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FACT

FUTURE ALL AVIATION CNS TECHNOLOGY

This Final Technological Demonstrators availability note is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 894616 under European Union's Horizon 2020 research and innovation programme.

Abstract

The primary goal of the project FACT is to evaluate the feasibility of a Performance-Based Integrated CNS (iCNS) concept, in order to support today's and tomorrow's air traffic challenges in the most cost-effective way without negatively affecting the overall operational safety. In particular, the project focuses on selected elements of iCNS concept exploring primarily a potential use of cellular networks (4G and 5G) as a complement to the existing CNS technologies within ATM and U space environment, with a particular focus on GA and drones' operations.

This deliverable provides description of the technical development and testing of systems used within the project's validations. It documents current availability and readiness of the systems as well as a short description of the performed or planned verifications/validations. The results of the final project's validations will be provided in the D5.3 (Second validation report) and D5.4 (Validation Assessment Report).

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1 Introduction

This document describes technological demonstrators used and developed/adapted within the FACT project. First technological evaluations based on demonstrators described in D3.2 were focused on evaluation of individual technological elements including different configuration of cellular networks. Results from these evaluations were used for refinement of initial system requirements as documented in D3.3 and preparation of the project's operational demo according to the Final Concept of Operations (D2.3).

The final technical demonstrators to be used in the final project's operational demo and prepared in accordance with system requirements described in D3.3 include:

- Experimental CNS devices to be installed onboard drones, GA aircraft and rotorcraft
- ATC simulator and ATC tower working position
- Drone platform (vehicle, C2 link and ground control station)
- Ground platform emulating Common Information Sharing (CIS) system and selected U-space services (USSP).

Within the demonstrators' development, the project's partners optimally benefited from synergy with other SESAR projects. For example, Honeywell participation in SESAR Uspace4UAM [1] provided an opportunity to collect large amount of data about a public 4G network during a series of drone flights focused on different objectives. These data were analyzed within the FACT project and results used to support design of the communication part of an experimental CNS unit.

Next, already finished project SESAR Emphasis [2] built an important knowledge related to the use of mobile networks and provided important lessons learnt concerning the design of an experimental onboard surveillance/communication unit.

In all cases it is always clearly distinguished which work was done within FACT project and what was reused from previous project.

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1.1 List of Acronyms

ADS-B	Automatic Dependent Surveillance-Broadcast
ARC	Aeronautical Research Center
ATC	Air Traffic Control
ATCO	Air Traffic Controller
BER	Block Error Rate
BW	Bandwidth
C2	Command & Control
CEPT	European Conference of Postal and Telecommunications Administrations
CIS	Common Information Sharing
CNS	Communication, Navigation and Surveillance
GA	General Aviation
GCS	Ground Control Station
iCNS	Integrated Communication, Navigation and Surveillance
ISM	Industrial, Scientific, and Medical
LPWA	Low Power Wide Area
MQTT	MQ (Message Queue) Telemetry Transport
NB-IoT	Narrow Band – Internet of Things
RSRP	Reference Signal Receive Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SINR	Signal to Interference plus Noise Ratio
TA	Timing Advance
TDM	Time Division Multiplex
UART	Universal asynchronous receiver-transmitter
USB	Universal Serial Bus

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USSP	U-space Services Provider
VoIP	Voice over OP

2 Experimental CNS Device

Onboard experimental CNS units will be installed on two drones and on general aviation aircraft as well as rotorcraft during final project validations in Eskisehir, Turkey. Experimental CNS units are slightly different for drone and aircraft/rotorcraft versions. A simplified architecture schema is shown in Figure 1.

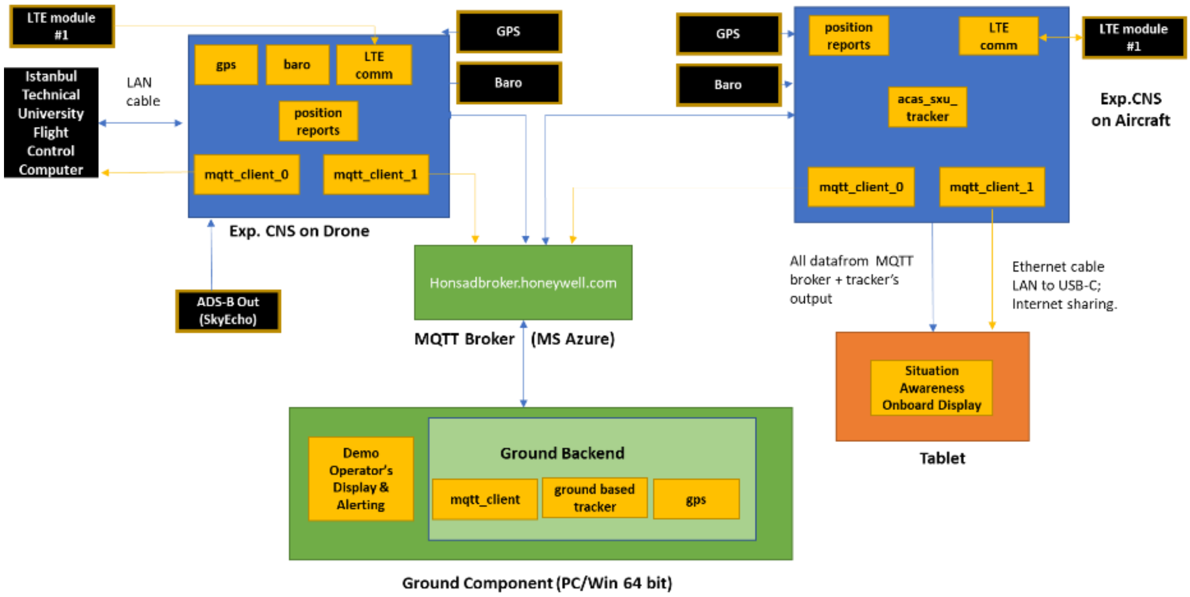

Figure 1: Schematic architecture of experimental CNS devices setup.

The experimental CNS unit to be installed on drone is responsible for following functions:

- Positioning report generation function
- Trajectory report generation function
- Communication with flight control computer of drone (receiving position, attitude and status data)
- Communication over cellular network
    - Providing position and trajectory reports
    - Receiving emergency commands (command to land)
- Receiving ADS-B data from surrounding vehicles
- Transmitting own position and velocity via ADS-B[1]

[1] Installation of ADS-B Out was not allowed for aircraft due to operational constraints.

The experimental CNS unit to be installed on GA aircraft/rotorcraft will be responsible for following functions:

- Positioning including position report generation function
- Communication over cellular network
    - Providing position reports
    - Receiving FIS and TIS data
    - Receiving alerts
- Receiving ADS-B data from surrounding traffic
- Traffic consolidation function providing data for pilot's display (implemented as an application hosted on the tablet or smartphone based on GA pilot's preferences).

Figure 2: Experimental CNS Device for Installation on Aircraft

Figure 2 shows experimental CNS device in aircraft configuration. It represents a stand-alone system without any connection to integrated avionics and consists of the following components:

- Black box containing Raspberry Pi 4 as a processing unit, barometric sensor and real time clock
    - Size 15x6x8cm
    - Unflammable plastic material
    - Fan for cooling down

- Orange box containing LTE module Quectel RM500Q-GL
    - 10x6x3cm
    - Four omnidirectional antennas
- GPS unit BU-334
- Powerbank CROSSIO JUmpPower FLEXI
    - Size 16,8 x 8,3 x 2,8 cm
    - Weight 460 g
    - Capacity 10 000 mAh
    - Output voltage 12V
    - Li-Ion technology

Overall weight is approximately 800 g. The unit passed functional and mechanical testing as well as connected testing with ground (CIS/USSP) system within Honeywell labs in Brno. In addition, connection with situation awareness application (see Section 6) was also thoroughly tested.

Figure 3: Experimental CNS device for installation on drone (here connected to power bank but on drone it uses power from drone).

Experimental CNS unit for installation on drones (shown in Figure 3) differs in following points:

- Power
  - Use of power from drone energy management
- Wiring to flight control computer
  - XT30 connector (power), ethernet cable (data)
- Position data source
  - Navigation data from flight control computer are used
  - MAVlink messages are read (GPS_RAW_INT, GLOBAL_POSITION_INT, ATTITUDE, SCALED_PRESSURE, HEARTBEAT, SYS_STATUS, RAW_IMU, SYSTEM_TIME)
  - Protocol is MQTT

The experimental CNS unit passed similar functional and mechanical tests as the GA version.

In addition, a commercially available ADS-B Out uAvionix Sky Echo (Figure 4) will be also installed onboard a drone:

- Size 6x8x3 cm
- Weight 120 g
- Own battery
- Transmits on 1090MHz with transmit power of 20W nominal output

Figure 4: Sky Echo ADS-B Out transmitter

3 ATC Tower Simulator

ATC Tower simulator (Eskisehir Technical University) consists of:

- BEST System Manager
- 4 x Controller positions
- 2 x Pilot positions
- 1 x Supervisor position
- 1 x Data Preparation position
- 1 x FAB position

Tower system provides realistic aerodrome image with 360 and 3D view. System has realistic aircraft and operational performances by aircraft library. All weather conditions can be simulated with visual perspective. Emergency conditions can be simulated during the exercise planning and running system. System has 6 different airport layouts including all busiest airports of Turkey such as Istanbul-Atatürk, Ankara-Esenboğa, Antalya, Izmir-Adnan Menderes, Dalaman and Anadolu airport. Airport layouts are created by FAB (Fast Airport Builder) provides modifications and new development of any type of airport. Pseudo pilot position can be extended by assigning position from radar pilot positions. Very effective airport and air traffic scenarios can be created as well as testing even emergency for purposes and dangerous situations in the air and on the ground.

ESTU aerodrome simulation general features can be listed as:

- Realistic aerodrome image with 360 and 3D view,
- Realistic aircraft and operational performances,
- All weather conditions,
- Emergency conditions,
- 6 different airport layouts including validation airport and airspace for the FACT,
- Airport layout design tool FAB,
- 4 operational positions and 1 supervisor with 2 pseudo pilot positions,
- Pseudo pilot positions can be extended with radar pilot positions.

Tower Visual System Comprises:

- 10 Image Generator PCs
- 10 BARCO Projectors
- 360-degree screen
- Space Navigator
- Joystick

Controlled by BEST System Manager can configure the system to assign airspace, exercise, weather and functions to positions. Data and System Backup/Restore is available. All controller/pilot positions run the same software. Working Positions can be configured to be any function as controller, pilot and supervisor. System can be configured to run one exercise group (circuit) or many. Each exercise controlled by the Supervisor position.

BEST System Manager has facilities to backup and restore: Data files (Access database and other general files); Airspace data files (text files); Recording archives; Configuration files; Exercises; System.

Back up 'Data Files' archives: Microsoft Access database; Communication system configuration; Strip format data; Other general (non-airspace specific) data

Stored in two formats within Data Preparation tool, data is stored as Access relational database; Data is exported to text file format prior to running in simulation to: Improve speed of loading; Allow data to be archived efficiently; To assist error processing.

Figure 5: ATC Tower simulator.

Within the scope of the project, 12 scenarios were created in this simulator environment. These 12 scenarios were designed in accordance with the project's ConOps. Again within the scope of the project, appropriate aircraft types were selected and run. These activities were aimed to develop scenarios specific to flight operations in the arrival, departure and aerodrome phases for general aviation aircraft and unmanned aerial vehicles. Another motivations underlying the running of the scenarios in the simulation environment was the evaluation, prevention and analysis of the unforeseen situations caused by ATC or the pilot of the aircraft, UAV and helicopter in the scenarios. These results were together used for refinement of the scenarios to be flown for the final operational demo in Eskisehir training airspace.

During the operational demo, air traffic controllers will contribute to realize the scenarios designed in Hasan Polatkan Airport Control Tower. In order to increase the situational awareness of the controllers as well as the pilots and operators using the aircraft, the interfaces are developed in addition to the existing equipment related to the provision of air traffic control service in the tower. Scenarios will be supported with this interface hardware and other hardware. During the demo flight operations, air traffic controllers (ATCOs) will be having advantage of the traffic situational display specific to FACT validation scenarios which provides drone and GA traffic positions and trajectories in the controlled airspace. Beside the conventional tower equipment such as R/T and navigational aids, situational display will support ATCOs to monitor traffics. Situational display has the potential to improve situational awareness of ATCOs.

4 Drone Platform

The drone platform which is reserved by Aerospace Research Center (ARC) of Istanbul Technical University (ITU) for FACT Project has 10 kg take-off weight and is powered by two 6-cell 22 Ah LiPo batteries which provides approximately 30 minutes flight duration including take-off and landing. It is equipped with

- a modern flight control computer with on board sensor set, running a reliable open-source autopilot software,
- a GNSS receiver which is capable of both tracking GPS and GLONASS satellites to fix position and velocity
- a long-range (40 km advertised, 5+ km tested) 868 MHz (ISM band) C2 radio link, which can be configured as peer-to-peer and time-division multiplexed (TDM) star network,
- a 2.4 GHz serial data-based RC receiver and remote controller.
- a 90 A / 60 V battery consumption sensor module developed and prototyped by ITU team.

The drone is shown in Figure 6 with its arms are open. They can be folded for the ease of logistics.

Figure 6: FACT test drone.

The drone has the remote pilot control for safety measures, although the demonstrations will be conducted by the drone operator using the ground control station software of ITUARC. The operator will command the drone using the GUI, which is based on CesiumIon environment for 3D and 2D visualization. Flight trajectory is planned according to the selected waypoints. At any time, the flight can be terminated by the operator. The drone can be returned to the take-off point or can be landed. Battery level, C2 link strength and RC link strength are also triggers for return-to-home or land reactions. It is configured by the operator. In the FACT project the operator will also have a VoIP connection to the air traffic controller. The ground control software, adapted for the FACT project is shown in Figure 7.

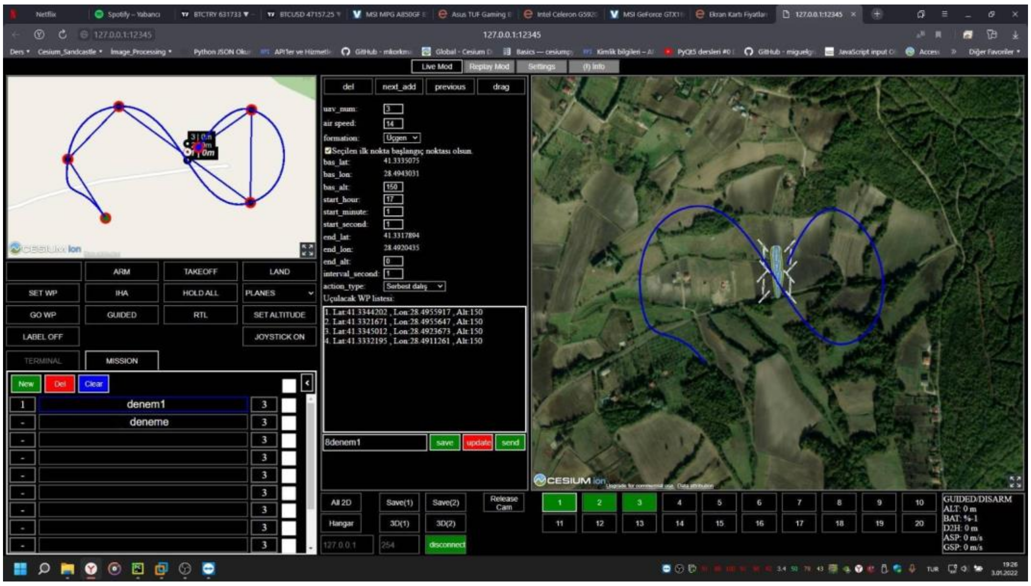

Figure 7: Ground control software adapted for FACT.

The flight control software of the drones is capable of tracking polynomial trajectories defining position, velocity and acceleration references. The ground control software will be capable of pre-flight trajectory planning, according to the waypoints and geofence/geocage constraints provided by the operator. The anticipated maximum trajectory tracking error is 5 meters. The geofence/geocage may consist of an altitude limit, a circle centered on the drone's home location, or a polygon defined by the operator. When the drone hits the geocage it can perform one of the three reactions, return to home, land, or hold position, according to its safety configuration.

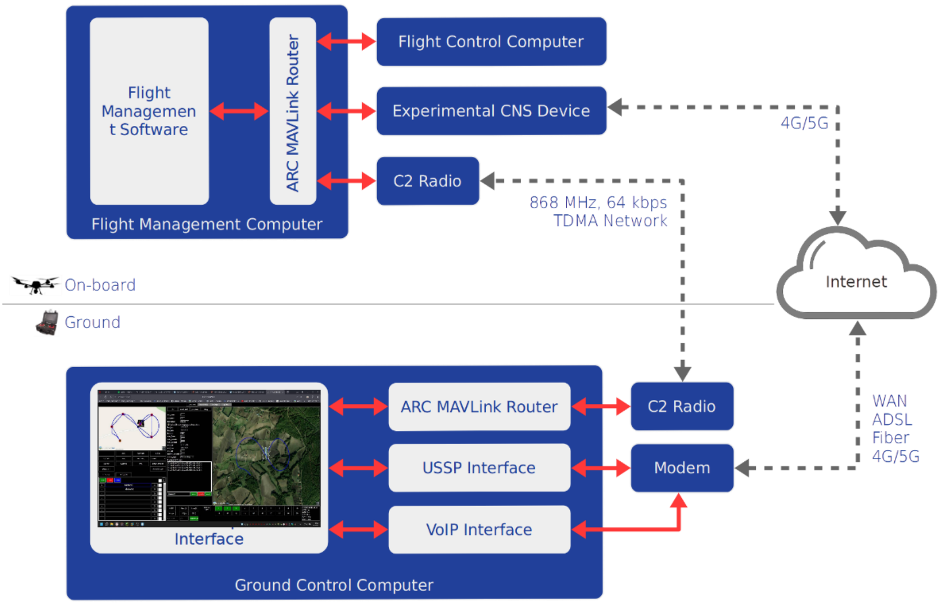

Figure 8: Block diagram of the drone platform and its ground control station.

In Figure 8, the components specific to the FACT demonstrations are illustrated as a block diagram. Ground control computer is capable of connecting to the internet in different ways, such as WAN, ADSL, Fiber, or mobile network. C2 link is the main connection between the drone and the GCS. The USSP interface added to the drone's operators interface and the VoIP interface uses the modem in order to have access to the internet. The MAVLink Router developed by ITU ARC is the fundamental software part in the flight management computer which routes the MAVLink messages between Experimental CNS Device, flight control computer, management software and C2 radio according to the system ID and target ID in the messages. It also has the ability to filter the messages according to the message type and message length.

Figure 9 shows the integration of Experimental CNS device (partly) and demonstration drone in ITU facilities. A plate has been cut and holes have been prepared to bring together the Experimental CNS device, 4G/5G modems, ADS-B out device, battery and voltage regulators. This plate and equipment, that are carried on it, are defined as the payload of the drone within the FACT project.

Figure 9: Experimental CNS system platform mounted under the demonstration drone.

Figure 10 has been taken in a trial flight before the test campaign of FACT vehicles. Remote piloted and operator-controlled flight capabilities are tested. Geofence/geocage features are validated in the pre-demonstration flights.

Figure 10: FACT demonstrator drone test flight.

5 Ground U-space Platform

Software infrastructure running on MS Azure cloud service was developed under the FACT project. Currently envisioned functionalities are especially:

- Data recording, storage and streaming
- Applications backend for surveillance and alerting
- Data link and off-boarded functionality, facilitating both the connection to ground, and between ground systems and cloud computing

To support different use cases and to achieve failure recovery the functionality is split into components. The components are loaded and initialized by the main module based on the provided configuration. The configuration specifies which components are to be used and both their generic and specific parameters. Components may also exist in multiple instances (e.g. using several sensors or data destinations of the same type), unless the component implementation forbids it. Components may serve as either a source or a destination role or both. The sources produce messages, while destinations consume them. Components need to follow a specific interface described in the main module. Some interface requirements only apply to either source or destination roles.

Main module runs a single message passing loop, attempting to automatically re-initialize any failed components. Sources produce messages independently and put them to a shared message queue provided by the main module on initialization. The components may act as asynchronous "microservices" or can be synchronously "driven" by the incoming messages, creating output based on the received message.

Components communicate *only via messages*. Messages are required to be JSON-serializable dictionaries, containing component-specific data. Messages in the queue are coupled with *message name* (conforming to *message source*) and *priority*.

When the main module dequeues a message, it is provided to all destination components that are configured to receive it, optionally with a re-mapped message source name. Destinations indicate compatibility by either providing a list of accepted sources or by indicating they accept all sources. This can be extended by providing a *source mapping* configuration, mapping original message sources to the sources accepted by the destination.

Components are not required to produce messages of a source matching the sender component name. This is often employed by the generic communication and recording components. Additionally, a message is never sent to the instance that has produced the message as a basic protection against loops.

The main three components which are currently under development and/or progressive testing are described in the subsequent sections.

5.1 Traffic Tracker

Traffic tracking functionality is crucial for enabling traffic surveillance applications. Supported sources of position are received ADS-B broadcast and position reports obtained through cellular network. Output of the tracker is smoothed and assessed position and velocity estimates from timestamped series of positions and velocities reported by vehicles.

The tracker implemented for the FACT project is based on the tracker used in ACAS sXu anticollision algorithm for handling ground surveillance data. Although ACAS sXu algorithm is intended for onboard use at small drones, it is possible to run the algorithm on the ground while maintaining communication with the flying vehicle. The advantage of ACAS sXu implementation is that interface supports all needed inputs:

- Broadcast Remote ID report (conforms to regular trajectory reporting)
- Airborne Position Report (obtained by ADS-B)
- Airborne Velocity Report (obtained by ADS-B)

5.2 Traffic Picture Consolidation

Traffic picture consolidation is software functionality responsible for merging information about traffic from different sources and creating traffic picture for given area at the required timestamp. This component prepares data for TIS broadcast function.

5.3 Conformance Monitoring and Alerting

Conformance monitoring component is intended for cases when a trajectory information (3D) is available for the given vehicle. It verifies whether the position information is consistent with agreed trajectory (within a pre-defined envelope) and in case of deviations of the trajectory envelope, an alert is issued and communicated to relevant airspace users/stakeholders.

5.4 Communication

Communication between all flight demonstration participants is solved via MQTT. MQTT broker is deployed in cloud and all it is an entity responsible for processing the data flow. Each participant (both human – e.g., ATC controller – or machine – e.g. experimental CNS device) is able to publish and reads from particular branches. These branches ale called ‘topics’ in MQTT terminology. Access to specific topics is given by settings of rights for each participant.

6 Situational Awareness Applications

Situational Awareness Applications are realized in three different versions in the FACT project:

- Situational Awareness Application for GA pilot
- Situational Awareness Application for ATCo
- Situational Awareness for Drone Pilot – Enhancement of Ground Control Station

The core functionality of Situational Awareness Application will be the same for all three applications, although the human-machine interface (HMI) design on display will be different. The display functionality does not include any larger internal processing – it is just displaying what it receives. The main differences in the display part are following:

- The view for GA pilot will be ownship-centric and will be provided by data from experimental CNS unit.
- The view for remote pilot and ATCo will be ground-centric and will be provided by data from cloud functions.

Honeywell is responsible for providing the Situational Awareness Application for GA pilot. Screenshots from application are shown at Figure 11 and Figure 12 for situations when a drone is violating its geofence constraint (Figure 11) or from its planned trajectory (Figure 12).

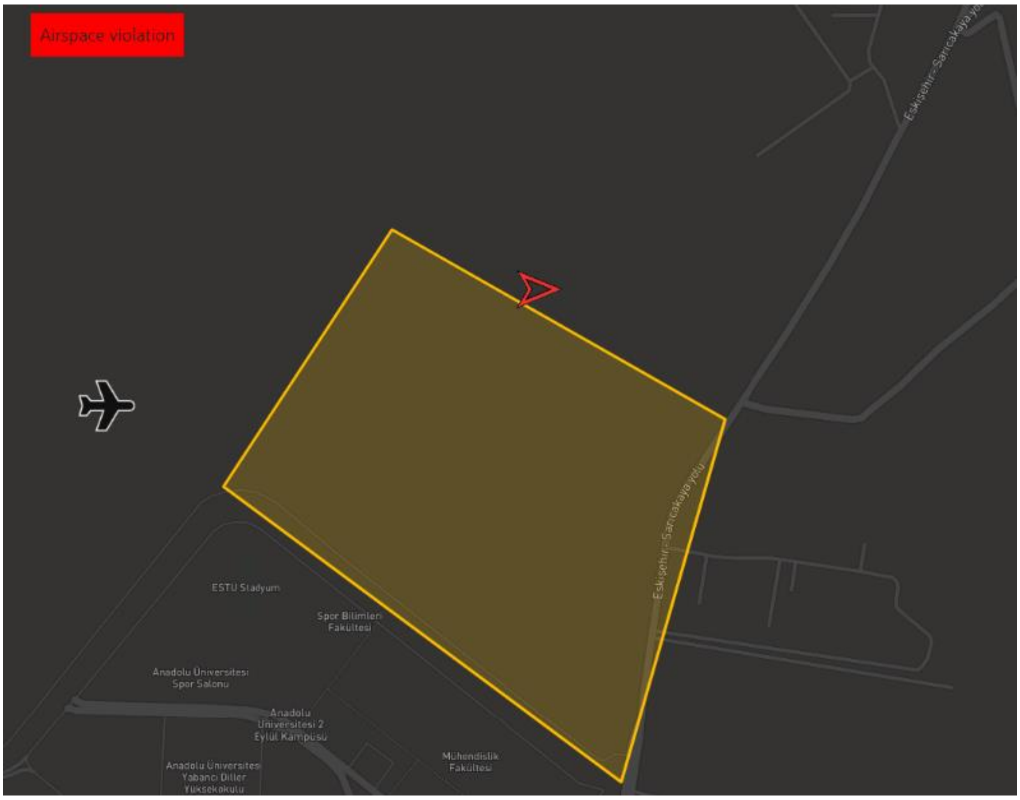

Figure 11: Situational Awareness Application for GA pilot showing a drone deviating from its allocated airspace.

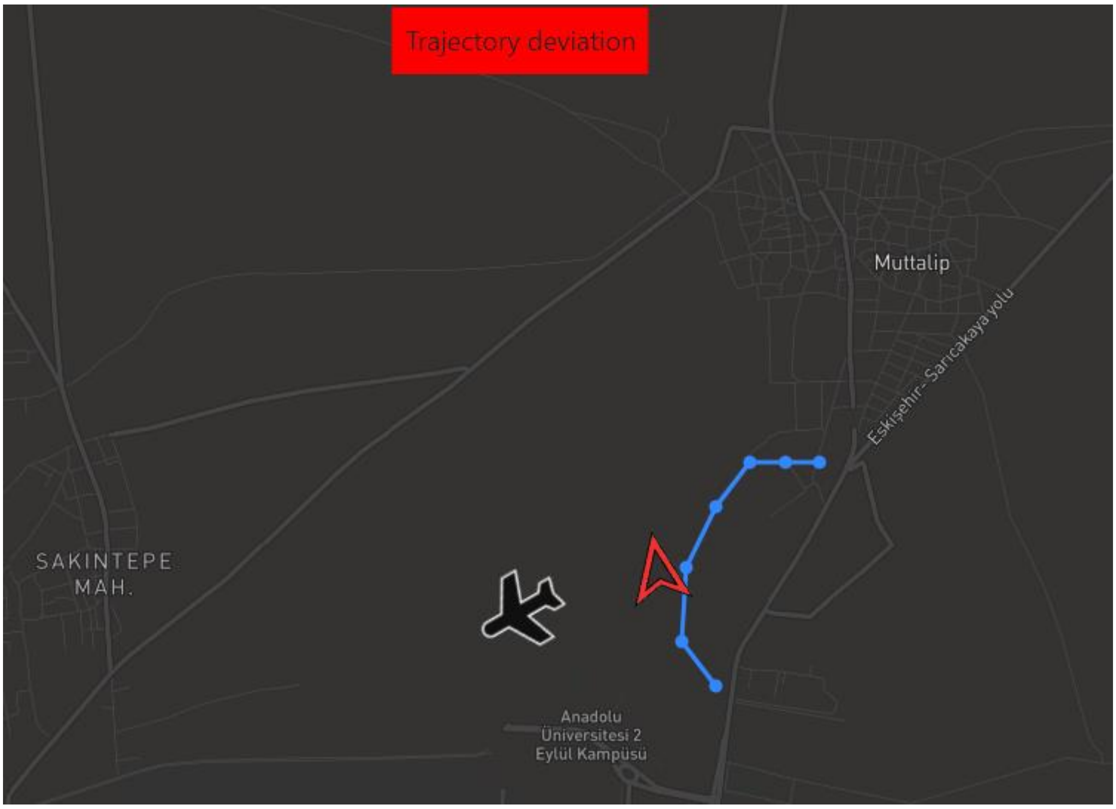

Figure 12: Situation awareness application for GA pilot showing conformance monitoring alert for a drone.

Finally, Figure 13 shows ITU's situation awareness software for remote pilot capable to use data from ground U-space platform.

Figure 13: Situation awareness application of the remote pilot.

7 Conclusions and Next Steps

Technical demonstrators described in this document are currently prepared for the final operational demo planned at the second half of July in Eskisehir. Elements of these systems were already used for project's Step1 validations in the projects and the results are described in D5.2 (First Validation Report) document. Technical lessons learnt were used to complete the final stage of the development. Integration of the elements was iteratively tested within Honeywell Lab and through remotely connected sessions with partners. One experimental CNS unit was also sent in advance to ITU for physical integration on the drone and to support these connected sessions. The results of the operational demo and associated technical measurements will be documented in D5.3 (Final Validation Report) and D5.4 (Validation Assessment Report). Overall project's results will be also shared through a dedicated dissemination event planned several weeks after the demo.

8 References

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