprioceptive sensors feature internal sensors as Accelerometers and Gyroscopes, while exteroceptive account for external sensors as cameras, LiDAR (Light Detection And Ranging), RADAR (Radio Detection and Ranging) and Ultrasound sensors.

4.1 Sensor Systems

Accelerometer - is used to measure static and dynamic accelerations. The state-of-the-art drones benefit from micromachined micro-electro-mechanical system (MEMS) accelerometers integrated into an inertial measurement unit, which provides fused drone state estimates, tilt and vibration measurements.

Performance	Pros	Cons
Dynamic Range: ± 18 g	Conveniently priced	Noisy reading
Sensitivity: ± 0.8 mg	Small form factor	Temperature dependent
Sampling rate: Up to 1000Hz		

Table 2 Typical accelerometer parameters

Camera - is a device containing Complementary MOS (Complementary Metal–Oxide–Semiconductor) or Charge-Coupled Device (CCD) sensors used in digital imaging to capture light photos from visible electromagnetic spectrum. A camera can be affected by environmental variations such as occlusions, illumination and weather variation.

Performance	Pros	Cons
Range: 3-100m	Inexpensive	Influenced by lighting conditions
FoV: ± 50°	Texture and colour information	Challenged by weather
Accuracy: 5 cm; 3°-1°; 0.5 m/s	Good accuracy in lateral measurements	Multiple cameras to cover 360° scene
Data: 30/60/120 Mbyte/s	The resolution: Up to tens of MegaPixels	Image without compression requires high data throughput

Table 3 Typical camera parameters

GNSS (Global Navigation Satellite System) Receiver - is in principle an electronic device (see Figure 1) designed to receiving and processing signals from space-based constellation of navigation satellites to principally provide time, position and velocity information for terrestrial navigation. On a system level, the GNSS receivers consist of a dedicated single purpose chips and typically support one or multiple systems, namely the GPS (Global Positioning System), GLONASS (GLObal NAvigation Satellite System), Galileo (European Global Navigation Satellite System) and/or BeiDou (Chinese Navigation Satellite System).

Performance	Pross	Cons
Sample rate: 1 or 5Hz	High precision options	Required GNSS satellite visibility
Accuracy: lateral up to 5 cm RMS	Full navigation solution enabled by global signal coverage	Limited accuracy in urban environment
Data: 600, 1200, 2400, 4800 byte/s	Conveniently priced	Restrictions in speed and load factor

Table 4 Typical GNSS receiver parameters

Gyroscope - is a sensor used to measure angular velocity. The state-of-the-art solutions are mostly Coriolis vibratory gyroscopes using a vibrating structure to determine the rate of rotation. Their MEMS implementation is simpler and cheaper than conventional rotating gyro systems. In many cases a single integrated circuit includes multiple axes gyro sensors.

Performance	Pros	Cons
Dynamic Range: ±400 °/sec	High accuracy	Gyro drift
Accuracy: better than ±0.05°	Small form factor (MEMS)	Higher calibration requirements during production
Sampling rate: Up to 1000Hz	High MTBF	

Table 5 Typical gyroscope parameters

Hyperspectral Camera - is a device for collecting and processing images from across electromagnetic spectrum using hyperspectral sensors. Hyperspectral imaging measures continuous spectral bands, as opposed to multispectral imagining which measures spaced spectral bands. Hyperspectral images are combined to form a three-dimensional hyper spectral data cube for processing and analysis.

Performance	Pros	Cons
Spectral Range: 400- 2500nm	Entire spectrum for each pixel	Large data storage needed
Max Frame Rate: Up to 350 Hz	Enabled data compression	Expensive
Line Scan Format: 150+bands	Laboratory level data	Limited availability

Table 6 Typical hyperspectral camera parameters [2]

Inertial Measuring Unit (IMU) - is the sensor part of an inertial navigation solution, which combines digitally processed sensor information from accelerometers, gyroscopes, magnetometers and pressure sensors to calculate position, orientation and velocity updates of objects moving in an inertial space.

Performance	Pros	Cons
Velocity Accuracy: ±0.05 m/s	Integrated filtering (e.g. EKF)	Prone to error that accumulates over time
Angular Resolution: < 0.05 °	High accuracy	An IMU does not contain sensor fusion software
Output Rate: 400Hz	High shock survivability	IMU does not contain a GNSS receiver to enhance precision

Table 7 Typical IMU parameters

LiDAR - is a device illuminating the target object with a laser light and measuring the reflection with a sensor. Differences in time of flight and wavelength are used to construct a digital three-dimensional representation of the target object in a form of a point cloud. The laser component of a LiDAR devices for non-scientific applications works with laser wavelengths of 600-1000 nm.

Performance	Pros	Cons
Range: 100 - 200 m	3D map of the surroundings	High procurement cost
FoV (Field of View): 360° Horizontal, 30° Vertical	Short wavelength allows to detect small objects	Deterioration under hot conditions
Accuracy: down to 1.5 cm; 3° - 0.1°	Independent of ambient lighting	Limited texture or colour information
Data: 2.5 Gbyte/s	Robust against interference	Ghost artefacts

Table 8 Typical LiDAR parameters [2]

Magnetometer - is a sensor measuring direction, strength or fluctuations in magnetic field at a particular position. Magnetometer is used as part of the inertial measurement unit, where it serves as a heading reference.

Performance	Pros	Cons
Heading: 2.0° RMS	Extremely small footprint	Prone to EM Interference
Accuracy: ±1gauss	Inexpensive	Soft and hard iron calibration
Sampling rate 150 Hz	High sensitivity	

Table 9 Typical magnetometer parameters

Optical Sensor - is a detector that converts electromagnetic radiation within the infrared to ultraviolet wavelength spectrum into an electrical signal. Commonly used optical sensors include photo-resistor, photo-diode and photo-transistor.

Performance	Pros	Cons
Detection Range: 2-200 cm	Highly sensitive / Small footprint	Temperature sensitive
Output: Analog, I2C, SPI	Inert to chemicals and EM interference	Interference from environmental effects

Table 10 Typical optical sensor parameters

Pressure Sensor - MEMS pressure sensors operate by converting pressure into an electrical signal using strain gauges implanted on a membrane. The membrane deflects under the pressure and the deflection is transformed into a change in sensed electrical properties. This technology can be seamlessly integrated into an inertial measurement unit.

Performance	Pros	Cons
Range: 10 to 1200 mbar	Small form factor	Temperature sensitive
Sensitivity: 0.04 mbar	Robust	Moisture sensitive
Sampling rate: 200 Hz	Inexpensive	

Table 11 Typical pressure sensor parameters

RADAR - is a device which uses radio waves to estimate position and velocity of target objects. The device consists of a radio transmitter, antenna, radio receiver and processor which estimates object's properties.

Performance	Pros	Cons
Range: short 30-70m; long 70-200m	Immune to visibility and lighting conditions	Difficulty identifying non-metallic objects
FoV: 60° Horizontal, 5° Vertical	Good accuracy in longitudinal distance measurements	Poor accuracy in lateral measurement
Accuracy: 5 cm; 3°-1°; 0.5 m/s	Return speed and distance	Interrupted with other signals
Data: 500 Kbyte/s	Radar has the ability to penetrate clouds, fogs, mist, and even snow	Limited texture or colour information because of the longer wavelength

Table 12 Typical RADAR parameters [2]

Ultrasonic Sensor - is a device which detects movement of targets and measures distance to them using sound signal. Ultrasound sensors are a suitable solution for clear object detection and liquid level measurements, even under high glare conditions.

Performance	Pros	Cons
Range: 0.1 – 4m	Widely used drone and automotive market	Cannot distinguish big and small object
FoV: 75° Horizontal, 45°Vertical	Detection resistant to dust, dirt and moisture	Sensing accuracy affected by soft materials
Data: 100Mbit/s	Night operation	Temperature sensitive

Table 13 Typical ultrasonic sensor parameters

4.2 Sensor Fusion

Data aggregation is defined as a process of aggregating data from multiple sensors and providing the information to the drone sensor fusion unit. The ambitious transition towards increased drone autonomy underlines the necessity of redundant system architecture as a mean of ensuring system level reliability and safety under various operating conditions. An organic part of the redundant architecture is the sensor network consisting of real, imperfect elements. The general idea behind sensor fusion is to estimate the system's true state by combining sensor information with a potentially corrupted content. The known sensor fusion algorithms can be clustered into two main groups, namely deterministic and stochastic ones, as shown in the table below. The most notable among the algorithms is the Kalman

Filter. This optimal state estimator is a generalized concept of Bayesian Inference that iteratively refines its state estimate using incoming measurement updates. Kalman Filter is a state estimation algorithm so well-known and so powerful, it has been used for decades, beyond other applications, for space satellites station-keeping tasks.

Deterministic	Stochastic
Extended, Unscented, Ensemble Kalman Filter	Maximum likelihood estimators
Wiener estimator	Bayes estimator
Particle Filter	Minimum mean squared error estimator
Minimum-Variance Unbiased Estimator	Markov chain Monte Carlo

Table 14 Sensor Fusion techniques

One of the first utilizations of Kalman Filter was in the inertial navigation domain and even by today's standards it still holds its place. The state-of-the-art MEMS Inertial Navigation Systems use implementations of Extended Kalman Filter (EKF) to fuse data from gyroscopes, accelerometers, magnetometers and pressure sensors. The Attitude Heading and Reference System (AHRS) takes the advantage of a general availability of the GNSS navigation signal and fuses it with the Inertial Measurement Unit using EKF.

The motion tracking using onboard cameras is in ground-based applications referred to as visual odometry. The assumption of having an onboard calibrated camera allows to consider the temporal consistency of captured images needed for real-time visual odometry implementation. The original sensor fusion algorithm for visual odometry using feature extraction relied primarily also on the previously introduced Kalman Filter. As the estimation of a drone pose is only one part of the autonomous navigation problem, the remaining one is the environment mapping and subsequent action planning. Applicable fusion algorithms for solving this extended task are SLAM (Simultaneous Localization And Mapping) methods. These methods are capable of camera motion tracking while simultaneously creating a map of the surrounding environment. Recent advances in stereoscopic vision, enabled by the market availability of low-cost RGB-D cameras providing depth information for every pixel, stimulated research in novel direct visual odometry estimation.

Computer vision and Inertial Measurement Unit sensor fusion represents a robust navigation alternative for GNSS denied environment in urban agglomerations. The inertial sensors (accelerometer and gyroscope) provide adequately fast motion estimates, while cameras eliminate drift. The convenience of this solution is augmented by the associated availability of simultaneous environment mapping. As in the case of AHRS, both, the tightly and loosely coupled navigation solutions exist for the visual-inertial odometry. The loosely coupled solutions, which treat the vision component as a self-contained stand-alone unit, use whether the extended or unscented Kalman Filter.

Combination of a range of exteroceptive sensors (cameras, LiDAR and RADAR) introduces a new class of terrestrial navigation solutions. Under these circumstances, the sensor fusion could be performed at two different abstraction levels, centralized or distributed. The centralized solution imposes high computational requirements. As an alternative, a distributed solution, which fuses sensor data at higher abstraction level, leaves locally executable actions to respective exteroceptive sensors, which in turn provide data to the fusion unit.

The designers of autonomous drones equipped with collision detection and avoidance capabilities must pay attention to avoid phenomena known as blindness (not seeing the obstacle) or object misclassification (mistakenly falsely classify object classes). Failing to identify collision objects or mistakenly under/over estimating their properties leads to a collision state and potential loss of the autonomous drone. Another challenging issue which underlines the necessity of sensor fusion, but this time for object tracking, is the phenomena of ghost obstacles. Their presence leads to potentially hazardous situations, when an autonomous agent abruptly reacts to an emerging ghost object using harsh manoeuvres, which could endanger the drone itself or can negatively impact swarm dynamics.

4.3 Beyond state-of-the-art solutions

COMP4DRONES project addresses improvements in the field of data aggregation and sensor fusion algorithms. One of such improvement is the fusion between Dynamic Vision Sensor and RADAR, anticipated for a robust real-time collision detection. Combining these two exteroceptive sensors in an event based sensory fusion would improve collision detection under low visibility conditions.

Another innovation effort is aimed at fusion of several localization systems to enable precision landing. External localization systems will complement the landing phase where vision augmentation is insufficient due to environmental conditions.

Vision based SLAM algorithms are computationally intensive processes to run on a drone platform. The proposed innovation advances the state-of-the-art by SLAM functionalities capable of real-time execution on an embedded GPU hardware.

A further innovation exploits Deep Neural Network based algorithms using raw sensor data from LiDAR, camera, GNSS receiver and IMU to reach desired position in unknown environment. State-of-the-art navigation solutions grow around detailed and most of the time heavy maps or use a set of predefined actions to be used by the drones to move to its workspace. A learning-based approach would let the drone to exploit all possible actions in line with its dynamics. The drone would then react to the environment changes performing obstacle detection and avoidance.

More advanced beyond state-of-the-art solutions are introduced in the following chapters.

5 Key technologies

The drone components can be grouped following the functions they will provide while considering the sensory systems and control/feedback mechanisms into:

- U-space functional and operational requirements (U1, U2, U3).
- Supporting flight control and systems functions.
- Payload technologies.
- Supporting tools.

This division is in line with the D2.1 [3] identified respective categories of Key Technologies, namely:

- U-space Capabilities as required from regulations (SESAR).
- Required sensory and computing systems addressing system functions described in KET Glossary.
- Payload technologies linked to the previously introduced use case scenarios and another payload.
- Supporting tools.

Table 4.2, 4.3 and 4.4 specifies the Key Technologies for previously identified three groups: U-space Capabilities, System Functions and Payload Technologies.

1. U-space Capabilities	1.1 U1	1.1.1 E-Identification
		1.1.2 Geofencing
		1.1.3 Security
		1.1.4 Telemetry
		1.1.5 Communication, Navigation and Surveillance
		1.1.6 Command and control
		1.1.7 Operations management
	1.2 U1/U2	1.2.1 Tracking
		1.2.2 Emergency Recovery
	1.3 U3	1.3.1 Vehicle to Vehicle communication
		1.3.2 Vehicle to Infrastructure communication (V2I)
		1.3.3 Detect and Avoid

Table 15 Categorization of Key Enabling Technologies for U-space capabilities

2. System Functions	2.1 Flight Control	2.1.1 Intelligent Mission Management
		2.1.2 Intelligent Outer Loop Control
	2.2 Flight Navigation	2.2.1 Take-off
		2.2.2 Landing
		2.2.3 Planning and Scheduling
		2.2.4 Fail-safe Mission
		2.2.5 Contingency Management
		2.2.6 Deconfliction
		2.2.7 Obstacle Detection and Avoidance
	2.3 Positioning	2.3.1 Indoor Positioning
		2.3.2 Geofencing
		2.3.3 Simultaneous Localization and Mapping
		2.3.4 Outdoor positioning and Attitude
	2.4 System and Environment State	2.4.1 Data fusion and processing
		2.4.2 Intelligent Vehicle System Monitoring
	2.5 Coordination	2.5.1 Drone and Rover
		2.5.2 Swarm formation and cooperation
	2.6 Communication	2.6.1 Network Centric Communications Systems
		2.6.2 Over the Horizon Communications
	2.7 Power & Propulsion	2.7.1 Regenerative Energy Storage
		2.7.2 Battery Technology
		2.7.3 Consumable Fuel Cell

		2.7.4 Propellant Storage & Feed
		2.7.5 Propulsion System

Table 16 Categorization of Key Enabling Technologies for System Functions

3.Payload Technologies	3.1 Optical Sensors	3.1.1 Active Optical: LIDAR
		3.1.2 Passive Optical
	3.2 Microwave Sensors	3.2.1 Active Microwave: SAR, IFSAR, and Wind Measurements
		3.2.2 Passive Microwave: Light Weight, Low Loss, Antenna Technology
	3.3 In-situ Sensors	3.3.1 Microsystems-based Chemical Sensor Arrays
		3.3.2 Chem. Detection using Laser Diode Spectroscopy
		3.3.3 Meteorological Data
		3.3.4 CO_2 Detection Using Non-dispersing IR Analyzer
		3.3.6 Trace Gas Detection Using Difference Frequency Generation Lasers
		3.3.7 Trace Gas Detection Using Cavity-enhanced Absorption Spectroscopy
		3.3.8 O2 Detection Using a Quantum Cascade Laser Spectrometer
	3.4 Drop Sondes	3.4.1 Meteorological Sondes/Probes
4.Tools	4.1 V&V for Autonomy Software	
	4.2 Design Tools	

Table 17 Categorization of Key Enabling Technologies for Payload and Tools

Figure 7 introduces the structure of respective key technologies associated with expected utilization within U-space capabilities domain for future drone operations. The three main branches include the Foundation, Initial and Advanced services. The Foundation services account for areas of E-identification, Geofencing, Security, Telemetry, Operations Management, Communication, Navigation, Surveillance, and Command & Control. The branch of Initial services focuses on drone Tracking and Emergency Recovery, while the Advanced services account for Detect and Avoid capabilities augmented by the Vehicle to Vehicle or Vehicle to Infrastructure communication.

Figure 7 Graph of drone capabilities for U-space operations

Table 4.5 shows the frequency of occurrence of respective Key Enabling Technologies (KET) deliverables within the Comp4Drone project. Associated counts indicate the amount of KET deliverables relevant to respective U-space Capabilities.

Key Enabling Technology	FoC
1.1.1 E-Identification	0
1.1.2 Geofencing	6
1.1.3 Security	3
1.1.4 Telemetry	7
1.1.5 Communication, Navigation and Surveillance	9
1.1.6 Command and control	9
1.1.7 Operations management	6
1.2.1 Tracking	4
1.2.2 Emergency Recovery	4
1.3.1 Vehicle to Vehicle communication	1
1.3.2 Vehicle to Infrastructure communication (V2I)	0
1.3.3 Detect and Avoid	10

Table 18 FoC of respective KET deliverables in U-space group

Figure 8 introduces the structure of Systems Functions relevant key technologies. The eight main branches include the Flight Control, Navigation and Positioning, System and Environment, Coordination and Communication, and the novel areas of Propulsion Systems and regenerative Energy Storage. The emerging technologies in flight control domain focus on providing solutions to Intelligent Mission Management and Outer Loop Control. The Navigation branch aims at novel estimation approaches for Take-off and Landing, Flight Planning and Scheduling, Contingency Management, Deconfliction, provisions for Fail-safe Missions supported by Obstacle Detection and Avoidance tools. The Positioning estimates are aimed at advances in Indoor Positioning, Outdoor positioning and Geofencing while utilizing the emerging approaches in Simultaneous Localization and Mapping techniques. The System and Environment Status branch direct the innovation potential towards Intelligent Vehicle System Monitoring and Data handling. The drone Coordination and Communication branch contain emerging technologies in Swarm formation and Cooperation for UAV and UAS platforms exposed to Network Centric and Over the Horizon Communication. The Propulsion System branch aims at innovative Internal Combustion and High-Power Density solutions which would benefit from Regenerative Energy Storage inventions within the fields of Propeller Storage & Feed, Regenerative Fuel Cells, Rechargeable Batteries and Consumable Fuel Cells.

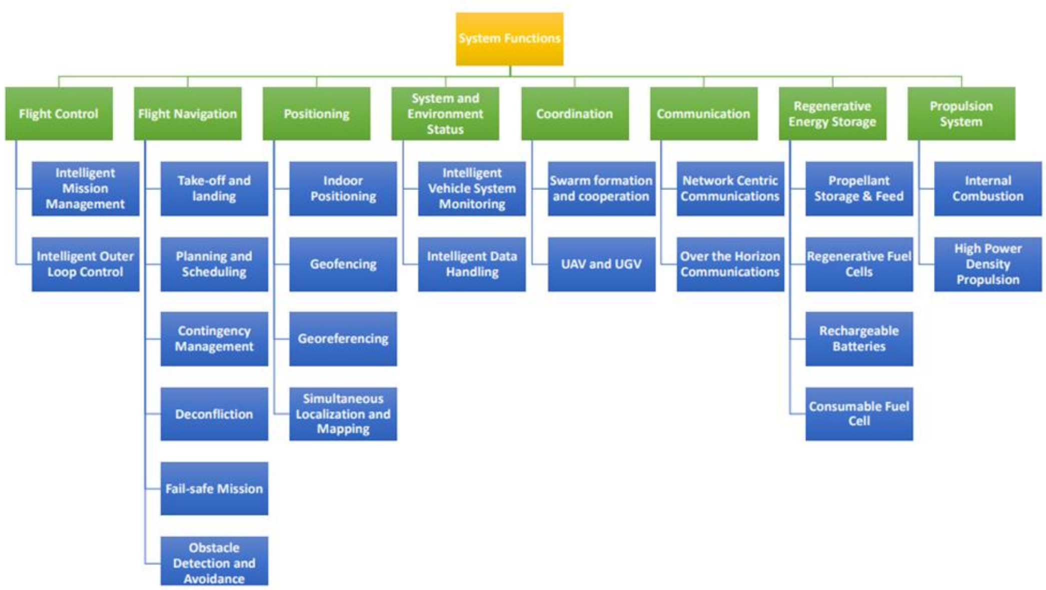

Figure 8 Graph of drone capabilities for System Functions

Table 19 and Table 20 show the frequency of occurrence of respective KET (Key Enabling Technologies) deliverables within the Comp4Drone project. Associated counts indicate the amount of KET deliverables relevant to respective System function capabilities.

Key Enabling Technology	FoC
2.1.1 Intelligent Mission Management	7
2.1.2 Intelligent Outer Loop Control	0
2.2.1 Take-off	8
2.2.2 Landing	8
2.2.3 Planning and Scheduling	11
2.2.4 Fail-safe Mission	10
2.2.5 Contingency Management	5
2.2.6 Deconfliction	4
2.2.7 Obstacle Detection and Avoidance	10
2.3.1 Indoor Positioning	8
2.3.2 Geofencing	3
2.3.3 Simultaneous Localization and Mapping	9

Table 19 FoC of respective KET deliverables in System Functions group – Part I

Key Enabling Technology	FoC
2.3.4 Outdoor positioning and Attitude	5
2.4.1 Data fusion and processing	18
2.4.2 Intelligent Vehicle System Monitoring	2
2.5.1 Drone and Rover	4
2.5.2 Swarm formation and cooperation	5
2.6.1 Network Centric Communications Systems	2
2.6.2 Over the Horizon Communications	2
2.7.1 Regenerative Energy Storage	0
2.7.2 Battery Technology	0
2.7.3 Consumable Fuel Cell	0
2.7.4 Propellant Storage & Feed	0
2.7.5 Propulsion System	0

Table 20 FoC of respective KET deliverables in System Functions group – Part II

Emerging Payload Technologies can be classified into four main branches, namely the Optical, Microwave, In-situ and External sensors. The Optical and Microwave branches aim at technological innovations active and passive sensing technologies. The In-situ sensors branch concentrates on innovations in Chemical Detection in conjunction with Meteorological data. The final innovative branch of External sensors aims at Geophysical and Perimeter Sensors, Drop Sondes and Weather stations. Figure 9 introduces a graph of Payload Technologies.

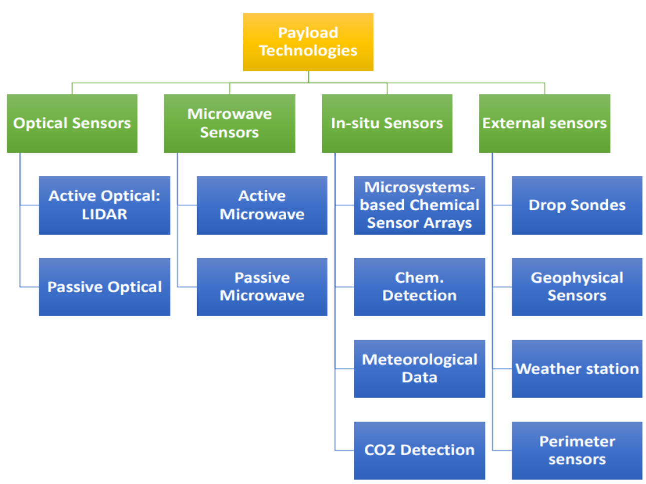

Figure 9 Graph of drone capabilities for Payload

Table 21 shows the frequency of occurrence of KET deliverables within the Comp4Drone project relevant to respective drone carried Payload.

Key Enabling Technology	FoC
3.1.1 Active Optical: LIDAR	1
3.1.2 Passive Optical	5
3.2.1 Active Microwave: SAR, IFSAR, and Wind Measurements	0
3.2.2 Passive Microwave: Light Weight, Low Loss, Antenna Technology	0
3.3.1 Microsystems-based Chemical Sensor Arrays	0
3.3.2 Chem. Detection using Laser Diode Spectroscopy	0
3.3.3 Meteorological Data	0
3.3.4 CO2 Detection Using Non-dispersing IR Analyzer	0
3.3.6 Trace Gas Detection Using Difference Frequency Generation Lasers	0
3.3.7 Trace Gas Detection Using Cavity-enhanced Absorption Spectroscopy	0
3.3.8 O2 Detection Using a Quantum Cascade Laser Spectrometer	0

Table 21 Frequency of occurrence of respective KET deliverables in Payload group

Table 22 shows the frequency of occurrence of KET deliverables within the Comp4Drone project relevant to design Tools.

Key Enabling Technology	FoC
4.1 V&V for Autonomy Software	0
4.2 Design Tools	2

Table 22 Frequency of occurrence of respective KET deliverables in Design Tools group

6 Components portfolio

6.1 U-space components

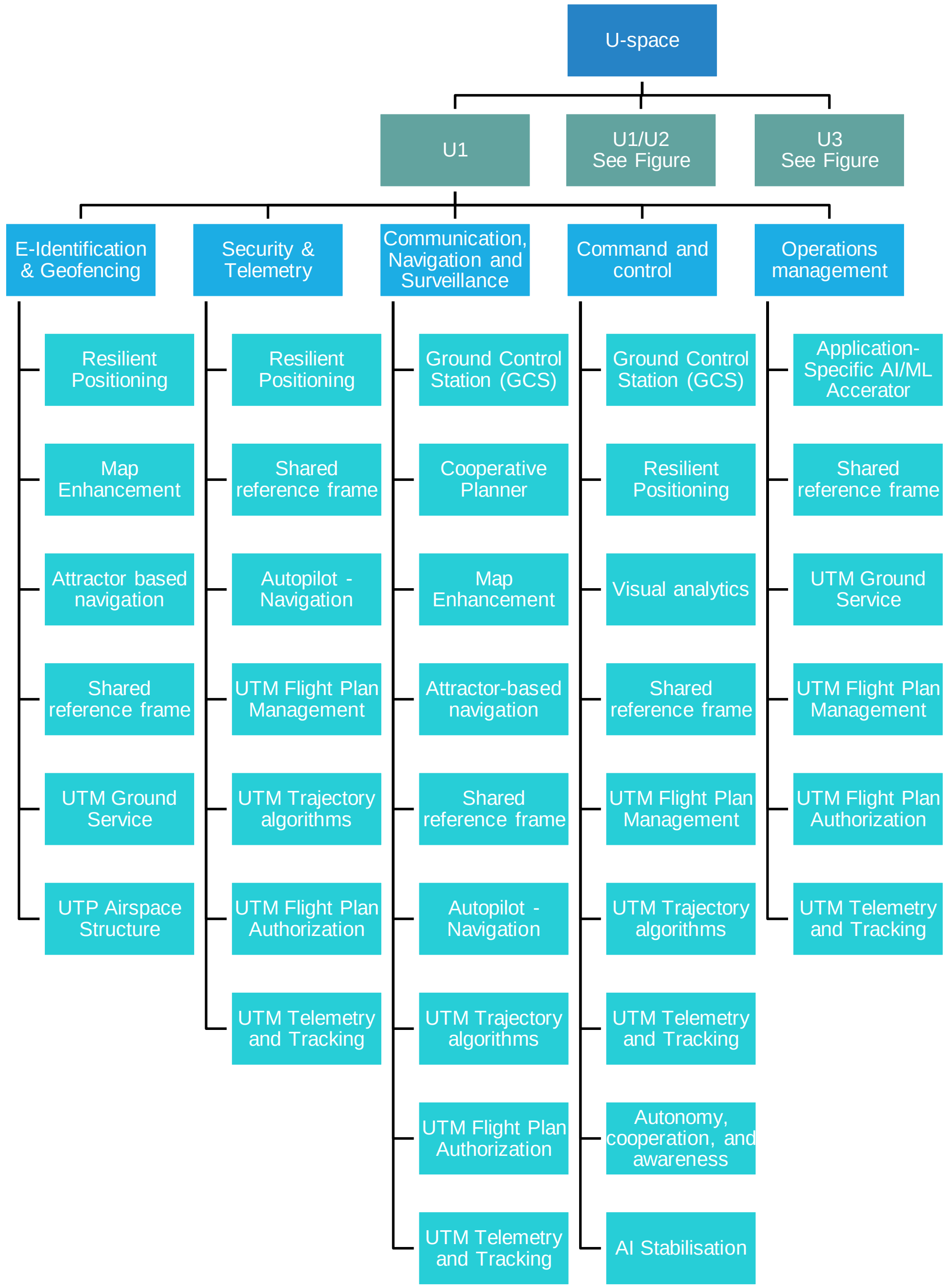

Figure 10 KET deliverables in U1

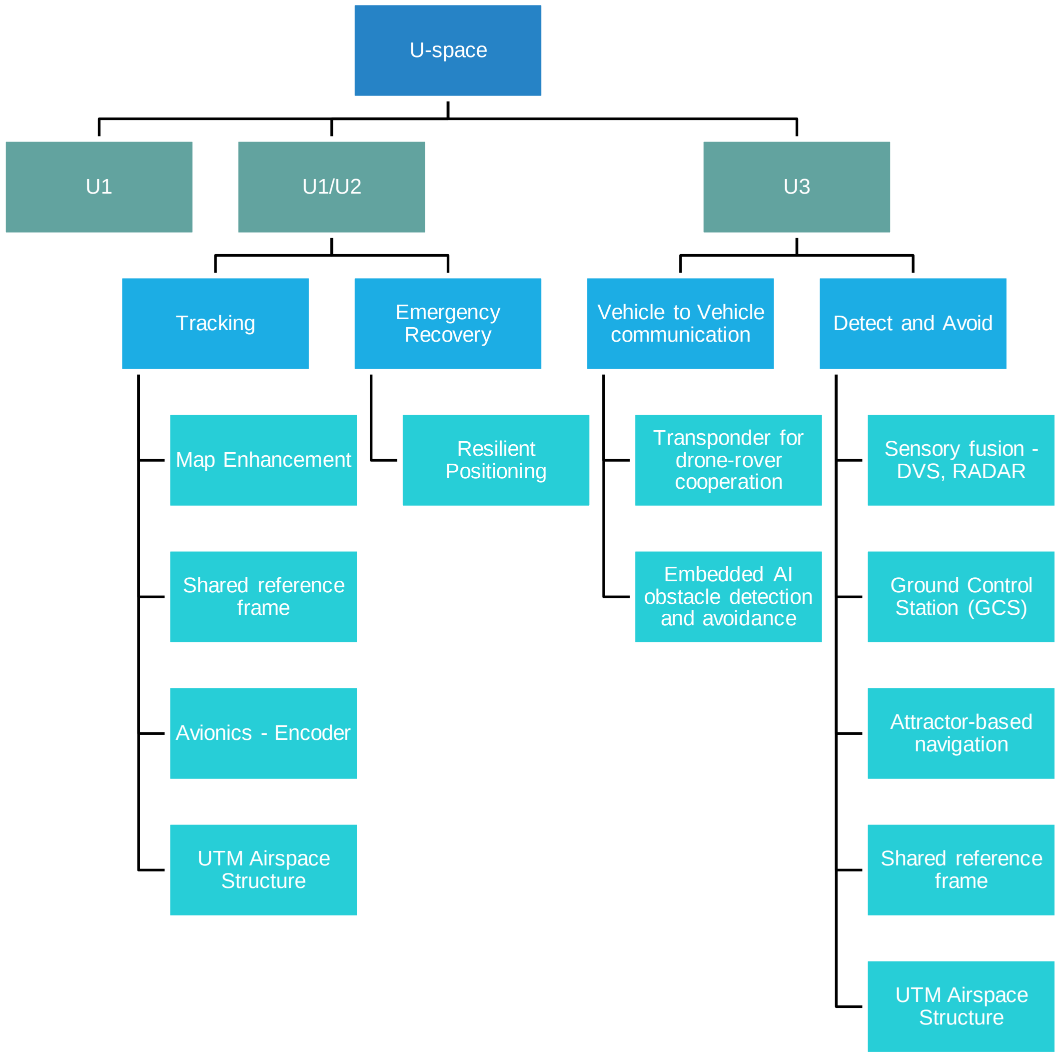

Figure 11 KET deliverables in U1/U2 and U3

6.1.1 U1

6.1.1.1 WP4-14 Map Enhancement

<table>
<tr><td>ID</td><td colspan="2">WP4-14</td><td>Category</td><td>U-space</td><td>KET</td><td>1.1.2 Geofencing
1.1.5 Communication, Navigation and Surveillance
1.2.1 Tracking</td></tr>
<tr><td>Name</td><td colspan="2">Map Enhancement</td><td>Licence</td><td>BSD</td><td>TRL</td><td>4</td></tr>
<tr><td>Owner</td><td colspan="2">ALM</td><td>Contributor</td><td>ALM</td><td>Contact</td><td>ALM</td></tr>
<tr><td colspan="7">Functional and non-functional requirements</td></tr>
<tr><td colspan="2">REQ ID</td><td colspan="5">Short description</td></tr>
<tr><td colspan="2">UC4-PRF-03</td><td colspan="5">Common model creation: Point of Interest determination</td></tr>
<tr><td colspan="2">UC4-PRF-04</td><td colspan="5">Common model creation: SLAM (Simultaneous Localization And Mapping) (aerial platform)</td></tr>
<tr><td colspan="2">UC4-PRF-05</td><td colspan="5">Common model creation: SLAM (SLAM Modelling and Simulation) (semantical rich modelling)</td></tr>
<tr><td colspan="2">UC4-SEC-01</td><td colspan="5">Autonomy: Strategy and path planning</td></tr>
<tr><td colspan="2">UC4-PRF-10</td><td colspan="5">User Interfaces: High level mission control</td></tr>
<tr><td colspan="2">UC4-PRF-11</td><td colspan="5">User Interfaces: Live model visualisation</td></tr>
<tr><td colspan="2">UC4-PRF-13</td><td colspan="5">Model creation is live, semi-real-time view of the environment</td></tr>
<tr><td colspan="2">UC4-INT-05</td><td colspan="5">Accuracy of the mapping and point of interest determination, as carried out by the drone shall be such that it can support human access and operation</td></tr>
<tr><td colspan="2">UC4-PRF-15</td><td colspan="5">User interface data is timely updated and rich enough to provide sufficient situational awareness and control.</td></tr>
<tr><td colspan="7">Technical specifications & Interfacing</td></tr>
<tr><td colspan="2">Category</td><td colspan="5">System</td></tr>
<tr><td colspan="2">Type</td><td colspan="5">Software</td></tr>
<tr><td colspan="2">Input</td><td colspan="5">ROS (Robot Operating System) TF (Transform)/map data, shared among multiple robots</td></tr>
<tr><td colspan="2">Output</td><td colspan="5">ROS TF/map data, also shared among multiple robots</td></tr>
<tr><td colspan="2">Input Interface</td><td colspan="5">ROS messages / ROS bridge-nodes / MQTT (Message Queuing Telemetry Transport)</td></tr>
<tr><td colspan="2">Output Interface</td><td colspan="5">ROS messages / ROS bridge-nodes / MQTT</td></tr>
<tr><td colspan="7">Specific standard and regulation requirements (Optional)</td></tr>
<tr><td colspan="2"></td><td colspan="5">NIL</td></tr>
<tr><td colspan="7">Specification</td></tr>
<tr><td colspan="7">There are various sources for the creation of information-rich maps/grids, which can be used for SLAM and navigation. This component explicitly focuses on a generic way of providing query-like access to this information, providing temporal, shared situational awareness. This is achieved by leveraging the current map meta-information (timestamps and frame identification number), augmented by additional meta-information per map-layer, e.g. trustworthiness, resolution, capture-time-range, etc. Especially additional information on whether the information is based on predictors or real sensors is relevant. Using this extended meta-info, a query service is provided through which map-products can be obtained for usage in navigation and as an input for SLAM algorithms. Input map information can come from a variety of sources, including multiple robots, existing 3D (Three-Dimensional) & BIM models, hardware-in-the-loop simulation, semantic maps, AI (Artificial Intelligence) & ML (Machine Learning) trained models.</td></tr>
<tr><td colspan="7">Improvements</td></tr>
<tr><td colspan="7">Currently, there are some ROS libraries for map merging, however, there are only a few fully-functional solutions that aim at shared situational awareness at a map level. Furthermore, there are some</td></tr>
</table>

experiments for an "environment descriptor", an approach for semantic maps. This component is aiming for a more generic, complete map enhancement service for seamless merging, enhancing, predicting maps, including more semantically rich logic.

6.1.1.2 WP4-15 Visual analytics

ID	WP4-15	Category	U1	KET	1.1.6 Command and control
Name	Visual analytics	Licence	BSD, Apache-2.0	TRL	4
Owner	ALM, OSRF	Contributor	ALM	Contact	ALM

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-PRF-10	User Interfaces: High level mission control
UC4-PRF-11	User Interfaces: Live model visualisation
UC4-INT-04	UI through laptop/workstation
UC4-PRF-13	Model creation is live, semi-real-time view of the environment
UC4-PRF-15	User interface data is timely updated and rich enough to provide sufficient situational awareness and control.
Technical specifications & Interfacing	
Category	System
Type	Software
Input	ROS TF (Transformation package) / map data, User-input
Output	rViz (ROS package for 3D visualization) / Gazebo visualisation
Input Interface	ROS messages
Output Interface	ROS messages
Specific standard and regulation requirements (Optional)	
	NIL
Specification	
Visual analytics module for mission control and system monitoring. A hardware-in-the-loop simulation environment can be used as a base for such a GUI.	
Improvements	
Current state-of-the-art in ROS is rViz, with various plugins. Some Gazebo integration plugins exist to setup a hardware-in-the-loop infrastructure with real-life robots, however, there is still work necessary to produce an easily accessible standard setup.	

6.1.1.3 WP4-33 Autonomy, cooperation, and awareness

ID	WP4-33	**Category**	U-space System	**KET**	1.1.6 Command and control 2.1.1 Intelligent Mission Management 2.2.7 Obstacle Detection and Avoidance
Name	Autonomy, cooperation, and awareness	**Licence**	Open Source	**TRL**	4
Owner	UNIVAQ	**Contributor**	UNIVAQ	**Contact**	UNIVAQ

Functional and non-functional requirements

REQ ID	**Short description**
UC5-DEM10-DSG-02	Efficient digital implementation of discrete–time controllers on FPGAs
UC5-DEM10-UR-01	Compensation and rejection of environmental perturbations, measurement uncertainties, and possible faults
UC5-DEM10-FNC-09	Autonomous and cooperative flight aerial-terrestrial drones, reference generation for autonomous navigation
UC5-DEM10-OPR-02	Management of critical situations with improved situation awareness
UC5-DEM10-OPR-03	Management of critical situations with power autonomy awareness

Technical specifications & Interfacing

Category	Control
Type	Software & Hardware design files
Input	Measurements from sensor signals
Output	Control actions
Input Interface	Subscriber messages
Output Interface	Publisher messages

Specification

A set of algorithms will provide functional requirements (autonomous and cooperative actions, reference generation), operational requirements (management of critical situations with improved situation awareness and with power autonomy awareness) and usability requirements (compensation and rejection of environmental perturbations, measurement uncertainties, and possible faults). Finally, they will satisfy given design constraints (efficient digital implementation of discrete–time controllers on FPGAs).

Improvements

The agents will have the capability of collaborating and facing scenarios having awareness of the situation, taking autonomous decisions. For example, obstacles costructing the passage will be avoided considering the situation of the agents in the scenario, and the energy available in their batteries. Also, perturbation rejections will be situation and energy aware. The algorithms to take decisions will be implemented efficiently onboard, and the expensive calculations will take advantage of pipelining or paralleling implementations on FPGAs.

6.1.2 U1/U2

6.1.2.1 WP4-01 Sensory fusion – Dynamic Vision Sensor (DVS), RADAR

ID	WP4-01	**Category**	U2	**KET**	1.3.3 Detect and Avoid
Name	Sensory fusion – DVS, RADAR	**Licence**	Software released under MIT License, Hardware is proprietary	**TRL**	5
Owner	TUD, IMEC-NL	**Contributor**	IMEC-NL, TUD	**Contact**	IMEC-NL

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-DEM2-PRF-03	This component exploits sensory fusion between a dynamic vision sensor (DVS240) [4] [5] and a radar (24Ghz) for robust real-time collision avoidance. By exploiting complementary sensors (vision and radar) this component can detect fixed and moving obstacles in low visibility conditions, low-light conditions, and in different weather conditions (fog, rain, cluttered environment).
UC4-DEM2-PRF-03 **UC4-DEM2-PRF-01**	Radar: Detect fixed and moving obstacles (max speed 10 km/h) in a range of 30 m with a range resolution of 50 cm. The angular resolution should be less than 10 deg. Field of view should be 80 deg horizontal and 20 deg vertical. DVS: The resolution will be determined by the optics chosen for the applications. Current version comes with the following parameters: Lens [2.8mm 3MP 1/2.5'' IRy]: 100 deg horizontal, 65 deg vertical, with a resolution of 0.55 deg/pixel. Lens [1.8mm 5MP 1/2.5'' IR Wide FoV]: 130 deg horizontal, 100 deg vertical, with a resolution of 0.78 deg/pixel. Due to the low latency of the sensor, speed is not expected to be a constraint here.
Technical specifications & Interfacing	
Category	Guidance
Type	Software & Hardware
Input	Complex (I/O) radar samples, Address Event Representation of contrast changes from DVS240
Output	Tracking obstacles with the following quantities: distance, angle, speed, magnitude, confidence of detection
Input Interface	ROS custom message (USB (Universal Serial Bus) interface for both camera and radar)
Output Interface	ROS custom message
Specific standard and regulation requirements (Optional)	
U-space	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 (International Civil Aviation Organization) RPAS (Remotely Piloted Aircraft System) Manual [6]: terrain and obstacles, hazardous meteorological conditions, ground operations and other airborne hazards.
Specification	
This component exploits sensory fusion between a dynamic vision sensor (DVS240) and a radar (24Ghz) for robust real-time collision avoidance. By exploiting complementary sensors (vision and radar) this component can detect fixed and moving obstacles in low visibility conditions, low-light	

conditions, and in different weather conditions (fog, rain, cluttered environment). It works computing optic-flow using monocular vision with an event-based silicon retina.
Improvements
State-of-the-art components rely on single sensor (LiDAR / RADAR / Camera / ToF (Time-of-Flight)) for collision avoidance and do not rely on event-based sensing technologies. This component exploits a novel Dynamic Vision Sensor [7], that offers high-dynamic range (120dB), low-latency performance (tens of microsecond in bright light conditions) and low-data rate output (compression of data), in conjunction with state-of-the-art automotive graded Radar sensor. The novel interface of the radar sensor enables event-based sensory fusion algorithms with the dynamic vision sensor, allowing for a reduced data rate, low-power consumption and low-latency output. All these properties will increase overall safety of the collision avoidance system. This component can also exploit FPGA dedicated hardware for running the sensory fusion algorithm in a lower power and lower latency mode.

6.1.2.2 WP4-11 Resilient Positioning

ID	WP4-11	**Category**	U2 Flight Navigation	**KET**	1.2.2 Emergency Recovery 2.2.4 Fail-safe Mission
Name	Resilient Positioning	**Licence**	Proprietary	**TRL**	4
Owner	MODIS	**Contributor**	MODIS	**Contact**	MODIS

Functional and non-functional requirements	
REQ ID	**Short description**
UC5-DEM1-FNC-01	Reliable GPS Messages: Detection of navigation system failures due to GPS signal hijacking or system malfunction
UC5-DEM1-FNC-02	Watchdog module: reaction to GPS Signal hijacking (e.g. start/enable geomagnetic based D-SLAM)
UC5-DEM1-FNC-03	AI system: autonomous decision making based on failure detection and alerts shall integrate with D-SLAM algorithms and control
UC5-DEM1-FNC-04	D-SLAM: Simultaneous Localization and Mapping algorithms shall allow for proper localization of the drone even in presence of GPS failures.
Technical specifications & Interfacing	
Category	Navigation
Type	Software
Input	GPS signal, sensor data (odometry, geomagnetical measurements)
Output	Space coordinates, alerts
Input Interface	SW APIs
Output Interface	SW APIs
Specific standard and regulation requirements (Optional)	
	NIL
Specification	
The component will be designed as an embedded, AI software module that 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 and react accordingly. Resilience will be improved via mirroring with a SLAM technology based on geomagnetical information. As a result, a continuous localization of the drone will be ensured.	
Improvements	
During the project will be evaluated, with the aim of implement them in UC5 demonstrators, AI-based algorithms to detect GPS-Spoofing attacks.	

6.1.2.3 WP4-22 Shared reference frame

ID	WP4-22	**Category**	U1/U2	**KET**	1.1.2 Geofencing 1.1.4 Telemetry 1.1.5 Communication, Navigation and Surveillance 1.1.6 Command and control
Name	Shared reference frame	**Licence**	BSD	**TRL**	4
Owner	ALM	**Contributor**	ALM	**Contact**	ALM
Functional and non-functional requirements					
REQ ID	**Short description**				
UC4-PRF-04	Common model creation: SLAM (aerial platform)				
UC4-PRF-05	Common model creation: SLAM (SLAM Modelling and Simulation) (semantical rich modelling)				
UC4-PRF-06	Autonomy: Waypoint navigation in (local) reference framework				
UC4-PRF-08	Autonomy: Reference framework definition (indoor, non-GPS)				
UC4-PRF-11	User Interfaces: Live model visualisation				
UC4-INT-05	Accuracy of the mapping and point of interest determination, as carried out by the drone shall be such that it can support human access and operation				
UC4-PRF-15	User interface data is timely updated and rich enough to provide sufficient situational awareness and control.				
UC4-SEC-04	Environment is in-door, non-public space				
UC4-SEC-05	Environment is unknown, cluttered, radio-hampering, GPS-denied				
Technical specifications & Interfacing					
Category	System				
Type	Software				
Input	ROS TF/map data, shared among multiple robots				
Output	ROS TF/map data, shared among multiple robots				
Input Interface	ROS messages / ROS bridge-nodes / MQTT				
Output Interface	ROS messages / ROS bridge-nodes / MQTT				
Specific standard and regulation requirements (Optional)					
	NIL				

Specification
Shared reference frame definition for in-door, GPS-denied, cluttered, unknown environment. Base station needs to share its pose/position estimate with all other drones during operation. Localization challenge, when beacons are moving in the map-frame.
Improvements
Current state-of-the-art for such reference frames: ROS Movebase's odom in map frame updates. However, sharing such a reference frame is not common yet. Especially under GPS denied environment. (ROS is mostly aimed at using Odom/IMU/Visual/LIDAR)

6.1.2.4 WP4-27 UTM Ground Service

ID	WP4-27	**Category**	U2	**KET**	Ground Service (UTM Ground Service)
Name	UTM Ground Service	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra

Functional and non-functional requirements	
REQ ID	**Short description**
DEM1-FNC-27	UTM system shall calculate the conformance of the drone and rise an alert in case of horizontal, vertical or longitudinal non-conformance.
DEM1-DSG-2	The area of operation shall be covered by the UTM system with a resolution of 5x5m2
DEM1-P&C-2	The UTM shall be compliant with European Union regulations
Technical specifications & Interfacing	
Category	Geographical
Type	Software
Input	Embedded software. Safe altitude for very waypoint of a Flight Plan is internally calculated automatically.
Output	Internal calculations set a minimum flight altitude to avoid ground risks
Input Interface	UTM HMI (Human Machine Interface) UTM HMI: Mavlink file import REST (Representational state transfer): calling Flight Planning API
Output Interface	UTM HMI UTM HMI: Mavlink file import REST: calling Flight Planning API
Specific standard and regulation requirements (Optional)	
U-space	NIL
Specification	
Ground service provides diverse functionalities both in pre-tactical and in tactical phases. Precise Ground data model gives UTM system the ability of a precise calculations both in pre-tactical and in tactical phases of the flight.	
Improvements	
Ground Service should be modified to fit demo flight area ground requirements. A specific Ground model (terrain plus obstacles) should be deployed in the system. This is necessary for both pre-tactical and tactical phases within UTM System.	

6.1.2.5 WP4-28 UTM Airspace Structure

ID	WP4-28	**Category**	U2	**KET**	Airspace structure
Name	UTM Airspace Structure	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra

Functional and non-functional requirements	
REQ ID	**Short description**
DEM1-FNC-26	UTM system shall permanently monitor all tracks to determine its conformance and detect any geofence violation or tactical conflict
DEM1-FNC-31	UTM shall be able to receive new or modified geofences in the UTM format from HORUS system and create them in the airspace.
DEM1-FNC-1	UTM shall be able to receive the delete input from HORUS system of a geofence within its jurisdiction.
DEM1-FNC-9	HORUS shall send the incident area geometries and required characteristics over UTM Hub API
DEM1-FNC-10	The HORUS HMI shall show the drones flying nearby the incident geofenced area
DEM1-FNC-12	The UTM system shall provide/be provided with the airspace status (official) in real time – public API drones.enaire.es
DEM1-FNC-14	The UTM shall modify airspace allocation when a Flight Manager or Operation Manager becomes unavailable.
DEM1-P&C-2	The UTM shall be compliant with European Union regulations
Technical specifications & Interfacing	
Category	Geographical-Regulatory
Type	Software
Input	Embedded software. Airspace structure is displayed in UTM HMI. Authorities can add/modify/delete these geofenced areas depending on their jurisdiction/province.
Output	Airspace structure information is shown to the UTM users.
Input Interface	UTM HMI REST: calling Geofencing Service API REST: New Flight Plan/Strategic Deconfliction services
Output Interface	UTM HMI REST: calling Geofencing Service API REST: New Flight Plan/Strategic Deconfliction services (UTM response)
Specific standard and regulation requirements (Optional)	
U-space	System adaptation should follow current Spanish Airspace regulations and structure. This information is provided by Spanish ANSP.

Specification
Airspace structure should be guaranteed. Obstacles and geofences should be properly marked in the UTM HMI (Human Machine Interface) for safety and awareness purposes. Flight rules (pre-flight phase) and alerts (flight phase) should be applied based on this airspace structure. Here lies the importance of a proper airspace structure management.
Improvements
The UTM system will display the most up-to-date airspace structures. Updates from Spanish AIP source will be drawn in UTM HMI in the whole area where all the demo exercises will be performed. In the other hand, HORUS system will be granted with the ability of geofence management (geofence creation, modification and delete) to enable the full process of Geofence Management during the demo exercises. This will be granted by two different ways: 1º By using UTM Geofence Management HMI and, 2º By using UTM Geofence Management API.

6.1.2.6 WP4-29 UTM Flight Plan Management

ID	WP4-29	**Category**	U2	**KET**	Flight Plan Management (UTM Flight Plan Assessment Service)
Name	UTM Flight Plan Management	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra

Functional and non-functional requirements	
REQ ID	**Short description**
DEM1-INT-3	UTM system shall be able to receive flight plan created by CMPD (Centro de Misión de Proceso de Datos) in the predefined format, calculate and request for authorization
DEM1-FNC-18	UTM system shall evaluate the validity of the flight plans requested by CMPD. The possible outputs shall be planned, manual or denied status
DEM1-FNC-19	UTM system shall provide alternative flight plans when possible if the original flight plan requested by CMPD was denied.
DEM1-FNC-20	UTM system shall be able to receive the authorization request for an alternative flight plan proposed to the CMPD. The complete authorization process shall be performed
DEM1-FNC-21	UTM shall provide the state/authority with each manual flight plan for its manual authorization.
DEM1-P&C-1	VLOS requirements & regulation requirements, according to "Real Decreto" 1036/17, signed on December 17th 2017"
DEM1-SEC-2	The drone shall fly following the flight plan created and authorised, as well as the contingency route to recover the RPA (Remotely Piloted Aircraft) in the event of loss link.
DEM1-FNC-14	The UTM shall modify airspace allocation when a Flight Manager or Operation Manager becomes unavailable.
DEM1-FNC-15	The UTM shall detect trajectory conflicts between different agents
DEM1-FNC-19	UTM system shall provide alternative flight plans when possible if the original flight plan requested by CMPD was denied.
DEM1-FNC-22	Flight plans in PLANNED status are authorized and ready to flight once its start time is reached
Technical specifications & Interfacing	
Category	Flight Planning
Type	Software
Input	Flight Plan file (following UTM schema)
Output	Flight Planning Status & Updates (UTM Responses)
Input Interface	UTM HMI UTM HMI: Mavlink file import REST: calling Flight Planning API
Output Interface	UTM HMI UTM HMI: UTM Flight Planning Mavlink file export REST: Flight Planning API communications
Specific standard and regulation requirements (Optional)	
U-space	Spanish "Real Decreto Real Decreto 1036/2017" [8]
Specification	

Flight rules for a proper Flight Planning Management should be implemented. Rules to be applied should comply Spanish current regulations. Due to regulations are being continuously upgraded, flight rules should be reviewed before demo exercises take place.
Improvements
Flight Plan Assessment service adaptation to adequate to Spanish National regulations. Rules and policies should be reviewed and adapted to enable a proper execution of all the **COMP4DRONES** demo exercises.

6.1.2.7 WP4-30 UTM Trajectory algorithms

<table>
<tr><td>ID</td><td>WP4-30</td><td>Category</td><td>U2</td><td>KET</td><td>Alarms and trajectory algorithms (UTM Air Monitoring Service & Registration Service)</td></tr>
<tr><td>Name</td><td>UTM Trajectory algorithms</td><td>Licence</td><td>Proprietary</td><td>TRL</td><td>6</td></tr>
<tr><td>Owner</td><td>Indra</td><td>Contributor</td><td>Indra</td><td>Contact</td><td>Indra</td></tr>
<tr><td colspan="6">Functional and non-functional requirements</td></tr>
<tr><td colspan="2">REQ ID</td><td colspan="4">Short description</td></tr>
<tr><td colspan="2">DEM1-FNC-28</td><td colspan="4">UTM system shall rise an alarm when a drone track violates an active geofence.</td></tr>
<tr><td colspan="2">DEM1-FNC-29</td><td colspan="4">UTM system shall rise an alarm when there is a tactical conflict between two or more drones.</td></tr>
<tr><td colspan="2">DEM1-FNC-30</td><td colspan="4">UTM shall send the tracking and alert information to the CMPD and HORUS systems.</td></tr>
<tr><td colspan="2">DEM1-FNC-15</td><td colspan="4">The UTM shall detect trajectory conflicts between different agents</td></tr>
<tr><td colspan="2">DEM1-SEC-2</td><td colspan="4">The drone shall fly following the flight plan created and authorised, as well as the contingency route to recover the RPA in the event of loss link.</td></tr>
<tr><td colspan="6">Technical specifications & Interfacing</td></tr>
<tr><td colspan="2">Category</td><td colspan="4">Software</td></tr>
<tr><td colspan="2">Type</td><td colspan="4">Software</td></tr>
<tr><td colspan="2">Input</td><td colspan="4">Embedded software</td></tr>
<tr><td colspan="2">Output</td><td colspan="4">During Flight Planning approval, internal calculations are performed</td></tr>
<tr><td colspan="2">Input Interface</td><td colspan="4">UTM HMI
REST: calling Flight Planning API
REST: New Flight Plan/Strategic Deconfliction services</td></tr>
<tr><td colspan="2">Output Interface</td><td colspan="4">UTM HMI
REST: calling Flight Planning Service API
REST: New Flight Plan/Strategic Deconfliction services (UTM response)</td></tr>
<tr><td colspan="6">Specific standard and regulation requirements (Optional)</td></tr>
<tr><td colspan="2">U-space</td><td colspan="4">NIL</td></tr>
<tr><td colspan="6">Specification</td></tr>
<tr><td colspan="6">Trajectory algorithms will enable UTM detecting possible conflicts and raise specific alarms when results of the calculations detect that a specific alert should be triggered.</td></tr>
<tr><td colspan="6">Improvements</td></tr>
<tr><td colspan="6">New Trajectory prediction algorithms in the Air Monitoring Service and specific dynamics definitions in the Registration Service will be implemented for both multirotor and fixed wing UAVs. New developments will be needed for handling all this information with the CMPD.</td></tr>
</table>

6.1.2.8 WP4-31 UTM Flight Plan Authorization

ID	WP4-31	**Category**	U2	**KET**	Flight Plan Status notifications (UTM Flight Plan Authorization Service)
Name	UTM Flight Plan Authorization	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra

Functional and non-functional requirements	
REQ ID	**Short description**
R-IND-40	UTM shall send CMPD a notification message with the complete output of the authorization process.
DEM-SEC-1	The drone shall be identified and registered in the UTM platform
DEM1-FNC-2	The drone operator shall create a flight plan based on the incident communicated by HORUS.
DEM1-PRF-1	The time elapsed from the permission to take off and the video display will be: 10 minutes (pre-flight) + 1 minute for each kilometre away from the take-off zone to the point of the incident
DEM1-P&C-1	VLOS requirements & regulation requirements, according to "Real Decreto" 1036/17, signed on December 17th 2017" [8]
DEM1-SEC-2	The drone shall fly following the flight plan created and authorised, as well as the contingency route to recover the RPA in the event of loss link.

Technical specifications & Interfacing	
Category	Software/Regulatory
Type	Software
Input	Flight Plan file (following UTM schema)
Output	Flight Planning Status & Updates (UTM Responses)
Input Interface	
Output Interface	

Specification
Flight Plan authorization process have lots of steps (some internal and some others need to be communicated to the end users). All actors involved should have the ability to obtain Flight Plan status.

Improvements
New notification flows from UTM system to CMPD will be implemented for managing the whole Flight Plan Authorization process.

6.1.2.9 WP4-32 UTM Flight Plan Authorization

ID	WP4-32	**Category**	U2	**KET**	Telemetry and tracking handling (UTM Tracking service)
Name	UTM Telemetry and Tracking	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra
Functional and non-functional requirements					
REQ ID	**Short description**				
DEM1-FNC-24	UTM shall support the reception of the drone telemetry from CMPD in the UTM format.				
DEM1-FNC-25	UTM shall keep an only track object for each cooperative target. It shall associate all data inputs referring to a same drone to a unique central track.				
DEM1-P&C-1	VLOS requirements & regulation requirements, according to "Real Decreto" 1036/17, signed on December 17th 2017" [8]				
DEM1-FNC-10	The HORUS HMI shall show the drones flying nearby the incident geofenced area				
DEM1-FNC-12	The UTM system shall provide/be provided with the airspace status (official) in real time – public API drones.enaire.es				
DEM1-FNC-16	The UTM shall detect unauthorized behaviour by any of the handled agents				
Technical specifications & Interfacing					
Category	Communication				
Type	Software				
Input	Drone position (telemetry or Track)				
Output	REST/MQTT				
Input Interface	REST/MQTT				
Output Interface	All UTM Traffic Information. (UTM Full/Enhanced Tracks)				
Specific standard and regulation requirements (Optional)					
U-space	N/A				
Specification					
UTM system receives drone telemetry/track from our own GCS (Ground Control Station) / flying app. It is also capable of receiving track/telemetry from 3rd party USPs (Unmanned Service Provider) or GCSs. The UTM system may receive tracking information from various sensors and merge (when possible) the track in a unique central track for each flying drone.					
Improvements					
UTM system should be modified for receiving drone telemetry/track in UTM format coming from the CMPD system.					

6.1.3 U3

6.1.3.1 WP4-10 Cooperative Planner

ID	WP4-10	**Category**	U1 & U3	**KET**	1.1.5 Communication, Navigation and Surveillance 1.3.3 Detect and Avoid
Name	Cooperative Planner	**Licence**	BSD	**TRL**	4
Owner	ALM	**Contributor**	ALM	**Contact**	ALM

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-PRF-03	Common model creation: Point of Interest determination
UC4-SEC-01	Autonomy: Strategy and path planning
UC4-INT-07	The system consists of at least one rover, and two drones.
UC4-PRF-17	The ambition is to have a system that can be controlled by a single, trained operator from the control station – by providing a shared planner the workload for a human operator is reduced.
Technical specifications & Interfacing	
Category	System
Type	Software
Input	ROS TF/map data, shared among multiple robots
Output	ROS navigation goals, also shared among multiple robots
Input Interface	ROS messages / ROS bridge-nodes / MQTT
Output Interface	ROS messages / ROS bridge-nodes / MQTT
Specific standard and regulation requirements (Optional)	
	NIL
Specification	
This component provides support for cooperation between drones and rovers, on a (global) planning level. By sharing a drone's plans, in a standardized manner, more optimal group behaviour can be achieved, through a group planner component. By designing this group planner through multi-agent techniques, this planner can be distributed over multiple robots.	
Improvements	
In the research fields of game-theory, multi-agent systems, and service orchestration, several strategies for cooperation have been developed. Most of these strategies have not yet been applied within a robotic environment, nor has there been much focus on cooperating robots. An exception to this is the field of Robotic Soccer and similar competitions and challenges, which apply voting-based planning through shared playbooks and role-assignment. This component will allow trying out such algorithms and strategies for any ROS-based system, by extending the navigation stack with a cooperative planner, on top of the current standard local and global planner.	

6.2 System function components

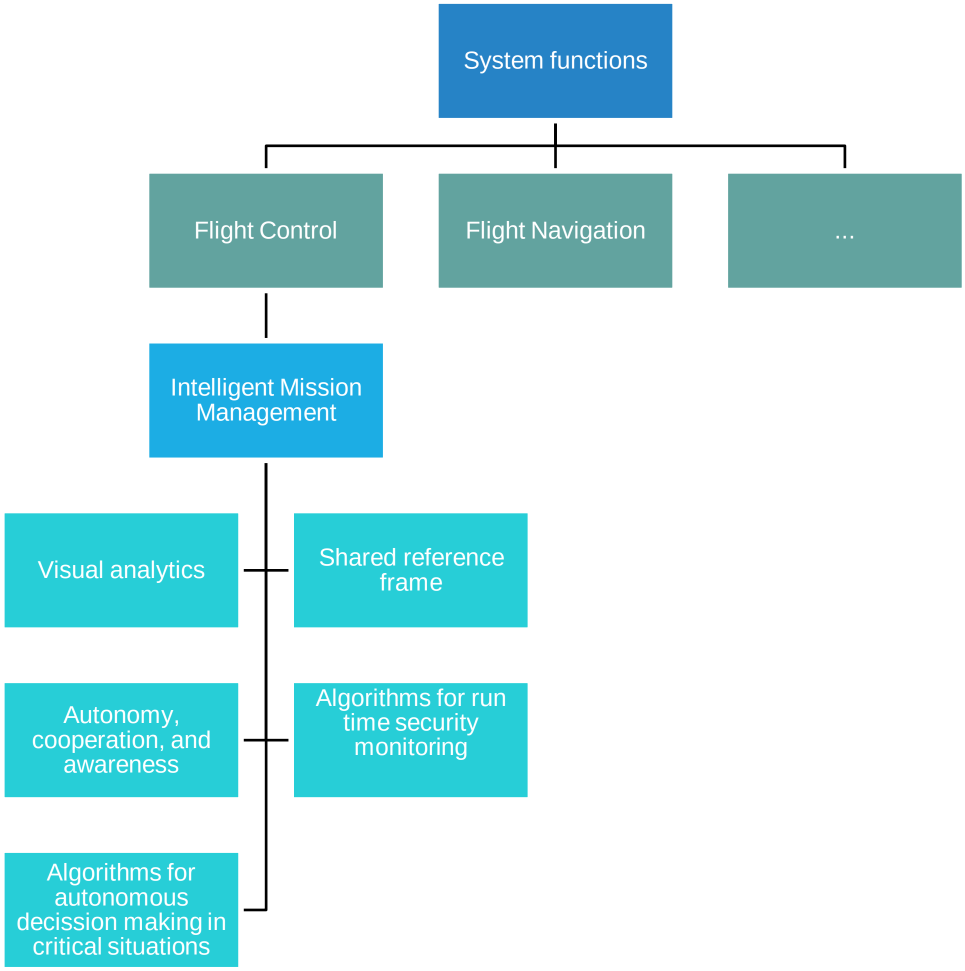

Figure 12 : KET deliverables in Flight Control

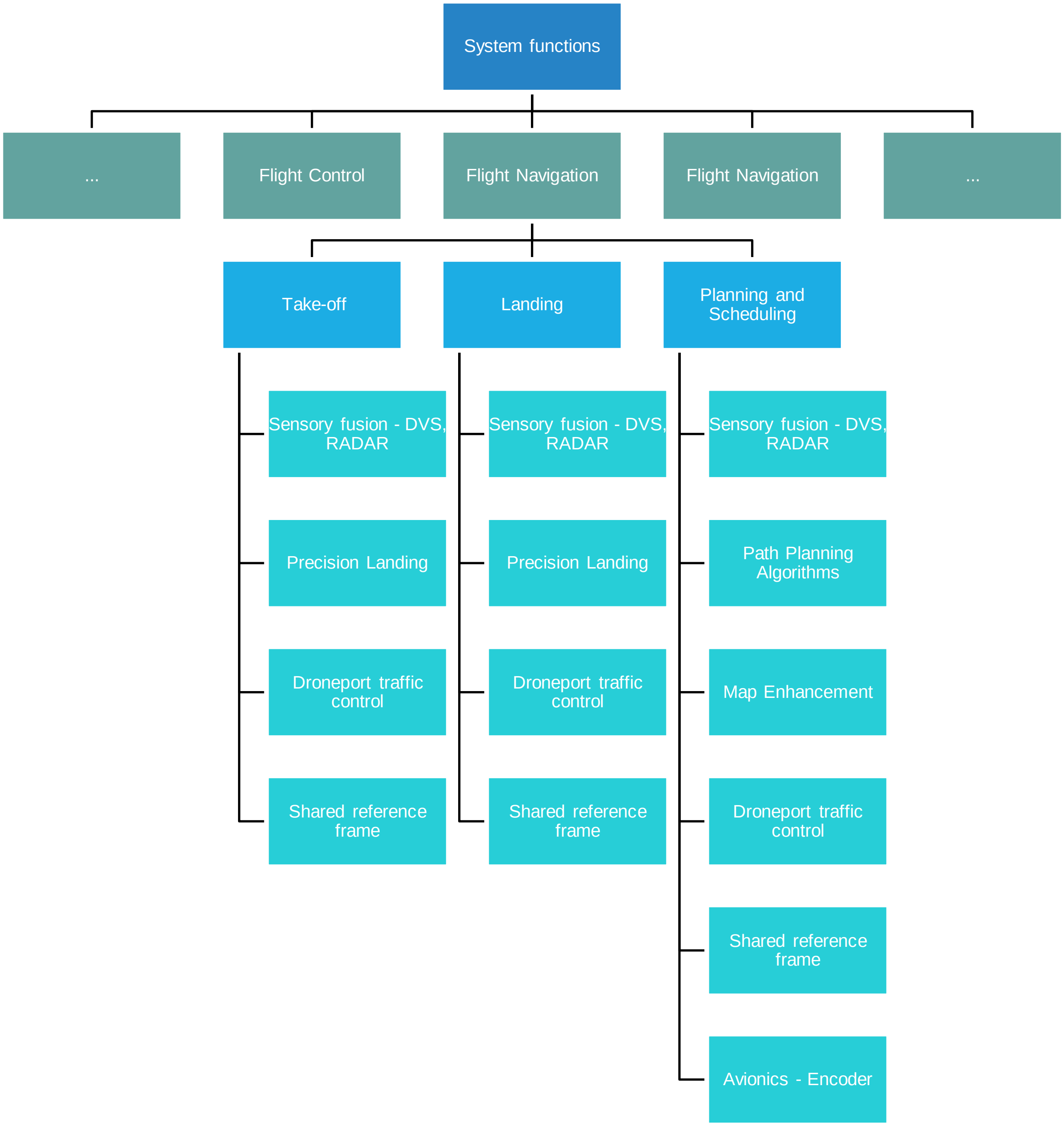

Figure 13 KET deliverables in Flight Navigation - Part I

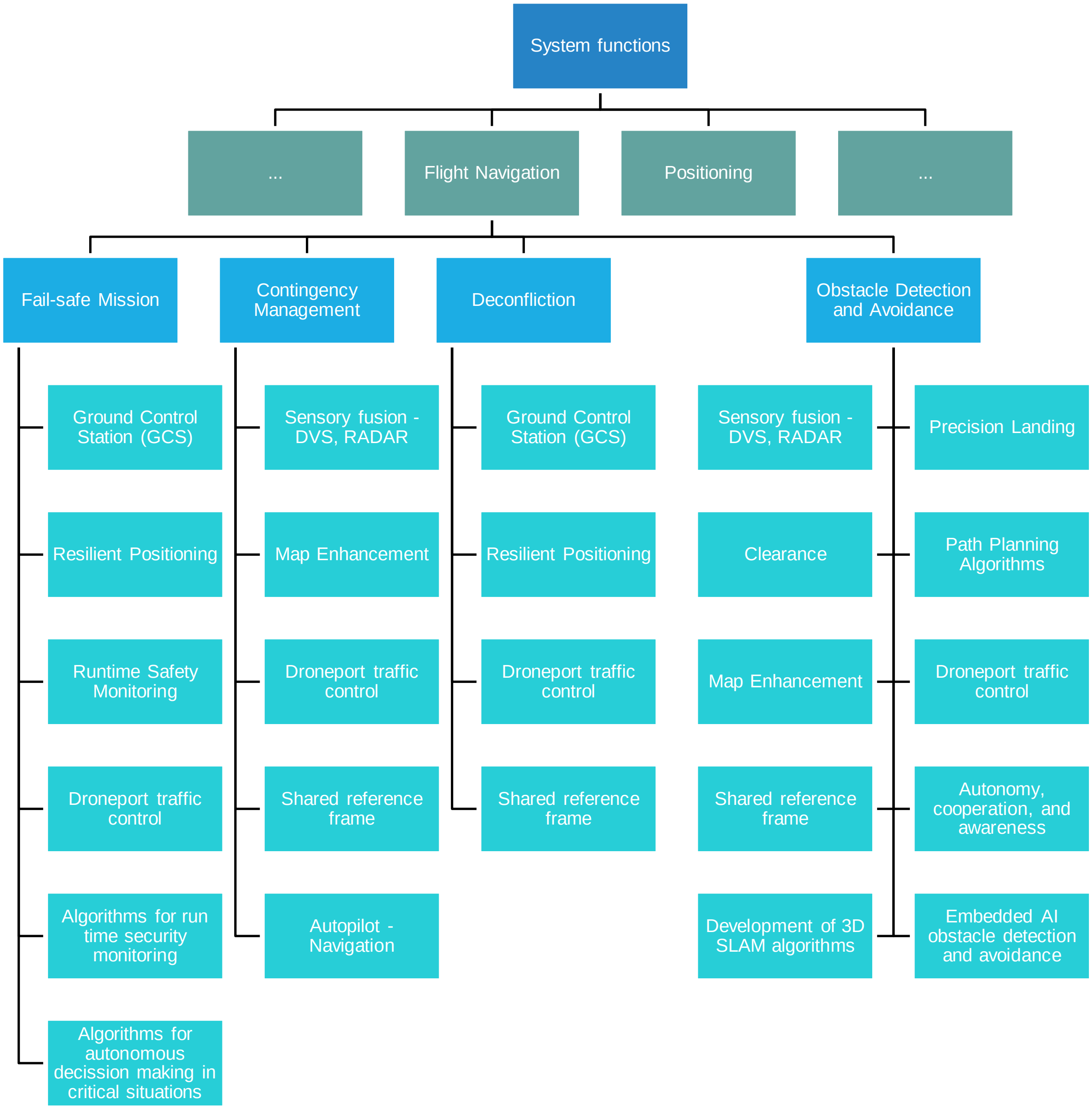

Figure 14 KET deliverables in Flight Navigation - Part II

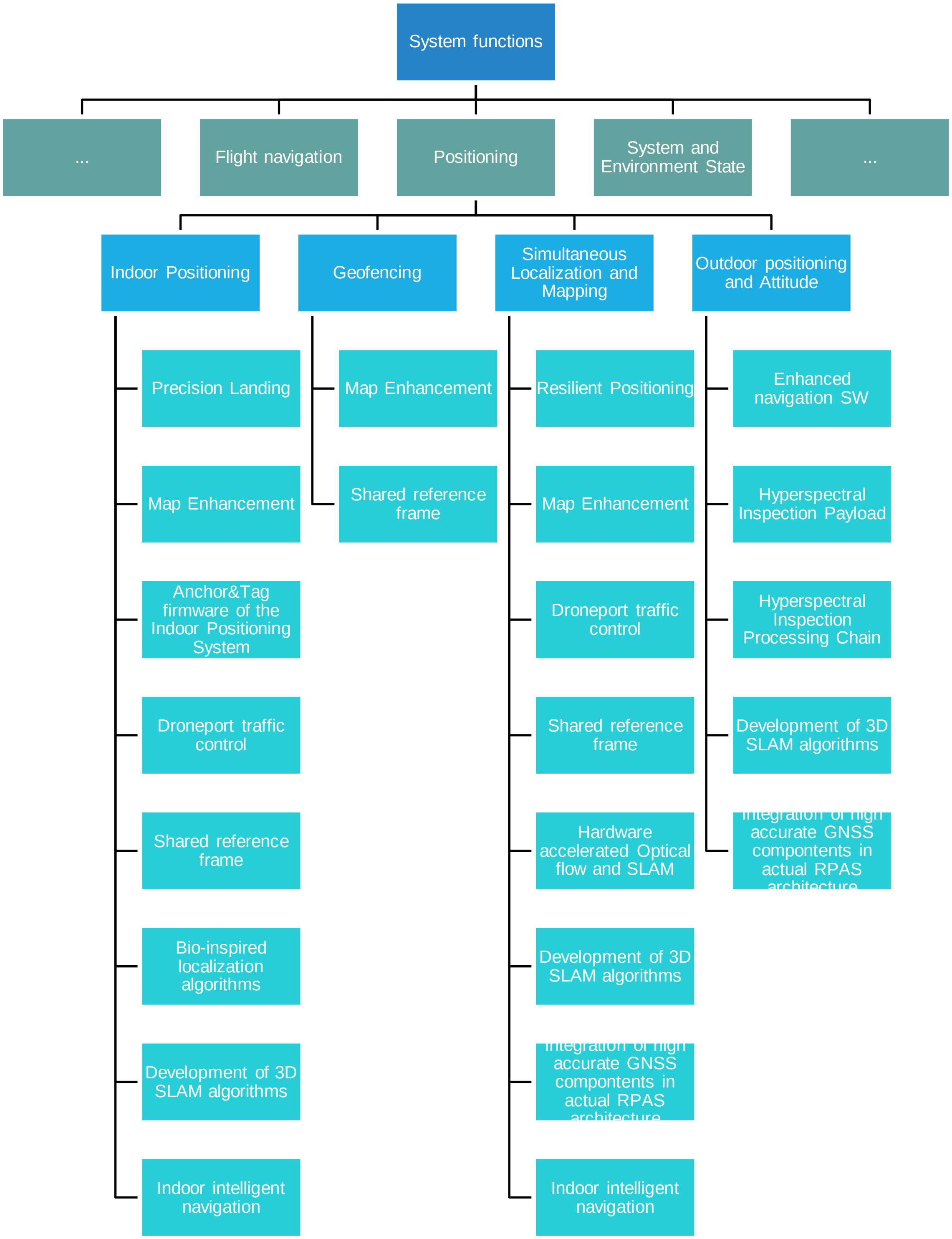

Figure 15 KET deliverables in Positioning - Part I

Figure

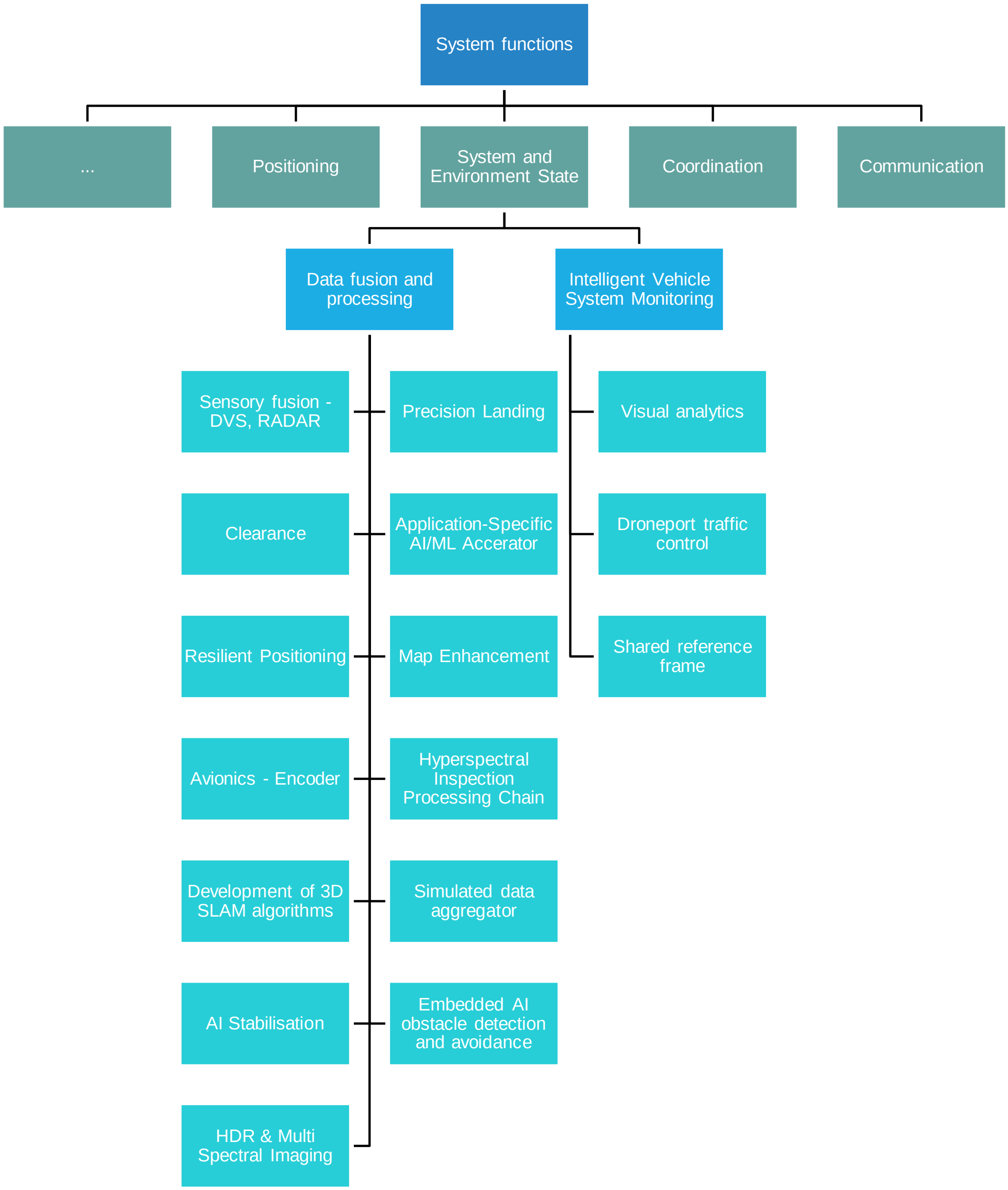

Figure 16 KET deliverables in System & Environment State

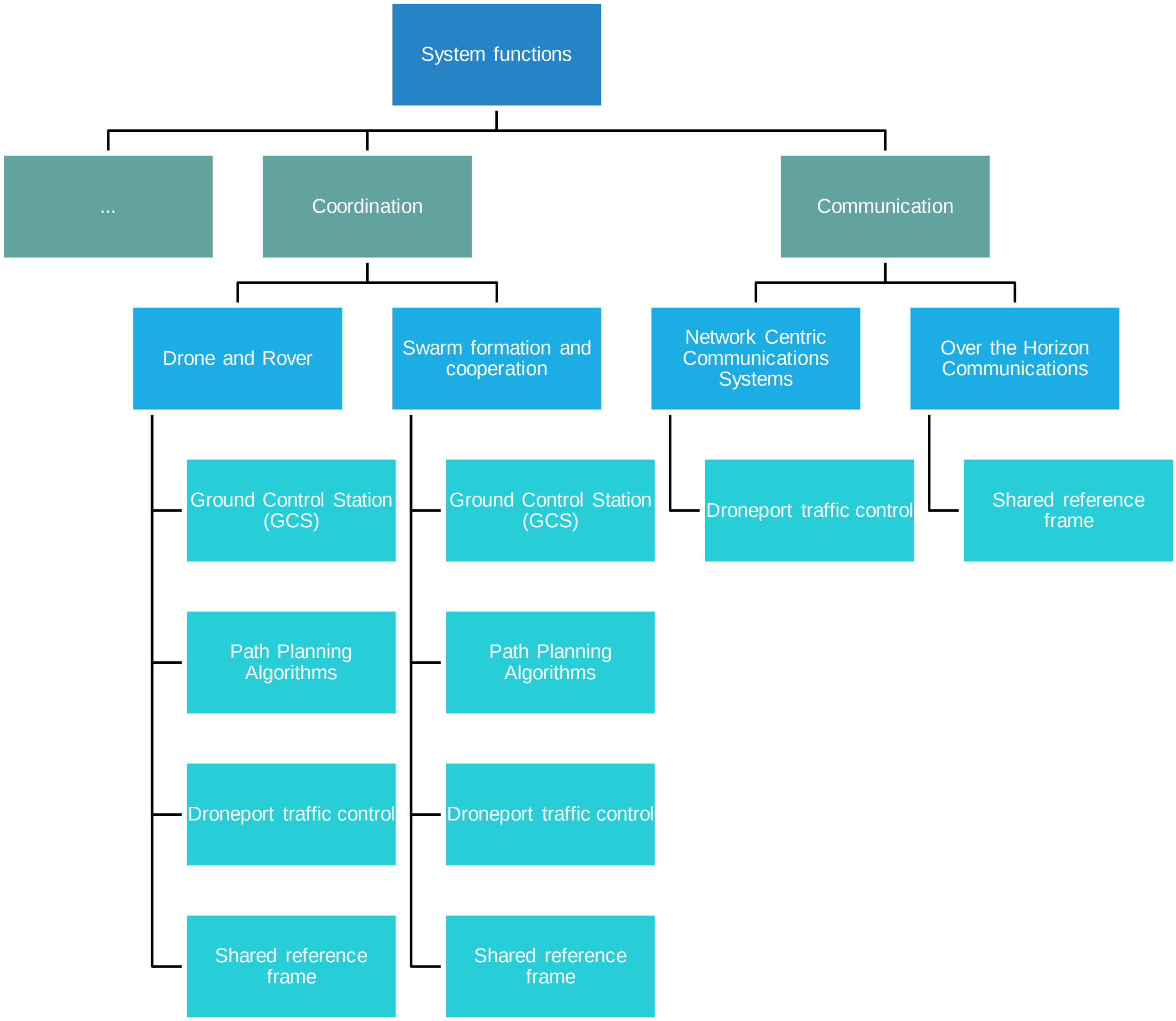

Figure 17 KET deliverables in System & Environment State

6.2.1 Positioning

6.2.1.1 WP4-02 Precision Landing

ID	WP4-02	**Category**	System	**KET**	2.3 Positioning 2.2.1 Take-off 2.2.2 Landing 2.2.7 Obstacle Detection and Avoidance 2.4.1 Data fusion and processing 3.1.2 Passive Optical
Name	Precision Landing	**Licence**	Proprietary	**TRL**	3
Owner	SCALIAN	**Contributor**	SCALIAN	**Contact**	SCALIAN

Functional and non-functional requirements

REQ ID	**Short description**
UC3-PRF-004	An UAV agent shall land precisely on its helipad, within a 50 cm radius to the target position even with a bad GPS signal.
UC3-FNC-010	An UAV agent shall use a dedicated external positioning system giving it its position relative to the dronepad. This system must be attached to the dronepad
UC3-FNC-013	An UAV agent shall use a computer vision to land precisely: it should descend with a close-loop controlling its position to the dronepad during the descent and adjust it.
UC3-FNC-015	An UAV agent shall rely on the combination of a dedicated external positioning system and a computer-vision algorithm to land precisely.
UC3-OPR-003	When an UAV agent takes off and lands, it shall ensure the clearance of the dronepad to ensure the safety of the operators that are servicing it. Both using the clearance algorithm and other means (e.g. perimeter sensors).

Technical specifications & Interfacing

Category	Navigation
Type	Software + hardware
Input	Images at more than 5 FPS (Frames Per Second) (combined), Mavlink messages with position from external positioning system
Output	Relative position of the helipad
Input Interface	CSI (Camera Serial Interface) for camera, Mavlink for external positioning system
Output Interface	ROS message

Specific standard and regulation requirements (Optional)

	NIL

Specification

A set of sub-components are used to allow the UAV to land more precisely than with GPS. Additionally, this permits the UAV to land when the communication and GPS are not available.

Improvements

To improve the usual landing system, the UAV will use a fusion of several localisation systems.
A visual serving will allow to not rely on infrastructure to land.
An external localisation system (RADAR, IR-beacon) will complement the system for phases where the vision is not sufficient or incapacitated (reflections, fog, low light, ...).

6.2.1.2 WP4-40 Integration of high accurate GNSS components in actual RPAS architecture

ID	WP4-40	**Category**	System	**KET**	2.3.3 Simultaneous Localization and Mapping 2.3.4 Outdoor positioning and Attitude
Name	Integration of high accurate GNSS components in actual RPAS architecture	**Licence**	proprietary	**TRL**	5
Owner	TOPVIEW	**Contributor**	TOPVIEW	**Contact**	TOPVIEW

Functional and non-functional requirements	
REQ ID	**Short description**
UC5-DEM10-INT-005	Autopilot Communication Interface
UC5-DEM10-INT-006	GNSS Receiver Interface
UC5-DEM10-PRF-02	Drone positioning accuracy in the horizontal plane
Technical specifications & Interfacing	
Category	Navigation
Type	Hardware
Input	GNSS SIS (Signal In Space)
Output	Position solution (NMEA) up to 20 Hz in RTK, Raw measurements (proprietary format or RINEX (Receiver Independent Exchange Format) GNSS) observables
Input Interface	Dual band L1/L5 Antenna (GNSS SIS – Navigation) / 4G-NB-IOT Antenna (Communication)
Output Interface	UART / I2C (or CAN (Controller Area Network) BUS in case of protectory drones' interface) to Autopilot
Specific standard and regulation requirements (Optional)	
Possible protocols	NMEA / RINEX / Mavlink for Autopilot. MQTT/JSON (JavaScript Object Notation) for U-space tracking service.

Specification

This component is an architecture composed by one or more state-of-the-art GNSS receivers, antennas, communication links (if any) for precision agriculture applications. The component will specify the interface requirements with RPA and RGS (Royal Geographical Society) considering common open protocols and standards (e.g. RTCM (Radio Technical Commission for Maritime), Mavlink, JSON, …) and new European GNSS differentiators if available. Position Reporting to U-space service provider is also possible with this component (Tracking service).

Improvements

This component is intended to address specific challenges in survey applications in smart farming applications. In particular:

- **Facilitation of A.I. algorithms analysis:** Thermal and Multispectral images with the actual relative low resolutions available are in general not suitable for accurate orthmosaic processes or to build up heatmap layers in software suites, unless the drone flights are very close to the terrain surface (with the drawback of too many images to handle). The proposed improvement is to collect a temporal time-series of nadiral Thermic / Multispectral images collected always in the same sampling spatial points with high accuracy in the positioning. This process will improve feature based A.I. algorithms to monitor the plants during the all growing phases, but it requires high accurate positioning performance in order to minimize false positive of the A.I. / Machine learning techniques.

- **Terrain Following:** High end productions as grapes for fine wines are typically located on hills. When planning a mission aimed at allowing A.I. analysis in post processing or spray fertilizers, it is important to reach each waypoint with a high positioning accuracy not only on the horizontal plane, but also on the vertical axis. The GNSS based component (with the utilization of European GNSS signal) will improve navigation and position performance also on the vertical axis without additional proximity sensors (ultrasonic, optical flow, LiDAR,...) that often-present issues over vegetation.
- **Galileo Added value:** The utilization of the European GNSSo differentiators (Galileo Navigation Message Authentication service OS-NMA (Open Service Navigation Message Authentication)) on GNSS COTS (Commercial-Off-The-Shelf) receivers (when available) may represent a first layer for the certification of position feature, opening up a new market for agricultural use (Insurance companies payback, traceability of organic food,...)
- **Enhance Link efficiency for Ground Sensor data collection:** Ground Sensors placed over the farmyard can be awaken with more reliability by a drone transponder, to upload data collected [TOPVIEW PATENT USPTO, 62895514 filed on Sept. 2019: "A System for Data Collection through Unmanned Aerial Systems (UAS) "].
- **U-space Position Reporting:** the component will compact Navigation and Communication features, implementing the tracking service.

6.2.2 Flight Navigation

6.2.2.1 WP4-05 Clearance

ID	WP4-05	**Category**	System	**KET**	2.2.7 Obstacle Detection and Avoidance 2.4.1 Data fusion and processing 3.1.2 Passive Optical 3.4 Drop Sondes
Name	Clearance	**Licence**	Proprietary	**TRL**	4
Owner	SCALIAN	**Contributor**	SCALIAN	**Contact**	SCALIAN

Functional and non-functional requirements

REQ ID	**Short description**
UC3-FNC-002	The dropping agents shall ensure, with a dedicated software, the clearance of a drop location before dropping a sensor.
UC3-FNC-004	The clearance algorithm shall detect intruders when they are: humans, animals, vehicles.
UC3-FNC-005	The clearance algorithm shall rely on visual camera.
UC3-FNC-006	The clearance algorithm should be able to use thermal camera.

Technical specifications & Interfacing

Category	Payload
Type	Software
Input	Electro Optical And Infra-Red images at least 5 FPS
Output	Regions in image where an intruder is detected (if any)
Input Interface	ROS image messages
Output Interface	ROS custom message

Specific standard and regulation requirements (Optional)

	NIL

Specification

The clearance algorithm must ensure the absence of intruders during two critical phases: when dropping the sensors, and during take-off and landing.

Improvements

The clearance must be reach reliability level that would allow fully-autonomous operations. In particular, when the UAVs are above the drop point, they must ensure that no intruder could be hurt. The UAVs must also ensure that the dronepad is clear when landing, and must only start their motors for take-off when all the operators have left the pad.

6.2.2.2 WP4-06 Ground Control Station (GCS)

ID	WP4-06	**Category**	System	**KET**	1.1.5 Communication, Navigation and Surveillance 1.1.6 Command and control 1.3.3 Detect and Avoid 2.2.4 Fail-safe Mission 2.2.6 Deconfliction 2.5.1 Drone and Rover 2.5.2 Swarm formation and cooperation
Name	Ground Control Station (GCS)	**Licence**	Proprietary	**TRL**	4
Owner	ALTRAN	**Contributor**	ALTRAN	**Contact**	ALTRAN

Functional and non-functional requirements	
REQ ID	**Short description**
UC3-INT-010	The GCS shall be able to receive feedbacks from the agents or system of agents.
UC3-INT-011	The GCS shall be able to display feedbacks from the agents or system of agents.
UC3-INT-012	The GCS shall be able to send commands to agents or system of agents.
UC3-FNC-025	The GCS shall detect trajectory conflicts between different agents
Technical specifications & Interfacing	
Category	Navigation
Type	Software
Input	Agents feedback data, U-space services data
Output	Orders for the agents, feedback for U-space services
Input Interface	TBC
Output Interface	TBC
Specific standard and regulation requirements (Optional)	
	U-space
	Common delegated regulation EU 2019/945 [9]
	Implemented regulation EU 2019/947 [10]
Specification	
The GCS shall allow for the safe management of multiple agents (UAV, UGV, USV, humans…) for large airspaces while complying with the latest regulations (EU) and being compatible with U-space services.	
Improvements	
Manage different type of agents (not only UAVs). Allow dynamic allocation of monitored airspace to different GCS Managers Link the GCS to U-space services	

6.2.2.3 WP4-07 Application-Specific AI/ML Accretor

ID	WP4-07	Category	System	KET	Continuous monitoring and optimization
Name	Application-Specific AI/ML Accretor	Licence	Property/Open source	TRL	3
Owner	Autopilot Producer	Contributor	ROT	Contact	ROT

Functional and non-functional requirements	
REQ ID	**Short description**
UC5-SEC-004	This component provides a manager that taking as input a set of safety rules and drone's sensors information performs a check and guarantees the rules to be respected. If safety rules are violated the manager evaluates the action that the drone has to perform in order to go back in a safety situation. The safety rules are defined by a risk assessment.
Technical specifications & Interfacing	
Category	Flight Management
Type	Software
Input	Sensor data (position, distance from obstacles, ...)
Output	Command
Input Interface	NIL
Output Interface	NIL
Specific standard and regulation requirements (Optional)	
Specification	
This component provides a manager that taking as input a set of safety rules and drone's sensors information performs a check and guarantees the rules to be respected. If safety rules are violated the manager evaluates the action that the drone has to perform in order to go back in a safety situation. The safety rules are defined by a risk assessment.	

6.2.2.4 WP4-08 Path Planning Algorithms

ID	WP4-08	**Category**	System	**KET**	2.2.3 Planning and Scheduling 2.2.7 Obstacle Detection and Avoidance 2.5.1 Drone and Rover 2.5.2 Swarm formation and cooperation
Name	Path Planning Algorithms	**Licence**	Apache 2.0	**TRL**	4
Owner	UNISANNIO	**Contributor**	UNISANNIO	**Contact**	UNISANNIO

Functional and non-functional requirements	
REQ ID	**Short description**
UC5-DEM10-FNC-04	The system shall provide a path in order to perform the image acquisition campaign.
UC5-DEM10-PRF-03	An algorithm that provides a minimum cost path by managing dynamically changing inputs.
Technical specifications & Interfacing	
Category	Navigation
Type	Software
Input	Starting and goal trajectory points (i.e., x, y, z, and yaw coordinates) - a ESDF (Euclidean Signed Distance Fields) or TSDF (Truncated Signed Distance Fields) map of the scenario
Output	A vector of Waypoints, i.e., x, y, z, and yaw coordinates.
Input Interface	ROS custom message
Output Interface	ROS "geometry_msgs/PoseArray" Message
Specific standard and regulation requirements (Optional)	
	NIL
Specification	
The algorithm uses the information coming from the environment (presence of obstacles, number and position of the plants on which to operate the campaign acquisition or to apply the spryer, etc.) to compute the minimum-length path for the UAV (Unmanned Aerial Vehicle) or UGV (Unmanned Ground Vehicle).	
Improvements	
With respect to the state of the art, UNISANNIO aims to design path planning algorithms in the context of precision agriculture by providing customized solutions for the use case, i.e., DEM10. Starting from the classic space partitioning algorithms (i.e., RRT, A *, etc.), UNISANNIO SHALL provide algorithms that minimize the distance by managing dynamic changes of the inputs (i.e., inputs from the operator, unexpected changing of the scenario, data from the onboard image computational board).	

6.2.2.5 WP4-12 Runtime Safety Monitoring

ID	WP4-12	Category	System	KET	2.2.4 Fail-safe Mission
Name	Runtime Safety Monitoring	Licence	Proprietary	TRL	4
Owner	CEA	Contributor	CEA	Contact	CEA

Functional and non-functional requirements	
REQ ID	**Short description**
UC3-DEM2-SEC-01	The navigation system shall include a runtime manager to detect abnormal robot/drone behaviour (hardware or software failures, environment uncertainty), triggering a different execution mode (e.g. a safe degraded mode), or re-plan the mission altogether.
Technical specifications & Interfacing	
Category	Navigation
Type	Software
Input	RGB images / 480x320; Grayscale depth images / 480x320; Lidar 2D scan / 1° resolution / 270°-360° aperture angle; ML (Machine Learning) / DL (Deep Learning) algorithm prediction uncertainty
Output	Position x,y,z @ 20Hz, Velocity vx, vy, vz @ 20Hz, Attitude roll, pitch, yaw @20Hz
Input Interface	ROS2 topic/service/action
Output Interface	ROS2 topic/service/action
Specific standard and regulation requirements (Optional)	
	NIL

Specification

Drone safety will be addressed in runtime to face with the limited computation resources by analysing the behaviour of the algorithms. Certain failure scenarios have been anticipated, together with potential reconfigurations that assure that critical functionality remains assured. However, it is not possible to anticipate all failures, in particular not the combination of failures, as the required database would become too big (combinatorial explosion). Therefore, some failures have to be handled at runtime; the system should autonomously take a suitable action. The **COMP4DRONES** architecture shall use safety monitors looking at past and current states, in order to verify correctness and validate the system; or focus on future states, with prediction algorithms and actively diminish risk by assessing threats. To ensure correct runtime functionality in a drone/robot component, its execution will be monitored according to predefined invariants that essentially specify a contract for the dynamic behaviour of the component. In the case in which it is not possible to find a feasible solution before that a decision must be made, a safety mechanism will need to take place.

Improvements

The proposed technological component advances the state of the art by providing a runtime monitoring module that deals with uncertain-unsafe situations by providing some kind of envelope of permissible behaviours, without compromising safety. This solution enables adaptive navigation and planning that cater for self-diagnostic and self-correcting regulation of system performance from the point of view of safety.

6.2.2.6 WP4-19 Droneport traffic control

ID	WP4-19	**Category**	System	**KET**	2.2 Flight Navigation 2.3 Positioning 2.4.2 Intelligent Vehicle System Monitoring 2.5 Coordination 2.6 Communication
Name	Droneport traffic control	**Licence**	BSD, Apache-2.0	**TRL**	2
Owner	UWB	**Contributor**	UWB	**Contact**	UWB

REQ ID	**Short description**
UC4-FNC-07	The software shall manage the energy refoulment requests for multiple drones
UC4-FNC-08	The software shall plan the refuelling mission
UC4-INT-08	The drone shall communicate using MAVLink messaging protocol
Technical specifications & Interfacing	
Category	Guidance
Type	Software
Input	battery state and position of individual drones
Output	landing permit from droneport, droneport position and/or path plan
Input Interface	MAVLink messages
Output Interface	MAVLink messages
Specific standard and regulation requirements (Optional)	
	NIL

Specification

Droneport Traffic control is system for multiple drone coordination during battery management. It monitors and predicts battery state of charge for each unit and manages the requests for Droneport.

The DP Traffic control consist of

- Battery state of charge estimation for multiple drones
- Multiple drone coordination
- Path planning between mission position and Droneport with geofencing
- Droneport availability prediction

Improvements

Droneport Traffic control is currently in concept stage (TRL 2). The expected improvements are to develop software components and test together with DP systems in the simulation and intended environment. So, the final TRL during the project should be at least 5.

6.2.2.7 WP4-20 Attractor-based navigation

ID	WP4-20	**Category**	System	**KET**	1.1.2 Geofencing 1.1.5 Communication, Navigation and Surveillance 1.3.3 Detect and Avoid
Name	Attractor-based navigation	**Licence**	BSD	**TRL**	4
Owner	ALM	**Contributor**	ALM	**Contact**	ALM

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-PRF-07	Autonomy: Attractor based navigation – navigation based on the relative location, compared to moving beacon on a rover
UC4-INT-02	Communication: Rover acting like a radio hub, ground station
UC4-INT-03	Communication: Communication independence from the environment. (Self-carried radio infrastructure)
Technical specifications & Interfacing	
Category	System
Type	Software (minor Hardware component)
Input	Radio ranging, direction and RSSI (Received Signal Strength Indication) data
Output	ROS TF/map data
Input Interface	ROS messages, Radio interfacing (Bluetooth, BLE (Bluetooth Low Energy), Wifi, etc.)
Output Interface	ROS messages
Specific standard and regulation requirements (Optional)	
	NIL

Specification
Navigation in a relative frame of reference, locked to a beacon on a (moving) base platform. We're going to explore navigation by radio beacons, like VOR (VHF Omnidirectional Radio Range), ILS (Instrument landing system) for drones, e.g. BLE beacons, adding directional info through multiple beacons (data-separated). And we are going to explore angle-of-arrival options in Bluetooth.
Improvements
Current state-of-the-art is: AR (Augmented Reality) tags with ranging based on size, radio beacons using signal strength as ranging, in the aviation sector, there is the concept of VOR (radio-beacon with ranging based on echo delay)

6.2.2.8 WP4-26 Autopilot - Navigation

ID	WP4-26	**Category**	System	**KET**	1.1.4 Telemetry 1.1.5 Communication, Navigation and Surveillance 2.2.3 Planning and Scheduling 2.2.5 Contingency Management
Name	Autopilot – Navigation	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra

Functional and non-functional requirements	
REQ ID	**Short description**
DEM1-FNC-4	Tracking: the drone shall be able to perform automatic tracking of objects and persons
DEM1-FNC-6	The drone must autonomously navigate with high position accuracy during landing
Technical specifications & Interfacing	
Category	Navigation / Control
Type	Software
Input	STANAG 4586 messages
Output	STANAG 4586 messages
Input Interface	UDP packets via radio frequency
Output Interface	UDP packets via radio frequency
Specific standard and regulation requirements (Optional)	
	NIL
Specification	
This SW component is in charge of the autopilot navigation capabilities embedded in the drone.	
Improvements	
Analysis, design, development and testing, necessary in the navigation area of the autopilot, to suit the flight plans created and authorized by the UTM system, as well as the contingency plan to be carried out in case of loss of link between the ground station and the aircraft. In addition, the flight modes related to tracking must be reviewed and redesigned to match the resolution of the new HD image, which will allow to increase the distances of detection, recognition and identification of the target objects of tracking.	

6.2.2.9 WP4-36 Algorithms for run time security monitoring

ID	WP4-36	Category	System	KET	2.2.4 Fail-safe Mission
Name	Algorithms for run time security monitoring	Licence	Proprietary	TRL	6
Owner	IMCS	Contributor	IMCS	Contact	IMCS

Functional and non-functional requirements

REQ ID	Short description
UC3-DEM2-SEC-01	The navigation system shall include a runtime manager to detect abnormal robot/drone behaviour (hardware or software failures, environment uncertainty), triggering a different execution mode (e.g. a safe degraded mode), or re-plan the mission altogether.

Technical specifications & Interfacing

Category	System
Type	Software
Input	Control actions
Output	Safety actions
Input Interface	ROS messages
Output Interface	ROS messages

Specification

Target domain is autonomous mission development, for COTS drones with built-in Autopilot, controlled from ROS. Drone has configurable response management for critical situations (for example object avoidance, battery control etc., …). Architecture also includes Human pilot , who can take control over Remote Control.

Model based approach will be used to develop and test scalable ROS based module for intelligent decision-making component in STATEFLOW for resolving critical situations (for example object avoidance) with main specifications:

- have to be built in the chain of decision-making units (Autopilot, Human pilot).
- have scaled approach to existing drone architecture and configuration settings.
- have to take in view dynamic factors. For example, human pilot unavailable, environment change (rain, light conditions).

Improvements

Explores scalability approach to autonomous mission development, oriented on the use of COTS drone and components. That makes developing work less complicated and certification less complex as it relies on-the-shelf functions of drone already heavily tested and certificated.

6.2.2.10 WP4-37 Algorithms for autonomous decision making in critical situations

ID	WP4-37	**Category**	System	**KET**	2.2.4 Fail-safe Mission
Name	Algorithms for autonomous decision making in critical situations	**Licence**	Proprietary	**TRL**	6
Owner	IMCS	**Contributor**	IMCS	**Contact**	IMCS

Functional and non-functional requirements	
REQ ID	**Short description**
UC3-DEM2-SEC-01	The navigation system shall include a runtime manager to detect abnormal robot/drone behaviour (hardware or software failures, environment uncertainty), triggering a different execution mode (e.g. a safe degraded mode), or re-plan the mission altogether.

Technical specifications & Interfacing	
Category	System
Type	Software
Input	Control actions
Output	Monitoring messages
Input Interface	ROS messages
Output Interface	ROS messages

Specification

Target domain is the autonomous mission development, for COTS drones with built-in Autopilot, controlled from ROS. Drone has configurable response management for critical situations (for example object avoidance, battery control, etc.). Architecture also includes Human pilot , who can take control over Remote Control.
Model based approach will be used to develop and test scalable ROS based module for intelligent decision-making component in STATEFLOW for resolving critical situations (for example object avoidance) with main specifications:

- have to be built in the chain of decision-making units (Autopilot, Human pilot).
- have scaled approach to existing drone architecture and configuration settings.
- have to take in view dynamic factors. For example, human pilot unavailable, environment change (rain, light conditions).

Improvements

The proposed technological component advances the state of the art by exploring possibilities to monitor more complex subsystems of drone including dynamical behaviour of drone in real time ROS environment.

6.2.2.11 WP4-38 Development of 3D SLAM algorithms to enable autonomous navigation of unstructured environments

ID	WP4-38	**Category**	System	**KET**	2.2.7 Obstacle Detection and Avoidance 2.3.1 Indoor Positioning 2.3.3 Simultaneous Localization and Mapping 2.3.4 Outdoor positioning and Attitude 2.4.1 Data fusion and processing 3.1.1 Active Optical: LIDAR
Name	Development of 3D SLAM algorithms to enable autonomous navigation of unstructured environments	**Licence**	Proprietary	**TRL**	6
Owner	DEMCON	**Contributor**	DEMCON	**Contact**	DEMCON

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-DEM8-FNC-001	3D SLAM functionality on aerial/ ground/ surface system
UC4-DEM8-FNC-002	Mapping component to map surrounding in TBD (To Be Determined) accuracy/ range for system SLAM & Collision Avoidance
UC4-DEM8-FNC-003	Localization component to localize itself in GPS(-degraded) environment TBD space
UC4-DEM8-FNC-004	The system shall be able to autonomously plan its route to a given destination in a simple obstructed environment.
UC4-DEM8-FNC-005	Unmanned mobile system to develop & test the 3D SLAM processing onboard

Technical specifications & Interfacing	
Category	System
Type	Software including COTS sensor/ hardware configuration (LiDAR + Embedded (onboard) GPU/CPU PC)
Input	Optical/ IR data (point cloud and/or depth map and/or image) TBD fps + IMU data
Output	POSE (orientation/ translation) + mapping for system navigation
Input Interface	ROS messages (IMU, pointcloud, pointcloud2, image) or direct with OpenCVmap
Output Interface	ROS messages (example occupancy grid)

Specification
Optical based SLAM algorithms require intensive computing power and processing complexity for applying such algorithms in drones. DEMCON develops Optical SLAM functionalities that need to be able to run on real-time GPU embedded (onboard) hardware.

Improvements
The proposed technological component advances the state-of-the-art by exploring possibilities to monitor more complex subsystems of drone including dynamical behaviour of drone in real time ROS environment. Also, by integrating different sensor inputs as IMU.

6.2.2.12 WP4-44 Embedded AI obstacle detection and avoidance

ID	WP4-44	**Category**	System Functions	**KET**	2.2.7 Obstacle Detection and Avoidance 2.4.1 Data fusion and processing
Name	Embedded AI obstacle detection and avoidance	**Licence**		**TRL**	4
Owner	AIK	**Contributor**	AIK	**Contact**	AIK

Functional and non-functional requirements	
REQ ID	**Short description**
UC5-DEM10-FNC-005	The drone MAY be equipped with an onboard unit capable to execute image pre-processing using DL algorithms.
UC5-DEM10-INT-001	The drone must mount an onboard camera (the type of cameras will be defined) to acquire images
UC5-DEM10-INT-006	The Autopilot of target drone shall be capable to interface GNSS receivers with suitable positioning performance
UC5-DEM10-FNC-008	The system shall integrate SLAM algorithms to allow the drones to safely navigate and interact with unknown environments.
Technical specifications & Interfacing	
Category	Navigation
Type	Software
Input	LiDAR samples, depth camera frames, GNSS data, IMU data
Output	Linear and angular velocity set points
Input Interface	USB for both camera and GNSS, ethernet for Lidar, UART for IMU
Output Interface	C++ library to access the output the component provides
Specific standard and regulation requirements (Optional)	
	NIL

Specification
This component exploits an algorithm based on Deep-NN (Neural Network) that uses raw data from sensors like LIDAR, camera, GPS and IMU to reach a goal position in an unknown environment. Through sensor fusion the drone is able to react to environment changes performing obstacle detection and avoidance. No map required. Neural networks are trained in tailored synthetic scenarios, then used in real one.
Improvements
Actual navigation systems are based on detailed and sometimes heavy maps or use a set of allowed predefined actions used by drones to move into its workspace. Furthermore, a lot of computational resources are required for real-time data processing. A learning-based approach let the drone to exploit all possible actions according to its dynamics. An initial time and computational effort during training phase are needed, but working in synthetic environment speeds up the learning process. Exploitation of raw data from sensors and ad-hoc boards for NN inference let the system to be suitable for different applications.

6.2.3 System and Environment State

6.2.3.1 WP4-09 Application-Specific AI/ML Accretor

ID	WP4-09	**Category**	System	**KET**	2.4.1 Data fusion and processing
Name	Application-Specific AI/ML Accretor	**Licence**	Open-Source	**TRL**	4
Owner	UNIMORE/UNISS	**Contributor**	UNMORE, UNISS, UNIVAQ	**Contact**	UNMORE, UNISS, UNIVAQ

Functional and non-functional requirements	
REQ ID	**Short description**
UC5-DEM10-FNC-004	Application-Specific AI/ML Accretor SHALL exploit the proposed overlay design methodology for fast deployment and low-latency programming.
UC5-DEM10-FNC-004	Application-Specific AI/ML Accretor SHALL be capable to effectively accelerate workloads compared host and/or remote execution time of AI/ML kernels.
Technical specifications & Interfacing	
Category	Payload
Type	Hardware
Input	Tensor Vector and Filter Vector, Variable Dimensions and Size, FP32 and INT 8-bit
Output	Tensor Vector, Variable Dimensions and Size, FP32 and INT 8-bit
Input Interface	AXI (Advanced eXtensible Interface) Interface
Output Interface	AXI Interface
Specific standard and regulation requirements (Optional)	
	NIL

Specification
Development of an application-specific AI/ML shared-memory accelerator (e.g., convolution). The application-specific accelerator will be implemented using the overlay methodology and platform FPGA-based heterogeneous SoCs (e.g., Xilinx Ultrascale+) outlined in WP3.
Improvements
The application-specific accelerator will be capable to execute efficiently highly computationally intensive workload for AI and Deep Learning and Machine Learning applications. The accelerator, deployed in FPGA-based heterogeneous SoCs onboard compute platform selected in WP3 will enable us to deploy SOA (Service-oriented architecture) machine learning kernels with Power (W), Energy (J) and Throughput (GOps/s) from one to two orders of magnitude higher compare general-purpose processing systems.

6.2.3.2 WP4-25 Avionics - Encoder

ID	WP4-25	**Category**	System	**KET**	1.2.1 Tracking 2.4.1 Data fusion and processing 3.1.2 Passive Optical
Name	Avionics – Encoder	**Licence**	Proprietary	**TRL**	6
Owner	Indra	**Contributor**	Indra	**Contact**	Indra

Functional and non-functional requirements	
REQ ID	**Short description**
DEM1-FNC-3	OEM Camera SHALL provide HD video (min 720p)
DEM1-FNC-4	Tracking: the drone shall be able to perform automatic tracking of objects and persons
Technical specifications & Interfacing	
Category	NIL
Type	Software
Input	Settings Parameters
Output	Settings Parameters updated
Input Interface	Acknowledgement
Output Interface	Encoder software HMI SLA Panel Plus
Specific standard and regulation requirements (Optional)	
	NIL

Specification
Encoder for the reception, treatment and parametrization of the video received from the 4 HD optics and tracking features.
Improvements
SW tasks associated with the settings, settings, configuration and tests that allow the encoder to be enabled for the reception and treatment of HD video from the 4 new HD optics for which it will be necessary to parameterize them taking into account the characteristics of each of them. Tracking: settings, configuration and tests that allow to improve the current tracking features available for SD video by applying them to the new HD video.

6.2.3.3 WP4-35 Hyperspectral Inspection Processing Chain

ID	WP4-35	**Category**	System	**KET**	2.4.1 Data fusion and processing
Name	Hyperspectral Inspection Processing Chain	**Licence**	Proprietary	**TRL**	6
Owner	Airobot, IMEC	**Contributor**	Airobot, IMEC	**Contact**	Airobot

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-PRF-05	Create 3D image based on RGB images
UC4-PRF-06	Localize where the hyperspectral images are taken on the structure
UC4-PRF-09	Restore the hyperspectral images, correct them for external factors and create hyperspectral cube
UC4-PRF-10	Detect potential location of corrosion and provide it to the operator
Technical specifications & Interfacing	
Category	Systems
Type	Software
Input	Raw Hyperspectral & RGB data, GNSS Position & satellite data
Output	Georeferenced hyperspectral cube, 3D image made using RGB image
Input Interface	Webinterface, API
Output Interface	Webinterface, API

Specification
The processing chain will take the collected hyperspectral data, restore the hyperspectral images, create multispectral cubes of the images and will indicate where corrosion is tough to be present in the image.
Improvements
The state-of-the-art is that hyperspectral imaging is used for material detection in controlled-light environments and not in an outdoor environment. A hyperspectral processing chain targeted at this application will be set up and integrated into the automated processing of the collected drone data.

6.2.3.4 WP4-39 Simulated data aggregator supporting intelligent decision in computer vision components

ID	WP4-39	**Category**	System	**KET**	2.4.1 Data fusion and processing
Name	Simulated data aggregator supporting intelligent decision in computer vision components	**Licence**	Open-source	**TRL**	6
Owner	HIB	**Contributor**	HIB	**Contact**	HIB

Functional and non-functional requirements	
REQ ID	**Short description**
UC2-FNC-01	SHALL capture High density point cloud
UC2-FNC-04	Point cloud shall be in Open format
UC2-FNC-05	Point cloud with precise location of samples

Technical specifications & Interfacing	
Category	System
Type	Software
Input	Simulation scenario parameters: Digital terrain model and objects to be detected in CAD format. Drone configuration parameters: Vision angle, inclination, viewing depth, flight height in JSON format
Output	Cloud of points in LASH format
Input Interface	NIL
Output Interface	NIL

Specification
This component intends to provide high amounts of simulated data by making use of some existing 3D drone simulators in background, that is, Airsim (open source SW) and Simulink (commercial SW), in order to support computer vision components for intelligent decision. This component allows generating the required training data for any convolutional Neural Network without need to perform multiple data collection campaigns with real drones.
Improvements
This component will speed up the constructive process of a civil infrastructure by generating a high amount of cloud points from scenario-tailored simulated drone flights, that will train the computer vision system, without need to perform multiple data collection campaigns to get training data. Cost savings by reducing initial data collection campaigns just to get data are possible when using this this simulated data aggregator. Additionally, this component will be able to assess the need of different cameras (RGB, LiDAR, ...) integrated in the real drone, starting from the simulated clouds point generated by the component. This would allow detecting which kind of camera could provide more suitable results for the analysis before launching the real drone flight.

6.2.3.5 WP4-43 HDR & Multi Spectral Imaging

ID	WP4-43	**Category**	System	**KET**	2.4.1 Data fusion and processing
Name	HDR & Multi Spectral Imaging	**Licence**	Open	**TRL**	3
Owner	BUT	**Contributor**	BUT	**Contact**	BUT

Functional and non-functional requirements	
REQ ID	**Short description**
	NIL
Technical specifications & Interfacing	
Category	Payload
Type	Software
Input	RGB/Grayscale/Bayer Image, 8bit Depth, 3x Exposition
Output	1x Image Data, 8bit Depth
Input Interface	C API
Output Interface	C API
Specific standard and regulation requirements (Optional)	
	NIL

Specification

This component will provide optimized multiplatform library for HDR (High Dynamic Range) imaging. HDR video acquisition is an important feature of modern surveillance, traffic monitoring, and other applications that exploit cameras. Typically, for both economic and technological reasons, the HDR video is acquired using multi-exposure using sensors with limited dynamic range which can be easily mounted on UAV. Algorithms for single HDR image processing are known quite well, but these algorithms are currently feasible on PC platforms and specialized accelerator. Real-time acquisition and processing of HDR video is still quite opened and challenging topic. In **COMP4DRONES** project BUT will provide techniques for processing HDR video from exposure sequence including merging, deghosting and tone-mapping.

Improvements

For HDR:

- Implementation of Deghosting in real-time – technique to minimize ghosting artefacts typical for HDR video.
- Acquisition of dataset which will contain high quality exposure sequence for HDR video merging
- Performance optimization of HDR algorithms.

6.2.3.6 WP4-42 AI Stabilisation

ID	WP4-42	**Category**	System	**KET**	1.1.6 Command and control 2.4.1 Data fusion and processing
Name	AI Stabilisation	**Licence**	Proprietary	**TRL**	3
Owner	SCALIAN	**Contributor**	SCALIAN	**Contact**	SCALIAN

Functional and non-functional requirements	
REQ ID	**Short description**
UC3-FNC-032	The UAV should resist to aggressive flight conditions
UC3-FNC-033	The stabilization block should be activated only in non-nominal conditions
Technical specifications & Interfacing	
Category	Control
Type	Software
Input	IMU
Output	UAV Attitude for autopilot
Input Interface	Triggered via ROS, IMU read through Mavlink
Output Interface	Mavlink messages
Specific standard and regulation requirements (Optional)	
	NIL

Specification

The stabilization algorithms used in autopilots are mainly based on classical control techniques such as PID (Proportional–Integral–Derivative) controller. These techniques are designed for nominal conditions of flight. However, they lake of robustness out of the nominal conditions. The objective of this block is to stabilize the UAV under non-nominal conditions in complementary to the classical control techniques. It is based on Artificial intelligence techniques and more precisely on the Deep Reinforcement Learning (DRL). An artificial neural network (NN) is trained using DRL technique to stabilize a UAV using a dedicated simulator until obtaining a satisfied result. The AI stabilization is a complementary block, that is, it is not used in nominal conditions of flight. However, it is used when the nominal conditions are violated to ensure a safe flight of UAV.

Improvements

The actual system is tested in simulation. To improve it, the trained NN will be embedded on a real drone to continue the training online. The NN will be trained under aggressive conditions and perturbations to ensure the robustness.

6.2.4 Positioning

6.2.4.1 WP4-16 Enhanced navigation SW

ID	WP4-16	**Category**	System	**KET**	2.3.4 Outdoor positioning and Attitude
Name	Enhanced navigation SW	**Licence**	Proprietary	**TRL**	5
Owner	ACORDE	**Contributor**	ACORDE	**Contact**	ACORDE

Functional and non-functional requirements	
REQ ID	**Short description**
UC2-DEM1-FUN-09	The GNSS/INS navigation system shall provide an accurate attitude & position trace that can be synchronized vs an absolute time reference for digitisation purposes
UC2-DEM1-PRF-01	Improved Position, Attitude estimation performance (attitude components <1dg, position accuracy <10cm)
UC2-DEM1-PRF-02	A low-cost solution for the accurate attitude-position output trace for digitisation (below FOG-based solutions < 3K € the cheapest)
UC2-DEM1-SEC-01	Integrity vs shadows, interferences, and malicious attacks of the attitude and position data for digitisation
UC2-DEM1-USA-01	The geo-referencing system will support an auto-calibration, such that, after integration, it will not require any user configuration for its operation
Technical specifications & Interfacing	
Category	Positioning
Type	Software
Input	multi-GNSS antenna signal, IMU and barometer sensed data, GSM modem signal (RTK corrections), SD card and serial port for configuration
Output	georeferenced position and attitude, additional navigation information (e.g., GNSS-reference time, velocity)
Input Interface	• Overall system: SD card for configuration, serial port for configuration via proprietary interface and SDK • For Navigation SW: platform abstraction layer (RTOS services API, drivers), configuration library
Output Interface	binary proprietary protocol, handled via a specific API on top of serial port, to be upgraded as stated in improvements section
Specific standard and regulation requirements (Optional)	
	NIL

Specification
The navigation SW is in charge of computing the geo-referenced position and attitude. It does it by fusing the information from the inertial sensors (IMU), from several GNSS receivers and from other low-cost sensors (barometer, temperature). The algorithm uses advanced data fusion algorithms, e.g., extended Kalman filtering, specific purpose mixed real-integer solving algorithms, and also heuristic-based functionalities. In addition, it also supports a complex configuration capability, which is simplified in terms of navigation profiles for the user.
Improvements
In **COMP4DRONES**, the navigation software will exploit improved hardware capabilities enabled in WP3, e.g. for reactive security (see WP5). With regard to WP3, additional features of the novel platform (e.g. multiconstelation) will be also exploited at functional level for a more reliable navigation data, which is crucial for autonomous navigation. Moreover, it will exploit AI, to enhance drone navigation profile, and machine learning for the enhancement of the functionalities currently relying

on heuristic techniques. Output interface will be improved to support a standard based specification (e.g., extended NMEA) to be agreed in the project.

6.2.4.2 WP4-17 Anchor&Tag firmware of the Indoor Positioning System

ID	WP4-17	**Category**	System	**KET**	2.3.4 Indoor positioning
Name	Anchor&Tag firmware of the Indoor Positioning System	**Licence**	Proprietary	**TRL**	5
Owner	ACORDE	**Contributor**	ACORDE	**Contact**	ACORDE

Functional and non-functional requirements

REQ ID	Short description
UC2-DEM2-FUN-10	An indoor positioning system will provide real-time geo-references position to drone for enable autonomous, waypoint-based flight within the indoor infrastructure
UC2-DEM2-INT-01	The indoor positioning system shall provide real-time navigation information at the drone side, that can be integrated by the autopilot, including raw data (ranges)
UC2-DEM2-PRF-01	The system shall provide real-time navigation data with submetric accuracy in all the infrastructure
UC2-DEM2-OPE-01	The system shall provide real-time navigation data, with sufficiently accuracy for autonomous, way point based navigation within the indoor flying volume (without obstacles).
UC2-DEM2-OPE-02	The indoor position navigation accuracy shall allow to track a sufficiently accurate route to allow effective indoor geofencing (without obstacles).
UC2-DEM2-OPE-03	The indoor position navigation accuracy shall have resilience against the presence of objects within the indoor infrastructure (machinery, etc) in operational conditions
UC2-DEM2-OPE-04	The indoor position navigation accuracy shall allow to track a sufficiently accurate route to avoid obstacles provided they position is known in advance (without obstacles).
UC2-DEM2-USA-01	The deployment of the system has to be easy for workers. The system will enable automatic anchor positioning, and manual recalibration by topographers, facilitated by configuration software and communication interfaces

Technical specifications & Interfacing

Category	Positioning (Indoor Positioning)
Type	Software
Input	Anchor geo-location, range and error related information
Output	Processed geo-location of tag and raw information (visible tags, their geo-locations, and ranges)
Input Interface	Custom Specific messages optimized for performance (best accuracy, minimum overhead)
Output Interface	Position messages (likely over serial port) and over standard protocol (NMEA). Raw messages under definition, preferably based on existing standards and/or project-related extensions based on gnss receiver manufacturer-based protocols

Specific standard and regulation requirements (Optional)

	NMEA

Specification

The Indoor Positioning System (IPS) firmware comprises both, anchor firmware and tag firmware. The IPS provides a real-time, sufficiently accurate position information for enabling a functional, safe navigation of a drone on an indoor structure. 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 is formed by several anchor nodes (green nodes) developed by ACORDE and deployed along the infrastructure. The firmware of these anchors enables them to serve the range requirements from the tag. Moreover, it enables their auto geo-positioning. 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 implemented in the firmware of the tag in real time its geo-reference positions, by relying on the geo-position of the circumvent nodes and the measured ranges (distances) to them.
Improvements
The IPS firmware is developed from scratch in **COMP4DRONES**, relying on the platform developed in WP3, and the IPS Modelling and Analysis Framework developed in WP6. This firmware will have several improvements with regard to other known approaches. The anchors firmware will provide them with customized autopositioning capability. In addition, tag firmware will be able to provide real-time high rate , highly accurate position after fusing inertial sensor data with UWB-based range data.

6.2.4.3 WP4-23 Bio-inspired localization algorithms

ID	WP4-23	**Category**	System	**KET**	2.3.1 Indoor Positioning
Name	Bio-inspired localization algorithms	**Licence**	Proprietary	**TRL**	3
Owner	EDI	**Contributor**	EDI	**Contact**	EDI

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-PRF-04	SLAM (aerial platform)
UC4-23-01	The bioinspired localization component shall enable agent to localize itself in a small (2m x 2m) 2D environment.
UC4-23-02	The agent shall be able to autonomously plan its route to a given destination in a simple obstructed environment.
UC4-23-03	The agent shall be able to localize itself with a precision of 10cm after moving 4 meters.
UC4-23-04	The agent shall be able to reach destination checkpoint with a precision of 10cm.
UC4-23-05	The agent's generated trajectory shall not deviate from optimal trajectory by more than 20%.
Technical specifications & Interfacing	
Category	Navigation
Type	Software
Input	Grayscale images of at least VGA resolution
Output	Position x,y,z, pitch, roll, yaw
Input Interface	Socket-based communication from simulator
Output Interface	NIL
Specification	
Grid cells, which were discovered more than a decade ago [7], have been shown to be a key component of a mechanism that provides updates about location. Nevertheless, there have been limited attempts on utilizing this discovery for application in robotics [11]. EDI is exploring these discoveries with the long-term ambition of utilizing them for localization solution for future drones. This includes starting off with a training of Long Short-Term Memory (LSTM) Recurrent Neural Networks (RNNs), exploring new network topologies, applying novel approaches to data generation and finding ways of applying findings in robotics.	
Improvements	
The explored novel algorithm space may result in a new research direction related to localization in robotics.	

6.2.4.4 WP4-24 Hardware accelerated Optical flow and SLAM

ID	WP4-24	**Category**	System	**KET**	2.3.3 Simultaneous Localization and Mapping
Name	Hardware accelerated Optical flow and SLAM	**Licence**	Proprietary	**TRL**	5
Owner	EDI	**Contributor**	EDI	**Contact**	EDI

Functional and non-functional requirements

REQ ID	Short description
UC4-PRF-04	SLAM (aerial platform)
UC4-24-01	Drone's SLAM component shall be based on mono-camera vision odometry.
UC4-24-02	Drone's SLAM component shall work in real-time with control loop's duration not greater than 200 ms.
UC4-24-03	Optical flow subcomponent shall be implemented in determined hardware (FPGA fabric).
UC4-24-04	Drone's optical flow accelerator shall utilize some variant or combination of scale invariant features.
UC4-24-05	Drone's optical flow accelerator shall simultaneously track at least 20 points.
UC4-24-06	Drone's optical flow component shall be able to produce outputs with a frequency of at least 20 Hz.
UC4-24-07	Drone's optical flow component shall be able to perform with images of at least VGA (0.3 Mega Pixel) resolution.

Technical specifications & Interfacing

Category	Navigation
Type	Software and Hardware
Input	Grayscale images of at least 0.3 MP resolution
Output	Position x,y,z @ 5Hz, pitch, roll, yaw @20Hz
Input Interface	Depending on the final progress achieved: DMA with an accelerator or socket-based communication with software
Output Interface	Depending on the final progress achieved: DMA with an accelerator or socket-based communication with software

Specification

Although, currently SLAM algorithms are SoA in mobile robotics, the computing complexity and the consequential power consumption is a barrier for applying such algorithms in drones. EDI develops hardware-based (FPGA) optical flow accelerator which would greatly reduce the complexity related to the frontend algorithms of the SLAM. Further, parts of frontend and backend algorithms will be probed for acceleration in a heterogeneous (FPGA + MPU) system with the long-term goal being the possibility of computing SLAM entirely in hardware.

Improvements

- The solution would make it more feasible to calculate SLAM algorithms on drone's onboard computer.
- The solution would reduce the power consumption and therefore increase the effective range of the drone.
- The solution potentially could enable drones to robustly return to a checkpoint when its communications (and positioning systems) are blocked.

6.2.4.5 WP4-45 Indoor intelligent navigation

ID	WP4-45	**Category**	System	**KET**	2.3.1 Indoor Positioning, 2.3.3 Simultaneous Localization and Mapping
Name	Indoor intelligent navigation	**Licence**	Proprietary	**TRL**	3
Owner	CATEC	**Contributor**	CATEC	**Contact**	CATEC

Functional and non-functional requirements

REQ ID	**Short description**
UC2-DEM2-FUN-01	Autonomous drone operation
UC2-DEM2-FUN-05	GNSS unavailability
UC2-DEM2-FUN-06	Low visibility
UC2-DEM2-FUN-08	Obstacle detection
UC2-DEM2-FUN-09	Obstacle avoidance
UC2-DEM2-OPE-01	Indoor positioning for autonomous navigation
UC2-DEM2-OPE-02	Indoor positioning for safe navigation
UC2-DEM2-OPE-03	Indoor positioning for safe operation on known static environment with obstacles

Technical specifications & Interfacing

Category	Navigation
Type	Software
Input	Sensors (LiDAR, accelerometer, gyroscope, barometer, etc.)
Output	Local relative position estimated and desired (xyz), velocity (Vxyz) and attitude (roll, pitch, yaw).
Input Interface	ROS interfaces for reading sensors data
Output Interface	ROS interfaces for given position, velocity and attitude.

Specification

The indoor positioning system is a software development that will run on the aircraft's onboard computer. It will estimate the localization of the aerial robot using all the input data. This module will detect obstacles and send proximity alarms to the controller in order to avoid them. The objective is that the precision of the navigation in real time that allows the aircraft to fly inside a tunnel is less than 1 m. This module allows the autonomous navigation of the drone in indoor environment such as a tunnel under construction.

This module is integrated in ROS, together with the DJI SDK [12] and driver of sensor. The output of this module would be the localization of the robot and commands to given to the positioning control system.

Improvements

The algorithm enables drones' systems with ROS and DJI autopilots to localize and navigate along indoor environments. Indoor constrained environments with potential bad illumination conditions (like a tunnel under construction) can be a potential risk for workers and avoiding hardware loss. Autonomous navigation will provide safety to the operation and, at the same time, efficiency.

6.2.5 Coordination

6.2.5.1 WP4-18 Transponder for drone-rover

ID	WP4-18	**Category**	System Functions	**KET**	2.5.1 Drone and Rover
Name	Transponder for drone-rover	**Licence**	Proprietary	**TRL**	5
Owner	TEK	**Contributor**	TEK	**Contact**	TEK
Functional and non-functional requirements					
REQ ID	**Short description**				
UC5-DEM10-FNC-001	Transponder for drone-rover cooperation				
Technical specifications & Interfacing					
Category	Navigation				
Type	Hardware, embedded software				
Input	Radiofrequency signals (Ultra-Wideband signalling)				
Output	Inter-vehicle distance and relative position				
Input Interface	Hardware: SPI (Serial Peripheral Interface) or USB. Software: C or Java library to access the interface the component provides.				
Output Interface	Hardware: SPI or USB. Software: C or Java library to access the interface the component provides.				
Specific standard and regulation requirements (Optional)					
	NIL				
Specification					
The component WP4-18-TEK provides the drone and the rover anti-collision and identification functionalities. WP4-18-TEK consists of Ultra-Wideband transceivers and the controlling and data processing embedded software. WP4-18-TEK is capable of cooperative ranging (internodal distance measurement based on the propagation time of the radiofrequency signals); when multiple transceivers participate in the ranging procedure it is capable of localization with respect to a relative frame. The drone is equipped with one transceiver, the rover can be equipped with two or more transceivers, optional fixed beacons can be used according the mission needs. The solution is explored by simulation and preliminary realization during the project year 1, developed and verified in laboratory environment during the year 2, and field validated during year 3.					
Improvements					
Currently the sequence of UWB signals that made up the ranging procedure is controlled by a master node. The WP4-18-TEK component brings the improvement of a non-centralized coordination that accommodates the node mobility and whose timings can be adapted to the variability of the number of nodes at run-time.					

6.3 Payload technologies

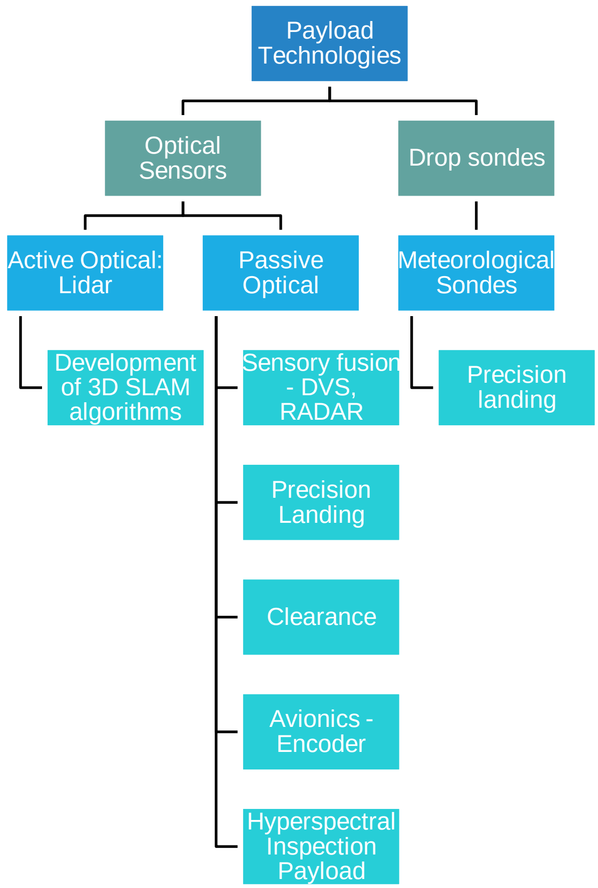

Figure 18 KET deliverables in Payload technologies

6.3.1 Optical Sensors

6.3.1.1 WP4-34 Hyperspectral Inspection Payload

ID	WP4-34	**Category**	Payload	**KET**	3.1.2 Passive Optical
Name	Hyperspectral Inspection Payload	**Licence**	Proprietary	**TRL**	6
Owner	Airobot	**Contributor**	Airobot	**Contact**	Airobot

Functional and non-functional requirements	
REQ ID	**Short description**
UC4-PRF-02	The payload shall accurately georeferenced collected hyperspectral data
UC4-PRF-04	The payload shall be able to collect RGB images & Hyperspectral data
UC-INT-04	The operator shall be able to see the output of the hyperspectral camera in real-time
UC-INT-08	The operator shall be able to change the configuration of the hyperspectral settings during flight
UC-INT-03	The operator shall be able to easily download the recorded, georeferenced data, and transfer it to the processing server.
UC-PRF-11	The payload shall have on-board processing power to run pre-processing and, if possible, detection algorithms

Technical specifications & Interfacing	
Category	Payload
Type	Hardware
Input	Commands to configure the camera, gimbal commands
Output	Hyperspectral images, hyperspectral 'video stream', signal to GNSS receiver for geotagging
Input Interface	IP interface, power, Mavlink interface (Gimbal)
Output Interface	IP interface, General Purpose I/O

Specification
The hyperspectral payload shall collect georeferenced RBG & hyperspectral data and (pre-)process the data on the drone.

Improvements
The state-of-the-art is that hyperspectral can be used for material detection in controlled-light environments and not in an outdoor environment.

6.4 Design tools

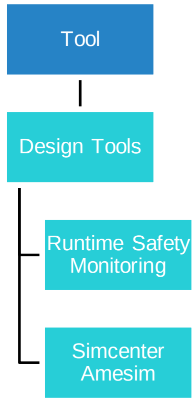

Figure 19 KET deliverables in Design Tools

WP4-41 Simcenter Amesim

ID	WP4-41	**Category**	Tool	**KET**	4.2 Design tools
Name	Simcenter Amesim	**Licence**	Commercial	**TRL**	6
Owner	Siemens Digital Industries Software	**Contributor**	Federico Cappuzzo	**Contact**	federico.cappuzzo@siemens.com

Functional and non-functional requirements

REQ ID	Short description
	NIL

Technical specifications & Interfacing

Category	Systems
Type	Software
Input	Mainly drone mission in terms of altitude and speed for each flight segment (climb, cruise, descent)
Output	Drone behaviour during the mission. Depending on the systems modelled, the results may include drone's acceleration, speed and position (flight dynamics), flight performance, electric motor and batteries performance, thermal behaviour.
Input Interface	FMU (Functional Mock-Up Interface) Co-Simulation and Model Exchange (1.0 and 2.0)
Output Interface	FMU Co-Simulation and Model Exchange (1.0 and 2.0)

Specific standard and regulation requirements (Optional)

	NIL

Specification

Simcenter Amesim is a system simulation software package. It allows to simulate physical multi-domain systems, to perform steady-state and transient analysis, and to test systems with MIL (Model In Loop) / SIL / (Software In Loop) / HIL (Hardware In Loop) and Real-Time. It is also an open platform with interfacing capabilities to other software tools. In particular, it can be coupled with other software tools providing environment and sensor modelling capabilities (e.g. Simcenter Prescan) to analyse autonomous flight algorithms.

Improvements

The following list is non-exhaustive and is likely to be adapted as the project advances:

- Provide functionality to generate a mission profile (altitude and speed definition for different flight phases)

- Develop component for coaxial propeller performance
- Improve fidelity of aerodynamics submodel for UAV applications
- Improve (with dedicated developments or through methodologies) the integration with other tools for environment simulation, sensors simulation and flight simulators. The goal is to provide a comprehensive simulation framework to address autonomous drones simulation.
- Industrialize demonstrators to help users understand the software capabilities and provide a starting point for UAV system simulation analysis

7 Conclusions

The presented document introduces a methodological guide on sensory systems and data aggregation for emerging drone platform designs. It shows reference drone architecture along with the Guidance, Navigation and Control framework enabling the unmanned/remotely controlled vehicle operations. The guide itself introduces key technologies having the potential to enable beyond state-of-the-art drone designs tailored to meet individual operational requirements. The presented drone component portfolio provides an intuitive and methodological list with respective drone sensory elements. Details on sensory components contain, among others, the degree of technological innovation, readiness levels, interface specifications and references to applicable standards.

The key difference justifying project realization is in the reflection of the state-of-the-art drone operational experience of today in contrast to the anticipated drone autonomy of tomorrow. The emerging drone platforms are envisioned to become fully integrated into a Cyber-Physical drone network enabling their seamless integration into everyday's life. For this vision to mature and become reality, addressed innovations in Unmanned Traffic Management relying on efficient integration of advanced communication, navigation and surveillance technologies, along with E-identification, novel Geofencing and Tracking, Autonomous Command and Control allowing safe Emergency Recovery need to materialize. Utilization of advanced techniques in Artificial Intelligence and Machine Learning are expected to enable advanced autonomy in strategic planning and autonomous decision making, thus enabling a safe and reliable coexistence of operationally autonomous cooperative and non-cooperative drones within one unifying Unmanned Traffic Management system.

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