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Ground Control Station Embedded Mission Planning for UAS

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Abstract

As the Unmanned Aerial System (UAS) Level Of Automation increases, Mission Planning relevance raises. A mission plan can be defined as all the information needed to reach the assigned goals, and it is composed by several sub-plans. In particular, the mission plan core is represented by the routes. Since the route creation process is very complex, the introduction of route creation and verification algorithms is required. These algorithms enhance also the crew replan performances during the mission execution, and permit to implement autonomous on-board replanning.

Furthermore, Planning/replanning processes could also have a key role in the integration of UAS in the civil airspace.

According to these considerations, a Mission Planner embedded in the Alenia Aermacchi UAS Ground Control Station has been developed, comprised of advanced planning algorithms.

List of Acronyms

ALT	Altitude
ARINC	Aeronautical Radio Incorporated
ATC	Air Traffic Control
ATM	Air Traffic Management
BLOS	Beyond Line Of Sight
C4I	Command Control Communication Computer Information
COMM	Communications
CUCS	Core UAV Control System
DME	Distance Measuring Equipment
DTED	Digital Terrain Elevation Data
ELOS	Equivalent Level Of Safety
EO	Electro Optical
FA	Fix to Altitude
FMS	Flight Management System
FoV	Field of View
GCS	Ground Control Station
GIS	Geographic Information System
GPS	Global Positioning System.
HALE	High Altitude Long Endurance
HF	High Frequency
HMI	Human Machine Interface
ID	Identifier
IFR	Instrumental Flight Rules
ILS	Instrument Landing System
IR	Infra Red

kts	Knots
LAT	Latitude
LOA	Level Of Automation
LON	Longitude
LOS	Line Of Sight
MALE	Medium Altitude Long Endurance
NAS	National Airspace System
NAVAID	Navigational Aids
RF	Radial to Fix
RTI	Run Time Input
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
SMAT	Sistema di Monitoraggio Avanzato del Territorio (Advanced Territory Monitoring System)
SSC	Stazione di Supervisione e Coordinamento (Supervision and Coordination Station)
STANAG	Standardization Agreement
STAR	Standard Terminal Arrival
TF	Track to Fix
T/O	Take Off
TACAN	Tactical Air Navigation
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VSM	Vehicle Specific Module
WGS-84	World Geodetic System 1984
WP	Waypoint

Introduction

The Unmanned Aerial Systems applications are widely used in different tasks both for military and civil applications. A key factor contributing for this success is the increase of the UAS Level Of Automation. This permits to improve the operative performances and the safety of Unmanned Systems, with a shift in the operator's role from a remote pilot of the vehicle to its supervisor.

Together with the automation, also the mission planning importance raises. Highly automated/autonomous UASs, in fact, require a detailed mission planning in order to effectively use the systems capabilities and reducing the operational risks, especially considering vehicles able to operate only in navigation autopilot mode (i.e. without the possibility of remote manual control or semiautomatic control). Planning process for UAS is very complex since there are more paradigms to consider than for a tradition manned aircraft, like – for example – lost link routes, sensors plan, need to avoid the overflight of populated areas and so on. The manual creation of a mission may be therefore quite long. As a significant example, the first versions of the "Global Hawk" (one of the most automated UAS in active service today), required nearly nine months to plan a mission (2000) [1], [2]. Long times are expensive and not compatible with an operative use of a UAS.

A way to reduce complexity and time is to adopt planning/validation algorithms that aid the operators.

The introduction of advanced planning algorithm introduces some issues about the Human Machine Interface. The operators, in fact, shall be also kept in the control loop in order to be aware of automation behavior and decisions. Referring to the Global Hawk for example, an accident with extensive damages to the vehicle caused by an erroneous setting of 155 kts as taxi speed has been reported. This misbehavior was due to a bug in the automatic planning software, but there was also a responsibility of the operators that have not monitored correctly the planning process and results. Monitoring, in any case, was difficult, since the interface was bad designed from the HMI point of view, with status report presented in hexadecimal code and no trend data for the operators [2].

Mission Planning is a fundamental issue also for the integration of UAS in the NAS, especially considering the future enhancement of the Air Traffic Management System.

In this work we present the results relative to the project of a mission planner for UAS embedded into the GCS of the Alenia Aermacchi Sky-Y demonstrator, which Human Machine Interface and

creation/validation algorithms have been done jointly with “Politecnico di Torino” within a research activity relative to the development of a Flight Management System for UAS.
This work has been positively tested during SMAT project (a research aims to develop an integrated systems with UASs of different classes to monitor the Piedmont Region, in the North West of Italy).

Mission Planners

Generally there are several planners available within the Unmanned System or strictly related to it:

- external planners,
- planners inside the GCS,
- autonomous replanning functions on the UAV.

External and GCS planners perform almost the same functions, with the exception of replanning that is allocated only to the second. The difference between them is in the detail of operation, since external planner has usually more information and a dedicated HMI with respect to the embedded GCS planners. The concept of operation is that the mission should be planned and validated in the more powerful external planner and then imported in the GCS. In the control station there is a planner that permits to modify the mission during flight if needed. In any case, although external mission planners are the most used device to create a mission, a GCS should also have the capability to edit a mission starting from zero.
Besides, from the computational point of view, in the external planners algorithm’s computation times are not constrained by the near real-time replanning requirements that affect the GCS’s planners and especially the on-board autonomous replanning. Also in the external planner, however, there are limits to the acceptable computational time.
The replanning is not an expectable capability and requires a quite advanced system. As an example, Global Hawk does not allow waypoints to be added during flight, forcing the operators to include a large number of WPs in the original plan in order to cover all possible areas of interest [1].
A first replanning is performed in the GCS and then transmitted to the vehicle. Taking into account that operators have also to monitor and control the UAV, the use of advanced algorithms is still too important in order to reduce the crew’s workload and the replanning time.
Finally, more complex and advanced replanning operations are performed directly by autonomous UAV according to external stimulus (e.g. a target, a threat, a failure, etc…). These operations rely completely on sophisticated algorithms. Autonomous replanning raises also issues about the role of the human, and in particular its capability to put a veto about automation decisions or performing override/modification of the system proposals. About autonomous replanning, in this paper we have considered a mission replanning essentially in terms of route modification/creation and not a path replanning (modification of UAV trajectory usually to avoid a threat like a possible intruder or terrain collision).

Mission Planning and Level Of Automation

Automation has been introduced in advanced systems to reduce the operator workload, replacing him/her in the execution of prolonged/repetitive tasks (e.g. flying an aircraft in cruise) or critical tasks like landing in low visibility conditions [3]. A system can have different levels of automation according to the allocation of decision making tasks between human and machine. In particular, as the machine role increases we have the transition from manual to automatic control first, and then from automatic to autonomous control. Differences between automatic and autonomous systems can be explained by the following definitions [4]:

Automatic systems are fully pre-programmed and act in the same manner regardless of the *situation and whether the solution is the most favorable.*

Autonomous systems optimize their behavior in a goal-directed manner in unforeseen situations (i.e., in a given situation, the autonomous system finds the best solution).

In other words, an automatic system is able to perform preplanned actions according to fixed rules without direct intervention by the operator. An example is the FMS of an airliner that – together with the autopilot system – flies automatically the preset flight plan with specific navigation laws. If there is the need to modify the route, this shall be done by the pilots.

An autonomous system, instead, monitors the situation and it is able to react to external stimulus without a request of the operator. In this way is also possible integrating in the system proper algorithms to optimize the machine decisions in order to maximize the performances.

LOA	Meaning
1	Human makes all decisions
2	Computer computes complete set of alternatives.
3	Computer chooses a set of alternatives.
4	Computer suggest one alternative.
5	Computer executes suggestion with approval.
6	Human can veto computer's decision within timeframe.
7	Computer executes, then reports to human.
8	Computer only reports if asked.
9	Computer reports only if it wants to.
10	Computer ignores the human.

Table 1. LOA scale of Parasuraman, Sheridan et al. [6]

Transitions between manual, automatic and autonomous control, however, are not fixed at univocal steps. Automation increase happens in a continuous domain and in fact for real systems there are usually a lot of intermediate conditions. Therefore there is the need to measure the LOA discretizing the automation continuum in more fine steps. At this purpose, several scales have been developed. In our work we have taking into account the scale of Parasuraman, Sheridan et al. [5], [6], that considers ten incremental LOA from full manual to full autonomous control according to the decision making task allocation, as we can see in the Table.1.

If we want to allocate the proper LOA at mission planning/validation processes, we shall distinguishing between ground planning/replanning and on-board replanning.

Planning/replanning on ground can be execute with different levels of automation. Taking for example the creation of a route, in fact, it can be done in several ways. In basic mode, for example, WP coordinates are entered manually by the operator in the system (LOA 1). In semiautomatic way, instead, the WPs are still manually entered, but the computer evaluates automatically the new leg reporting possible problems (LOA 2, 3 or 4). Finally, in automatic mode, after the entering of some parameters, the route is created by an optimization algorithm with the possibility for the operator to approve, modify or reject the result (LOA 5). To resume, on external and GCS planners we can have the first 5 LOA, with the possibility for a single system to operate at different levels according to the operator request.

For autonomous on-board replanning, instead, the higher 6th [6] and 7th levels are more suitable. The sixth level is used for all replanning tasks that require a rapid system reaction giving however the possibility to the crew to override the system decision. An example could be the replanning to avoid the foreseen link loss or to return to the base in low fuel conditions. On board replanning, in fact, affects all functions that require generally quick response and execution, making the system robust from link failure since the human intervention is not needed. Other functions that could require more complicated scenario analysis and decision making process, are instead allocated to the GCS replanning. Furthermore, from the civil certification point of view, the possibility of the operator veto is probably more acceptable for a first integration of UAS in the NAS. Seventh level can be used in particular situations, like for example the sensor-slaved autopilot mode. In this case the operator authorizes the system to follow autonomously its sensor and when the UAV calculates a new optimized route to observe a target, a further authorization by the GCS is not needed. The vehicle shall start to fly the new route that is however transmitted to the operators in order to enhance their situational awareness.

Mission Concept for UAS

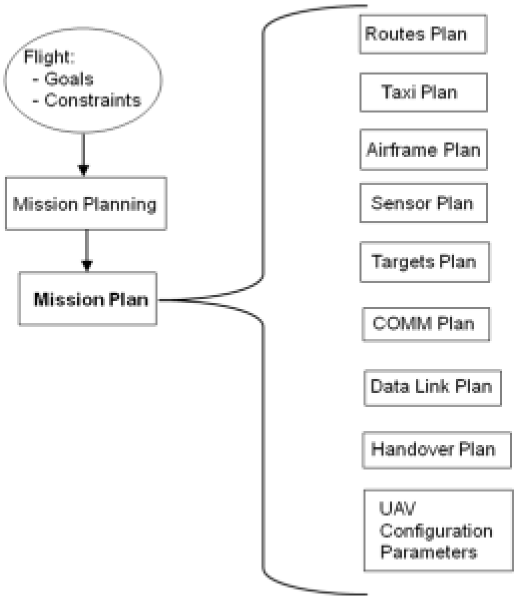

Figure 1. Mission Plan Elements

For UAS planning we can consider the current doctrinal philosophy used for the manned aviation, adding some features that take into account the unmanned peculiarities (e.g. datalink management and failures) [7]. In general, we think to the concept of mission plan, that is a kind of whole containing all information needed to perform the assigned goals. This is a wider concept then the traditional Flight Plans of manned aircraft, since it comprised more data then the routes usually provide for airliners. In a mission, in fact, we can distinguish different elements as shown in Fig.1.

Routes plan is the core of a mission and, according to the specific missions, can be made up by a main route or by more shorter routes. In the first case we have a situation analogous to the classic airliner flight plan, with a primary route relative to all flight from take-off to landing (plus possible diversion to an alternate destination airport), and some secondary routes that taking into account possible destination changes due to operative constraints (e.g. bad weather) or failures. This could be the case of a ferry flight or a monitoring of fixed targets. Another possible situation is the mission profile in which the UAV loiters at high altitude monitoring an area with possible diversions on opportunity targets (profile typical of HALE).

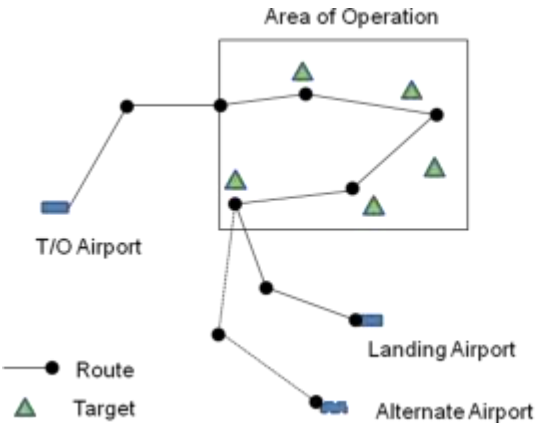

Figure 2. Example of mission with a single route

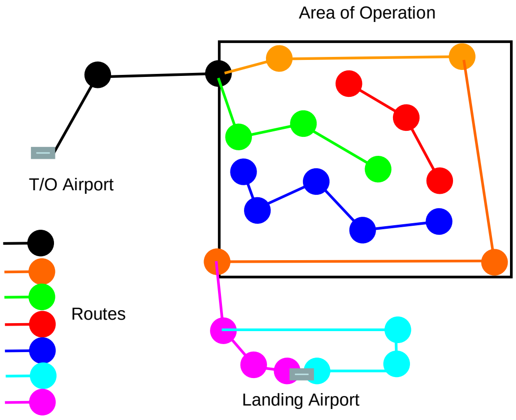

Figure 3. Example of mission with multiple routes

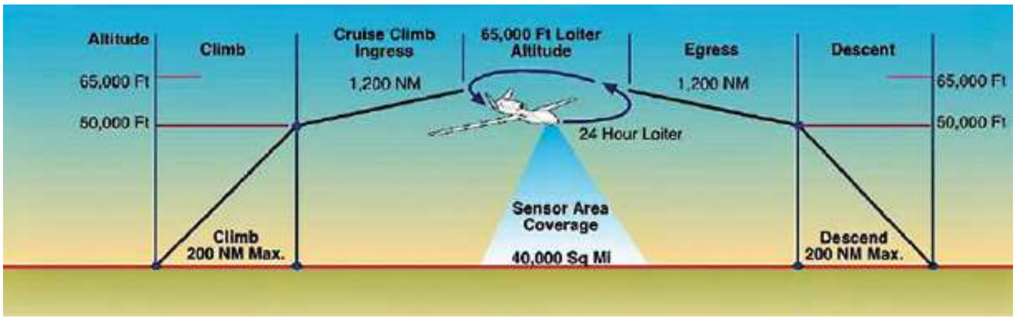

Figure 4. Example of Route profile with the UAV loitering on Area of Operation [8]

For UAS, however, another common situation is having more short routes that usually start from a WP not coincident with an airport, in order to provide flexibility to the operators that can vary the flight path according to the mission conditions. For example, given a wide area to monitor without prior known targets, the operators can create several possible routes to react quickly when a target is discovered. Other examples are different approach routes for different runways of the same airport, so that the operators are able to select the most suitable path according to the traffic and wind conditions. This planning philosophy is almost mandatory for UAS that does not have the provision for a replanning, in order to obtain a mission flexibility. However, also UASs that have the capability to replan the mission could adopt this type of plan that can be useful to improve the reactivity to scenario changes, especially when possible alternatives had been clearly identified during the planning.

Previous issues are referred to the “normal” routes, but for an UAS there is the need to plan also contingency routes/WPs and safe crash points. Differently for what happens for manned aircraft, it is essential to plan proper routes to be flown in case of lost link condition (i.e. a lack of datalink communication between GCS and UAV) or when some failures occur. These routes, usually, terminates on a safe crash point. In case of severe failures, in fact, there is the need to terminate the vehicle reducing as much as possible damages on ground. According to the considered UAS, single WP or routes for the emergencies might be planned.

Taxi plan describes taxi path and actions for each considered airport. It consists usually of information like [9]: taxiways to use, waiting points, taxi starting and ending time.

Airframe plan represents the airframe actions (e.g. landing gear extraction – retraction) scheduled at fixed positions and/or times of the mission. This is an another example of typical unmanned feature and it is a way for high automatic UAS to reduce the operator commands.

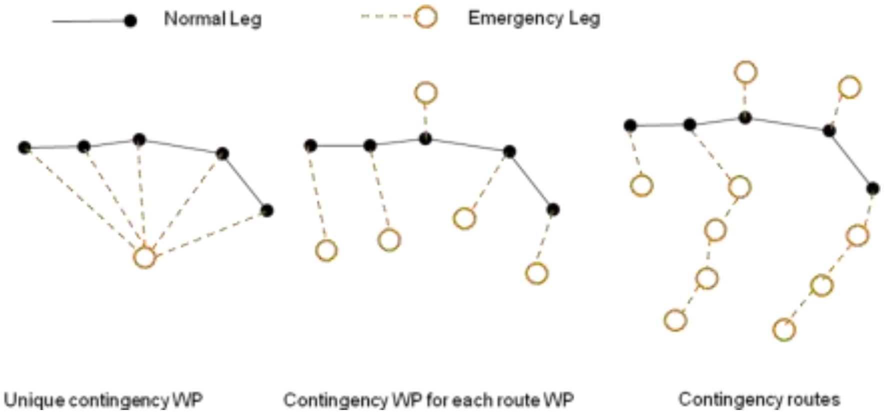

Figure 5. Example of contingency WPs/routes

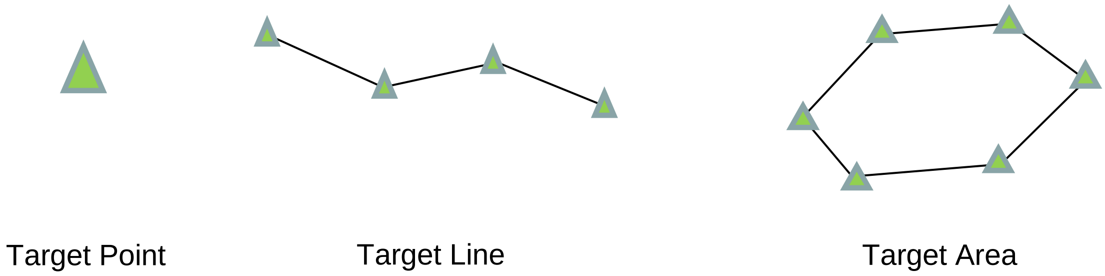

Figure 6. Example of fixed target types

And the same goes for the sensor plan, relative to the UAV payload (EO/IR, SAR, etc.). Of course Route, Airframe and Sensor Plans are strictly related one to another, also if they have been represented by different blocks in Fig.1 due to their conceptual differences. In practice, in fact, is very common to associate vehicle or payload actions to route's WPs. In any case, these plans will be even less important as UAS autonomy increases, since the relative actions will be performed at the optimal point/time by the system.

Target plan provides all needed information relative to the planned target. For fixed target, at least the relative coordinates shall be given in input. At this purpose, we can distinguish between target point, line and area. The first is simply identified by its Latitude, Longitude and Altitude. The second and the third are described by the vertex's coordinates (LAT, LON, ALT) of the segment composing the target line or defining the area's perimeter. Other information like a target ID, description or images can be added to aid the operator. Images (also thermal), in particular, should be considered for automatic target identification system. Target plan is strictly related to the sensor plan, since for each target we can specify the sensors to be used and associating automatic relative action (e.g. camera and Field Of View selection for an EO sensor).

COMM Plan represents the list of radio frequency and relative station IDs that will be used during the flight, plus the transponder ID. Usually radios are divided primarily by GCS radios, On-Board Radios and SATCOM, and secondarily – for the GCS and On-Board radios – by the frequency spectrum (HF, VHF and UHF). If the considered UAV is able to navigate also using NAVAID (i.e. radio navigation devices like for example VOR, DME, TACAN and ILS), relative frequencies, station IDs and their positions if required shall be provided within the COMM Plan. At this purpose, automatic transition from a NAVAID to another may be planned (e.g. associating the shift to a WP).

Datalink plan contains all data needed to manage the ground and air datalink terminals, like for example frequencies, datalink IDs, ground terminal position, antenna mode, channel priority and so on. In particular we distinguish between "Line Of Sight" and "Beyond Line Of Sight" (i.e. satellite) datalinks.

Strictly related to the datalink plan is the handover plan, that is all information relative to the handover procedure used to pass from LOS to BLOS datalinks, and to handoff or request control of a vehicle or a payload. This information is for example datalink frequencies, other station IDs, handover point coordinates and so on. Like for airframe and sensor plans, also the handover procedure could be associated to a WP. This plan is very important since the handover is a critical issue for the UAS operations.

Finally, there could be some mission specific Configuration Parameters to be provided. Examples can be airport data (if not present in a navigation database) or specific maps to be used in the mission (e.g. the DTED of the mission zones).

In the near future, large, complex, time-critical missions will likely require multiple UAV and multiple operators, able to combine their efforts as a team, coordinated by high level control centers (i.e. a C4I). This raises new challenges to the mission creation process. Joint operations, in fact, require efficient mission planning and mission monitoring capabilities. In particular, sharing of information between UAS and ground external interface (C4I) is the key for Effective Joint and Combined Operations.

UAS must be fully integrated into Network Operations Framework, providing the main capability to import a new mission from a C4I Center of Control or a Supervision and Coordination Station (like in the SMAT project).

STANAG 4586 Route Concept

STANAG 4586 has been considered as a reference for the project of the entire Alenia Aermacchi GCS and consequently for the project of the Mission Planner embedded in the GCS. It defines the Mission Plan in a very similar way to the previously exposed concept [10]:

"Mission Plan is the route planning, payload planning, data link planning (including frequencies planning), and UAV emergency recovery planning (rules of safety) for a UAV flight."

Considering the standard frames from the CUCS (core of a GCS 's control system) to the VSM (bridge between data-link interface and a specific vehicle) [10], we have the mission structure of Fig.7. Each mission can have more routes, defined by their WPs. Route can be of different type: Launch (i.e. T/O route), Flight, Approach (i.e. landing route) and Contingency. Waypoints are defined in all their four dimensions [10]: lateral position (expressed in absolute LAT/LON with respect to the WGS-84 or in terms of relative position with respect to a defined relative reference system), altitude, arrival time to the WP or speed to WP. Accordingly to STANAG 4586 different types of WP have been considered: Fly-By (short turn), Fly-Through (flyover), and loiter type (Circle, Race Track or Figure Eight).

In addition for each WP it is possible to assign two contingency WPs (A and B), from which contingency routes can be created. Having two emergency routes/WPs could be useful to distinguish two different contingency paths according to the emergency type, like for example lost link recovery point and route to an alternate airport.

For the loiters, further the geometric characteristics, only loitering time can be set as parameter, that determines also the planned exit condition from them. In general a greater flexibility will be liked. For example, a UAV usually loiters at a speed lower then the value used in cruise in order to enhance the endurance, but a loiter speed is not provided in the frame for the Loiter WP. Similarly, loiter number of rounds and exit radials are not provided as possible exit parameters, although in practice they can be requested by the operators.

Airframe and Payload actions permit to associate some vehicle and sensor operations to a WP, like for example turn on the navigation lights or setting the sensor pointing mode [10]. In both cases, according to the STANAG 4586 philosophy, only general actions are defined, with the provision to add specific vehicle actions. These actions are triggered when the relative WP becomes the destination waypoint.

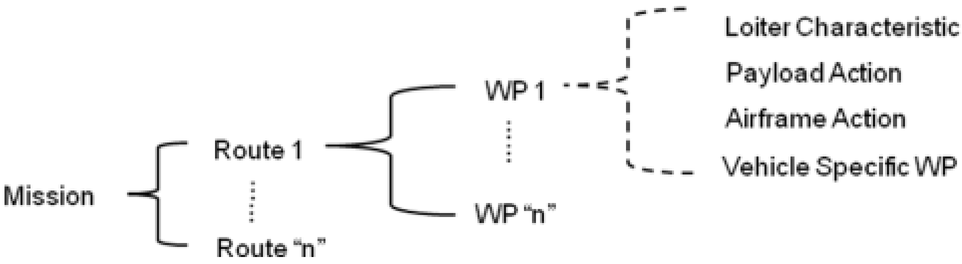

Figure 7. STANAG 4586 Mission Structure

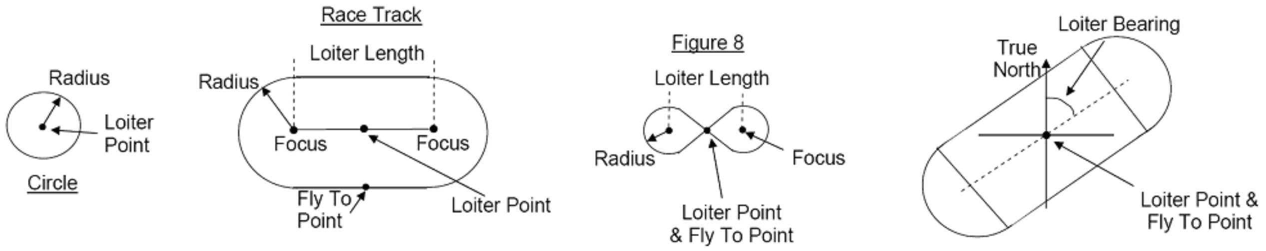

Figure 8. STANAG 4586 Loiter types [10]

To resume, STANAG 4586 considers as top planning block the mission, that is composed by one or more routes, each of them defined by the relative WPs, for which is possible to associate a vehicle/payload action. UAV specific features and STANAG limitations can be resolved by adding VSM specific frames (as foreseen by the STANAG itself).

Planning Issues in the UAS Civil Integration

In order to be integrated in the manned civil air traffic, UAS shall satisfy the following three macro requirements [11]:

- demonstrate an Equivalent Level Of Safety (ELOS) with respect to manned aircraft,
- operate in compliance with the existing aviation regulation,
- appear transparent to other airspace users.

Mission Planning process assists to reach these objectives by ensuring that the plan respects the air rules and reporting it in a compatible format with respect to the standard Flight Plan. For the first point, apart to adopt proper plan verification algorithms, it is important to include the standard IFR procedures into the plan (we assume that a MALE UAV flies usually in instrumental conditions being the operator physically separated by the vehicle). Relative information are provided by standard Navigation databases, that includes the following data [12]: standard WPs, airways, NAVAID (DME, VOR, ILS, etc.), airports, runways, Standard Instrument Departure (SID), Standard Terminal Arrival (STAR), holding patterns and other specific information.

Great circle track between two WPs

Constant radius turn between two WPs

Course between two WPs

Track leg from a WP to a specified altitude at an unspecified position

Track from a WP to a specified radial distance from a database DME

Procedural course reversal starting from a WP

Figure 9. Example of ARINC 424 legs

Relative information are provided by standard Navigation databases, that includes the following data [12]: standard WP, airways, NAVAID (DME, VOR, ILS, etc.), airports, runways, Standard Instrument Departure (SID), Standard Terminal Arrival (STAR), holding patterns and other specific information. These procedures, in practice, are coded in the airliner Flight Management System by using the path and terminator concept according to the ARINC 424 [13]. This is a different way to define a route with respect to the WP, since it specifies not only the leg terminator but also the way in which the leg is flown. According to this philosophy, 23 legs have been created to translate into computer language procedures created for compass and clock manual flight [13]. In general, it is preferable to use leg that do not have possible interpretation [13], like the TF (track between two WPs) or the RF (constant radius turn). Course type legs, in fact, have the problem of possible mismatches due to the magnetic variation, while the leg ending at an unspecified position are by definition inaccurate. This is particularly unacceptable for an UAV that do not have a pilot on-board that monitors physically the aircraft state. In any case, leg that can be interpreted are not compatible with the STANAG 4586 route concept that required a fixed altitude for each WP. Besides, current UAVs navigates primarily with inertial reference system augmented by differential GPS, that consider as reference angle the track and not the course.

For the Flight Plan report, instead, standard format shall be updated for the UAS, since there is the need to add some typical unmanned information like for example: datalink frequencies, handover points, loiter WPs and contingency WPs/Routes.

The above issues are referred to the current Air Traffic Management, but the UAS shall consider also the future enhancements of the ATM, currently studied by several research programs. Taking into account the “Single European Sky ATM Research” (SESAR) as example, for the planning point of view, the main change is the concept of business trajectory. The idea is that all aircraft (manned and unmanned) fly optimized trajectories defined in 4D (the fourth dimension is the time) in order to increase the overall efficiency of the ATM system [14]. Changes to these trajectories shall be avoided as much as possible, with the exception of time critical or emergency situations. Current pre-defined routes, in fact, should be activated only when needed to increase the system capability (e.g. in high congested zone near hubs) [14]. To ensure this concept, an UAS’s mission planner shall have the capability to plan and replan near real time a 4D routes taking into account the possible ATM constraints. In particular, planning algorithms will permit to calculate easily the optimum 4D solutions.

Anyway, the issues reported in this paragraph will be part of close future, but in current operations they are not taken into account since UAS still usually operates in segregated areas.

Route Creation/Validation Algorithms – General Issues

In order to increase the Level Of Automation in the planning process – in particular for the route plan that is the core of a mission – advanced route creation/validation algorithms are needed.

Creating a mission is a very complex task, since there are many paradigms (objectives in optimization problem language) to consider, many times in contrast between them (e.g. sensor constraints vs. fuel consumption). When a route is manually created, the operator is responsible to weight the several aspects to obtain the global optimum, taking into account its operative experience and the specific mission context. Reproducing this knowledge based decision process with an algorithm is not a trivial issue, especially considering constraints in the computational time. A way can be identifying main parameters, for which route creation algorithms that optimizes the relative paradigms are developed. The decision of what algorithm has to be used could be demanded to the operator (ground based planners) or to a top level algorithm. When a complete route is created, the objective changes along it: parts between the airports and the area of operation will be probably created considering the best range paradigm, while sensor performances and targets observation will drive the planning in the operational area. For small routes, it is easier defining the parameter to consider. Another possible approach is to run several algorithms and then combine the different routes with proper weights in order to obtain a global optimization of all aspects. In any case, also if a main paradigm has been identified, there are several general secondary parameters (e.g. minimize the UAV path changes) and mission constraints to take into account. In particular, we shall distinguish between general constraints that limits the possible acceptable routes (e.g. avoiding terrain conflict) and specific constraints that are included in the objective (e.g. create a route of minimum fuel consumption taking into account the maximum available quantity). Therefore, from the mathematical point of view, we have a multi objectives optimization problem.

We can define several optimization objectives (both primary or secondary parameters according to the relative assigned weight), like for example:

- minimum time,
- minimum distance,
- minimization of flight path changes,
- minimum risk considering given threats to avoid (each of them with an assigned risk probability variable with the distance from them),
- threats or obstacles avoiding with minimum path changes,
- best range given an available fuel quantity,
- best endurance given an available fuel quantity,
- best targets observation using a specific sensor,
- best data-link coverage.

As constraints, instead, we can have:

- avoiding threats or obstacles (e.g. No Fly Zones, terrain, thunderstorms) with a possible safety margin to consider,
- operating inside a given area/corridors (critical limit now, with the UAS flying in segregated air spaces),
- altitude limitations,
- fuel available,
- datalink coverage,
- respecting of the air rules,
- time constraints.

Algorithms Certification

From the civil certification point of view, planning algorithms raises several issues, especially the route creation functions. STANAG 4671 [15]- considered valid by the EASA policy E.Y013-01 as base for the certification [16], [3] – asserts only that the automated mission planning calculation must not lead to unsafe conditions. The problem, however, is more complicated then this. An important requirements concerns the computational time that shall be lower then an acceptable threshold and deterministic (i.e. running more times the algorithms with the same input, the output and the computational time shall be the same). In general, determinism is another focal issue for route creation algorithm, since it is crucial for certification according to the current aviation standard [6]. Nevertheless, this is not easy to obtain, since several optimization methods are probabilistic. If the aviation authorities will not accept this behavior, a way can be to certify as safety critical the validation algorithms (deterministic) and use them to check the routes created by not safety critical algorithms. This issue is particularly important for the on-board replanning.

Mission Planning System: the Alenia Aermacchi Experience

General Design Principle

Mission Planner functionalities are integrated into the Alenia Aermacchi Ground Control Station for mission importing, creation and exporting of the mission plan.

Basic functions as mission loading, creation, editing and deletion are performed using the GCS Interfaces.

In addition, dedicated devices (i.e.: laptop) are considered to be developed for advanced stand-alone mission planning management maintaining the commonality with GCS standard interfaces in terms of functionalities, algorithms and HMI.

Provision for the on-board migration of the planning functionalities has been considered in order to increase the system LOA, also for the point of view of multiple UAVs control.

Main features

Main feature of the Mission Planning System are described in the following:

- Creation of mission folder (database) with all the information needed to perform a specific mission:
    - geo-referenced maps (vector maps, raster maps and GIS),
    - geo-referenced images,
    - aviation data (airports, airspaces, airways, etc.),
    - take off and landing data,
    - operational area data.
- Mission plan management:
    - creation, saving and deleting plans,
    - importing and exporting plans.
- Digital Terrain Elevation Data and No Flight Zone for Mission Plan creation and validation.
- Advanced Mission Planning/Replanning functionalities taking into account the following items:
    - Fuel consumption optimization / Time to arrival check,
    - Targets/Payloads characteristics,
    - Data Link Coverage,
    - Weather conditions,
    - Navigation Aids,
    - Vehicle failures (only replannig).

Mission Planner Interfaces

Mission Planning is managed through a Touchscreen display, integrated into the Alenia Aermacchi GCS as an innovative interface for the UAV control [3].

The use of touch screens gives the following advantages with respect to classic Multi Function Displays [3]:

- more instinctive interactions,
- new types of interaction (e.g. scroll slider),
- flexible formats and control allocation (maximising support for information-intensive applications),
- top-level control functions are managed principally by button controls and pop-up menus.

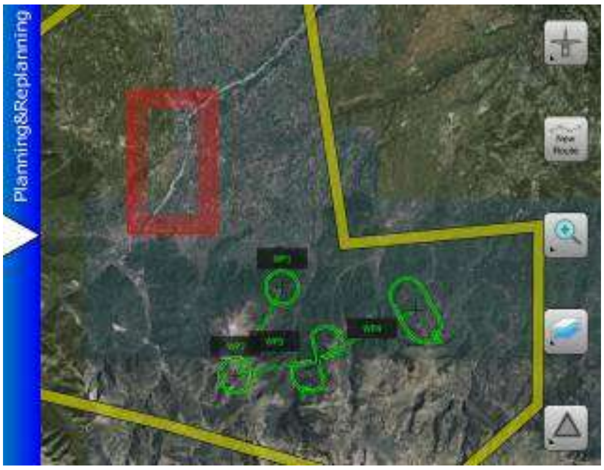

Figure 10. Example of Mission Planner on Touch Screen

Planning Creation/Validation Algorithms

In particular, in our work, we have studied the functional requirements for the route creation algorithms reported in Table 2. Exceptions are the creation of standard research patterns, that is a function that permits to create a path to use in the Area of Operation with simple geometric rules, without an optimization process. This is however an aid for the operator during the planning since he/she does not calculate the geometry of the pattern. These algorithms are parametric functions, and they are conceived to be modular blocks to integrate in a mission planner both on ground (external or integrated in a GCS) or on board.

Complementary to the route creation algorithms we have also studied some validation algorithms, reported in Table 3. They can be used to check a manually created mission or an imported mission. Besides they can be used in an iterative process in order to validate a route created according to an objective for other parameters (e.g. we can create a route to observe a target and then validate it for fuel consumption and datalink coverage). Besides the validation check corresponding to the creation criteria reported in Table 2, we have considered also verifications for No Fly Zones, Area of Operations and Corridors.

Algorithm	Main Objective	Secondary Objectives	Constraints
Target Line or Target Area Monitoring with an EO/IR sensor, considering an automatic target line/area pointing mode.	Best target visualization considering the sensor performance.	Minimization of UAV flight path changes.	• Obstacles free (terrain) along the sensor LOS. • Altitude constraints. • Terrain Avoidance. • UAV performances.
Creation of standard research patterns (step ladder, expanding square, sector scan).	Not Applicable.	Not Applicable.	Not Applicable.
Route creation according to the fuel consumption given starting and ending WPs.	There are two possible optimization modes: • best range, • economic (minimization of fuel consumption with respect to the flight time).	Minimization of UAV flight path changes.	• Altitude constraints. • Terrain Avoidance. • UAV performances.

Table 2. Route Creation Algorithms

Algorithm	Checks
Check that a given route permits to observe a target line with an EO/IR sensor.	• Complete observation of the target line with the requested quality. • Terrain avoidance. • Respects of altitude constraints.
Check of fuel consumption and UAV performance for a given route.	• Available fuel permits to fly the route. • Respect of arrival time assigned to the WPs. • Terrain avoidance. • Respect of altitude constraints.
Check of No Fly Zone Avoidance for a given route.	No Fly Zone Avoidance considering a possible safety margin given in input.

Respect of Area Of Operations and Corridors for a given route.	The input route is comprised in Area Of Operations and Corridors if available.
Datalink coverage forecast (on board monitoring)	Verify that the required link is guaranteed at the UAV foreseen position after a time span given in input.

Table 3. Validation Algorithm

Mission Planning test

Mission planning functions, embedded into the GCS has been positively tested during SMAT project flight test campaign. The purpose of the SMAT project is to study and demonstrate a surveillance system capable to support prevention and control of a wide range of events (e.g. fires, floods, landslides, traffic, pollution, cultivations). The first phase of SMAT project (identified as SMAT-F1) was successfully completed in September 2011, with the scope to demonstrate an integrated surveillance capability within a primary scenario of interest in the North West of Italy (Piedmont Region).

Since SMAT-F1 project involved three unmanned air surveillance platforms (*UAS Sky-Y, UAS Falco XN and UAS C-Fly*) with relevant Ground Segments working in parallel, coordinated by the Supervision and Coordination Station (SSC) there was the need for a global plan which integrated the plans for the specific platforms.

The Mission Plan, coming from the SSC, was send to the UAS GCSs for approval: the SSC Mission plan is a high level Mission Plan normally expressed as task orders, based on targets and related time schedules.

The GCS embedded Mission Planning System has the capability to convert this high level Mission Plan and exploit it applying check algorithms and additional functionalities according to the UAS platform constraints.

Conclusions

Planning and replanning processes have gained more and more importance for modern Unmanned System having a high Level Of Automation. In particular, the need to adopt advanced planning algorithm is underlined. Taking into account the specific planning issues and the STANAG 4586, a GCS embedded planner has been developed for the Alenia Aermacchi Sky-Y UAS. As distinctive feature, an innovative touch screen solutions has been adopted for the Human Machine Interface. Advanced route creation/validation algorithms are an enhancing capability of ground planner, for which the provision for on-board hosting has been considered.

Mission Planner functionalities have been successfully tested during the SMAT-F1 project, into a joint environment with three different UAS platforms coordinated by a single Supervision Station.

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