FEASIBILITY OF USING SYNTHETIC VISION TECHNOLOGY FOR UAV OPERATOR SUPPORT

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Abstract

Both in commercial and military aviation, prototypes of synthetic vision systems have been developed and flight-tested. The main goal of these systems is to make the safety and efficiency of the operation independent of visibility conditions. This is achieved by providing the information needed for guidance and situation awareness through a spatially integrated depiction of data regarding the flight path and all relevant constraints. Even more than with manned missions, UAV operators are constrained with respect to the visibility of the environment in which they operate, thus limiting their situation awareness. This paper explores possibilities to achieve an increase in UAV operator situation awareness by using synthetic vision technologies. Based on an analysis of similarities and differences with manned missions, the rationale behind the implementation of a concept demonstrator of a UAV operator interface based on synthetic vision technology is presented.

Introduction

Unmanned Aerial Vehicles (UAVs) are unmanned flying platforms that carry various payloads and can be used for a large number of operations, especially for those in which the risk of loss of human life or the level of repetition is high. Their military value has been demonstrated by recent operations, notably in Afghanistan and in the Persian Gulf region. In NATO Project Group 35 (PG/35) a number of NATO navies, among which the Royal Netherlands Navy (RNLN), are working together in the combined development of a UAV system.

Problems and Challenges

Both the efficiency with which an operator of a UAV can make mission-related decisions and the correctness of these decisions depend on the level of situation awareness (SA). With respect to the UAV mission, essential elements to achieve a basic level of SA comprise knowledge of the vehicle's condition, its position relative to the intended path and relevant locations of other vehicles, terrain, man-made obstacles, threats and the target area(s). Given a sufficient level of SA the pilot will be better prepared for situations in which new information needs to be taken into account.

The physical separation of the crew from the aircraft can cause problems due to time delay, e.g., a reduction in the amount of timely information can cause poor coordination and reduced SA. In manned aircraft, pilots and crew receive a large amount of information by looking out of the cockpit window, but also auditory feedback and motion cues. UAV operators, on the other hand, are currently limited to a reduced stream of sensory feedback delivered almost exclusively through the visual channel [1], typically impaired through a rather limited field of view, providing what is often referred to as a 'straw view' picture [2].

Furthermore, today's UAV operators are assigned with complex, simultaneous tasks such as replanning, command, control and communication. Plans for single operator control over multiple UAVs (a significant change from the current configuration of multiple crew members controlling a single vehicle) will make the operator's task even more demanding [3].

A reduction of operator workload can be achieved by automation of certain basic flight and mission tasks. However, as the autonomous capabilities of UAVs increase, the operator has to perform higher levels of multi-tasking. The automation of flight management tasks in civil aviation has introduced a number of new SA related problems. Sarter and Woods [4] argue that design-related factors such as opaque interfaces contribute to these problems. Therefore, the introduction of automation to cope with the increasing complexity of mission management has to be accompanied by a corresponding improvement of the UAV operator interface.

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Synthetic Vision Technology

With manned aircraft, synthetic vision (SV) is regarded as a means to increase SA and reduce the effect of limited visibility conditions. In order to increase SA, SV-technology provides the flight crew with a computer-generated depiction of the environment comprising both physical objects (e.g., terrain and obstacles) and non-physical objects (e.g., flight path and airspace constraints). SV-technology integrates various types of data, such as:

- Ownship state and status;
- 4D navigation plan and task/payload plan;
- Digital charts and maps;
- Terrain elevation data;
- Obstacle data;
- Other traffic, enabling the possibility to see and avoid other aircraft;
- Weather Data;
- ATC-instructions;
- Temporary changes and restrictions;
- Real-time sensor data (e.g., radar, video/IR), providing up-to-date information about areas of interest and danger zones. Sensor data can also serve as an integrity check of the static (stored) environment data.

In the near future, satellite or surveillance imagery may also be integrated to provide additional (near) real-time information in military scenarios.

Given the similarities in information requirements regarding the vehicle and the operating environment between manned aircraft and UAVs, it seems logical to investigate the potential of SV-technology for operator support in UAV mission management.

Research Approach

Rather than using an approach based on existing components for the simulation of the out-of-the-window view [2], typical for flight simulation, a research SV system [5] was modified. In conventional computer-generated imagery (CGI), such as simulators, the emphasis lies on attaining the best possible illusion that the environment is real. This is accomplished using static databases of geometry data and photo textures. The age of the data only becomes an issue when significant changes have been made to an airport environment. In contrast, SV databases regarding terrain, man-made obstacles, airport and restricted airspace must always be up-to-date. Furthermore, the research SV system inherently provides a high degree of flexibility regarding the mapping of data to specific representations, the integration of elements that have no physical counterpart and the dynamic depiction of elements based on a set of rules.

To investigate the potential of SV-technology in both navigation and tasking aspects of UAV mission management the following approach was used.

- Analysis of a typical UAV Reconnais-sance, Surveillance and Target Acquisition (RSTA) mission and identification and classification of its required functions;
- Classification of the data required by these functions;
- Identification of the operator interface design issues concerning information presentation and control, specific to UAVs;
- Implementation of a concept demonstrator based on existing SV-technology software components.

The resulting system has been used to involve experts from the RNLN in this project and to initiate a discussion about the operational value of the proposed operator interface concept.

Mission Management Process

To be able to recognize opportunities to increase SA and analyze the requirements of a future operator support system, we first have to understand the mission management process. This will lead us to a categorization of the information requirements that will be used later as a design basis for the operator interface.

Figure 1 shows an overview of the functions and data involved in the mission management process of a UAV system. This overview was derived from an analysis of a number of representative mission types [6]. The ovals represent the data and the rectangles represent the identified functions. Based on the overall mission plan, possible conflict data, operator instructions, UAV capabilities and goal-related data, a short term *current plan* is generated. This plan consists of a 4D navigation and a mission payload plan. During the mission, the current plan is continuously updated based on new information regarding:

- changes in threat environment, e.g., a pop-up Surface-to-Air Missile (SAM)-site;
- changes of mission objectives, e.g., new target, new restrictions;
- non-conformance of the current UAV state, e.g., position errors or a change in UAV capabilities due to failures;
- hazardous weather;
- separation conflicts, i.e., a member UAV or manned aircraft exceeds the specified separation criteria;
- integrity conflicts, i.e., discrepancies between different information sources.

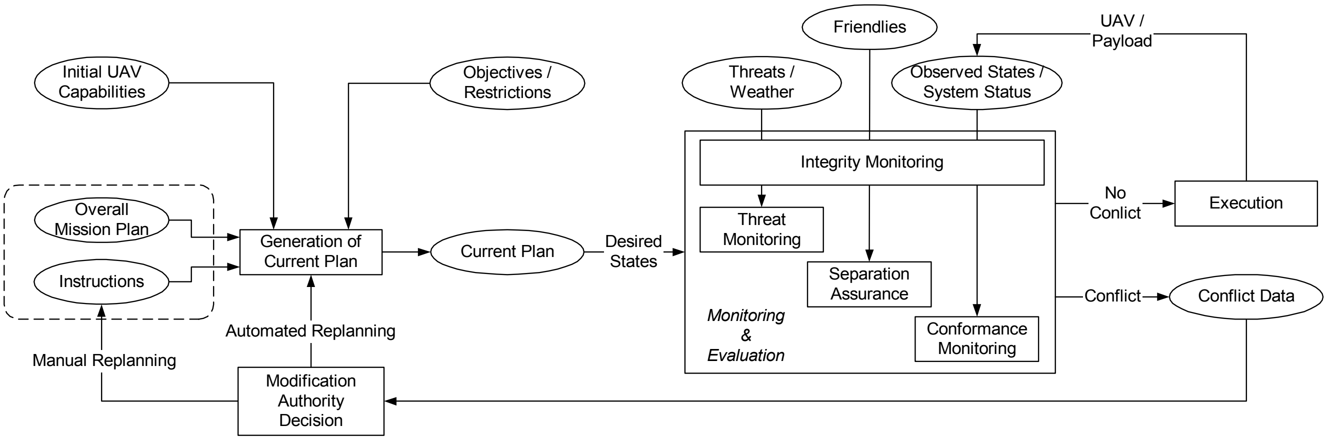

Figure 1. Mission Management Process

The proposed mission management process of the UAV is built around four main functions, i.e., *conformance monitoring, separation assurance, integrity monitoring* and *threat monitoring*, each of which will be separately discussed. Together these functions constitute a monitoring and evaluation (M&E) function, which monitors the physical world and evaluates the current plan to ensure its effectiveness in producing conflict-free trajectories and effective execution of the mission tasks. The outcome of this process is either a plan approval (no conflict), or a trigger to modify the plan (conflict).

Moreover, Figure 1 distinguishes two categories of plan modification: automated replanning and manual replanning (performed by the operator). This decision is dependent on the complexity of the conflict, the available time[1] to resolve the conflict, consequences of a wrong or non-timely modification and the required UAV flexibility. These automation and authorization issues will be discussed in more detail in the section about control aspects.

Conformance Monitoring

The conformance monitoring function determines whether the intent, the current plan, is being followed. System status feedback enables failure[2] diagnosis.

Separation Assurance

The separation assurance function is to provide safety from mid-air collisions and wake vortices by monitoring the surrounding airspace for other aircraft. With manned aircraft in controlled airspace, non time-critical separation assurance is provided by Air Traffic Control (ATC). This is based on monitoring the positions and intentions (flight plans) of all aircraft in a specific area. As a safety net for time-critical separation conflicts, systems such as the Traffic Alert and Collision Avoidance System (TCAS) or Enhanced TCAS (ETCAS) are used. In the United States, both armed forces and civil UAV operators must seek waivers from the Federal Aviation Administration at least 60 days in

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[1] Mission plans typically cover three different time domains: strategic (hours), tactical (minutes) and time-critical (seconds) [7].

[2] In this context failures include both own and infrastructural deficiencies.

advance to conduct a UAV flight in civil airspace [8], severely limiting the flexibility of UAV operations. Hence, various research efforts aim at providing see-and-avoid technologies to enable routine UAV operations in civil airspace [8]. Because in-flight replanning causes the UAV to be in unexpected places at unexpected times, the ability to dynamically deconflict routes is crucial [7].

Integrity Monitoring

The term integrity is used in the aviation community as a performance metric, indicating the quality or state of being free from error, fallacy, or misapprehension [9].

Integrity monitoring consists of performing consistency checks among independent data sources to improve *data integrity* and applying built-in test equipment (BITE) to improve *data processing integrity*. This reduces the likelihood of an undetected failure and thereby increases the *total system integrity*.

Threat Monitoring

Threat Monitoring deals with external situations that threaten UAV survivability and mission effectiveness. These have been categorized into adverse weather threat and hostile threat.

Information Requirements and Sources

Based on the mission management process, this section will identify the information requirements and sources. In addition to the previously defined information categories, we will introduce the category of goal-related data. Furthermore, it is recognized that the information requirements and priorities are mission phase dependent.

Conformance Data

The conformance monitoring function compares the observed UAV behavior with the current plan, which contains both navigational and tasking aspects. Additionally it also includes failure monitoring.

Navigational Aspects

Navigation requires the determination of the position and velocity of a moving vehicle. Obviously, for a sufficient level of SA, it is essential that the operator at all times knows the actual and intended location, speed and track of the UAV. The operator should also be aware of the endurance since this indicates the extent towards which the UAV can accomplish all of the mission goals.

Tasking Aspects

Evidently the tasking aspect of the conformance monitoring function is mission dependent. In an RSTA scenario, the UAV payload will generally consist of sensors. In this context, relevant tasking performance parameters are the actual and intended *sensor area coverage*, *targets in the field of view* and the *quality of the sensor data* required for object detection, recognition and identification.

Operator support can be provided by means of automated target tracking. To improve the ability of RSTA platform operators to deal with uncertainties concerning the locations of dynamic targets, Bell [3] describes an automated search area planning system. Using digital terrain data, target mobility models and sensor capabilities, a minimal search area for detection and location is computed. Automated monitoring of the quality and the contents of imaging sensor data is quite complicated and therefore still requires some degree of supervision. Automated monitoring of imaging data lies beyond the scope of this paper.

Failures

Failure monitoring takes place either directly, through BITE in mission-critical systems, or indirectly by observing failure consequences (e.g., position errors due to a failure of a navigation system).

To provide operator decision support it is important to not only show the failure characteristics, but also to translate these into operational constraints. To this end the SV system proposed by Theunissen [10] takes into account total system energy in computing possible resolutions in case of engine failures at low altitudes.

Separation Data

Data envisioned for the use of separation assurance comprises both data from commercial TCAS and data from onboard optical sensors and radar to pick out aircraft without transponders [8]. In addition, non time-critical separation data may be provided by systems such as an Airborne Warning and Control System (AWACS).

Integrity Data

Integrity data is all data from which can be concluded that a system is not operating within its specifications. A duplex system (two redundant devices) enables fault detection only, whereas a triplex (or more) system with voting architecture allows fault isolation, ignoring the erroneous device.

As with system failures, the operator should not only be informed about integrity conflicts, he should also be informed about the operational consequences of these conflicts.

Threat Data

As explained earlier, UAVs may be exposed to adverse weather threat or hostile threat.

Adverse Weather Threat

Information about hazardous weather can be received from own or external weather radars or LIDARs. Important characteristics are type (e.g., turbulence, precipitation, icing), location, extent and effect on operation (i.e., influence on vehicle and sensor capabilities, datalink, etc.).

Hostile Threat

Information about hostile threats can be received from own or external sensors such as surveillance and tracking radars, IR and Electronic Support Measures (ESM) sensors. Essential information comprises location (relative range and bearing), behavior (in order to deduce its intentions) and capabilities (of both its sensors and weapons). Together these concern the UAV's susceptibility. ESM sensors are useful in monitoring and assessing adversaries. By detecting hostile electromagnetic emissions these provide information about exposure to hostile radars. A threat exposure figure can be defined, with increasing penalty for search, tracking and fire control radars.

As with dynamic targets, we might use the earlier discussed method [3] to determine the most likely locations of (known) moving adversaries.

Goal-Related Data

Based on political, strategic or tactical grounds, the mission objectives and restrictions might change. This directly influences the current plan as it will yield a new reference frame of mission goals and constraints in which the operator has to plan the actions of the UAV. To assist the operator, it is important to show the effects of these constraints with respect to the current plan and to show the range of possible solutions from which the operator is allowed choose. Examples of time and mission phase dependent constraints are rules of engagement (ROEs) and emission control (EMCON) plans.

Information Presentation

Having identified the required information, we continue with the options of presenting that data. This requires both choices regarding the representation of the data (objects, symbols and attributes) and how this data is viewed (e.g., frame of reference and projection method). These affect both the effort required for data interpretation and the level of operator SA and consequently influence the decision-making capability and the ability of timely conflict resolution.

In manned aircraft SV is typically used to support the manual control task. It provides spatially integrated information about the prescribed trajectory and all relevant constraints in an *ego-centric reference frame*[3] (ERF) to minimize the required mental effort for data collection, mental rotation and integration. The choice for such a reference frame follows from the fact that it is optimal for the task with the highest information bandwidth requirement. Since in UAV mission management the operator's tasks are mainly beyond a near-time horizon, the selection of the reference frame must be revisited.

Viewpoint of the Synthetic Camera

The way data is viewed is determined by the 'viewpoint' of the synthetic camera, i.e., its position and orientation in 3D space and the projection type (orthographic or perspective).

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[3] Ego-centered frames of reference present information from a momentary, (changing) point of view as seen from the vehicle.

Camera Position

The camera position can either be *ego-centered* (camera located at the vehicle) or *exo-centered* (camera located outside the vehicle). An exo-centric point of view can be vehicle-connected (also denoted as a vehicle-slaved or tethered viewpoint), following the movement of the vehicle through the world, or world connected.

In general, global spatial awareness improves with viewpoint exo-centricity, while navigational awareness for local guidance and control decreases correspondingly [11]. This means exo-centered viewpoints are best in presenting a strategic overview of the situation while (near-) ego-centered viewpoints provide more SA in the tactical and time-critical domain.

Camera Orientation

The frame of reference in which the data is presented is also determined by the coupling of the three camera orientation axes to either the vehicle or the world reference frame axes. This can affect the level of SA because the navigational awareness of a pilot or UAV operator greatly depends on the ability to make a cognitive coupling between the *world centered reference frame*[4] (WRF) and the ERF [12].

In general, ERF displays provide the advantage of alignment of the vehicle movement (left and right turning as well as nose-up and –down maneuvers) with the displayed reference system. Since the operator does not have to perform mental rotations on the presented information, the probability of control reversal is reduced. On the other hand, WRF displays provide the advantage of consistency, a stable frame of reference that eases coordination between different vehicles or units [13]. Therefore we suggest that situations which demand quick resolutions or maneuvering, would benefit from ERF displays, while WRF displays are best suited for planning and other higher-level decision making.

Projection Type

To present data of the environment of the vehicle on a display, some kind of projection has to be used. *Perspective projections* provide a realistic presentation of depth, appropriate for 3D data sources, but the resolution varies as a function of distance along the line of sight. *Orthographic projections* of 3D data have constant scaling but suffer strongly from ambiguity problems.

Earlier research has shown that when pilots are presented with a plan-view representation of a conflict situation, in which the altitude is presented at discrete locations, the resolutions they generate are mainly in the horizontal plane [14]. Theunissen [15] concludes "an emphasis on a certain spatial dimension causes a bias in the decisions, and certainly not always yields the best solution". For UAV mission management, conflicts in the tactical and time-critical domain, such as pop-up threats, are likely to require multi-dimensional resolutions. Such replanning will therefore benefit from a spatially integrated perspective presentation of conflict data. On the other hand, for more strategic tasks, the reduction in resolution of the data along the line of sight is likely to be a driver for an orthographic projection. Given the inherent ambiguity problems with orthographic 3D depiction, a sufficiently augmented orthographic plan- and side-view presentation is likely to be a very good solution for strategic replanning.

Level of Realism

A certain level of realism of the presented data is necessary to obtain sufficient SA and operator trust in the system. However, too much realism may bias the (sensor) operator regarding the actual available intelligence about the environment. For instance, the contours of the terrain are typically rendered based on terrain elevation data. However, as soon as photo realistic textures are used to increase the level of realism, the age of the data becomes an issue. One could argue that only the real-time conversion of sensor-derived data into terrain textures provides the appropriate information. When using other information sources (previous aerial photographs or satellite imagery), visual attributes should be included to keep the operator aware of the age of the data.

Control Aspects

Control refers to the actions that should be undertaken in order to achieve the system's objectives.

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[4] Earth-fixed, or world centered frames of reference present information from a stable, world oriented viewpoint.

Automation, Autonomy and Authority

Automation of basic flight and payload tasks enables the operator to focus on higher-level decisions. However, the introduction of automation and autonomy leads to the problem of authority. For instance: when should the operator or automation have ultimate authority? Levels of autonomy and automation can be identified using a ten level scale proposed by Sheridan [16], shown in Table 1. Important questions arising in the design of a modern UAV system are:

- Should there be certain states for which the automation will take over control from the operator, e.g., when the operator tries to exceed the flight envelope or datalink range?
- Should the automation be able to deviate from the current plan if unexpected circumstances arise, e.g., pop-up threats, separation conflicts or targets of opportunity?
- If the operator programs certain maneuvers or payload tasks ahead of time, should the UAV automatically execute these at the designated time/ location, or should the operator be asked for approval? This question is becoming more and more important as UAVs will be equipped with weapon systems.
- Should possible subsystem abnormalities be reconfigured automatically, with after-the-fact display of the conflict and its resolution? Or should the automation wait to take action until the operator has learned about the conflict, perhaps been given some advice on options, and had a chance to take initiative?

It should come as no surprise that there is no general answer to the above questions. The appropriate level of automation varies from function to function and the authority to operate on a certain level of automation depends on type of mission and mission phase. Aspects, which in our view are important in determining a level of automation, are:

Time available for replanning: in the case of time-critical events there may not be enough time for the operator to understand the problem, let alone to generate a successful resolution.

Complexity of the conflict or problem: higher-level decisions, and decisions in unfamiliar situations require the knowledge-based reasoning capability of the human mind.

Consequences of a wrong decision: this is closely related to the aspect of liability and responsibility. Or as stated in Pritchard [7] ". . . as long as we feel the need to be able to blame someone when things go wrong, we will always want a human operator in charge".

Dilemma between controlling and monitoring: if the operator does all the controlling, there is the danger of becoming overloaded and fatigued. On the other hand, if the operator is purely monitoring the progress of an automatic system there is the danger of becoming bored and less attentive.

Table 1. Levels of Automation, Sheridan [16]

1	Automation offers no assistance, the human must do it all;
2	Automation offers full set of action alternatives, and
3	narrows the selection to a few alternatives, or
4	suggests one, and
5	executes suggestion when operator approves, or
6	allows the operator a restricted time to veto before automatic execution, or
7	immediately executes automatically, then necessarily informs the operator, or
8	informs the operator after execution only if the operator asks, or
9	informs the operator after execution if the automation decides to;
10	Automation decides everything autonomously and ignores the operator.

Levels of Control

Regarding vehicle navigation, three levels of control can be distinguished. In order of increasing control action bandwidth these are *outer-loop*, *directional* and *inner-loop* control.

The most outer-loop facilitates dynamic replanning and is part of the navigation function. The directional control loop, or the guidance function, represents the loop in which the short-term progress is monitored and controlled. The inner-loop represents the typical control function, which tracks a computed reference value [17].

In our RSTA concept of operations, the UAV operator specifies the goals, constraints and procedures for execution. He is the responsible planner and decision maker who is interpreting information about the system performance. Thus the UAV operator provides the reference for the outer-loop control function. The intermediate, directional control function can be assigned to both the operator and the UAV. Although preferably to a large extent assigned to the UAV's automation, some situations, such as ATC vectoring, still require directional intervention from the operator. The inner-loop will cover the basic flight and payload tasks such as flight or camera stability and is fully automated.

UAV Control Scheme

Taking into account automation issues, the described control levels plus earlier navigational and tasking aspect considerations, yields a UAV control scheme as presented in Figure 2. This figure shows the different levels of control and the way in which the operator intervenes. Separation between navigation (top) and tasking (bottom) aspects as well as an arrangement of the control functions based on their bandwidth is proposed (dashed rectangles). The current plan, as discussed earlier, consists of a 4D (navigation) plan and a payload (tasking) plan. In the case of an RSTA mission, the navigation plan is a set of 4D waypoints and the payload plan describes the locations at which the field of view (FOV) of a sensor should be aimed at. At this level, in the outer-loop, the current plan is time and space discrete. At the directional loop, the guidance processes translate the discrete plans to continuous functions which describe the trajectories of both the vehicle and the payload's FOV. These serve as references for the inner-loop control functions. At the inner-loop the Automatic Flight Control System (AFCS) and the Automatic Payload Control System (APCS) generate commands to the actuators to implement the forcing function and payload function.

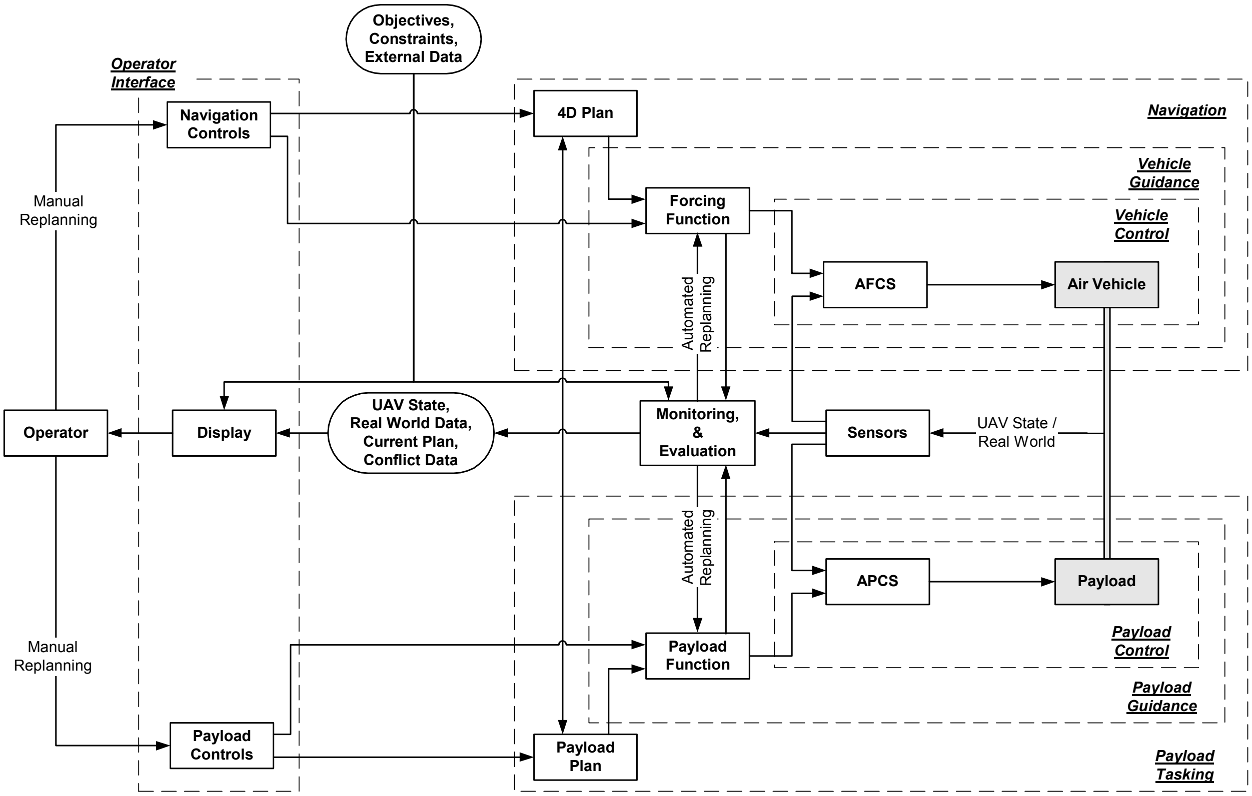

Figure 2. UAV Control Scheme

Figure 2 shows the relationship between automated and manual replanning. The operator can control the system by means of the navigation and payload controls. He can either adjust the discrete current plan (outer-loop control), or he can directly influence the guidance process by specifying a reference function, which might be a stored/predefined action (directional control), that serves as the input for the fully automated inner control loop. Examples of such reference functions are commanded headings and altitude hold commands. The required information is presented on the operator interface display(s). In the case of automated replanning, the mission management system will adjust the reference condition automatically. As discussed earlier, the monitoring and evaluation function is the key element that triggers the mission replanning process.

Relating Table 1 and Figure 2, we see that at levels 2-4 the automation is purely providing decision support. Based on the information originating from the M&E function, the operator interface presents the operator with possible solutions or constraints required for outer-loop control. These automation levels will therefore apply on higher-level decisions, mostly in the strategic time domain, such as planning of an optimal route. Levels 5 and 6 relate to manual directional control. While the initiative is still on the side of the operator, level 6 only allows a restricted time for the operator to make up his mind. These levels will typically apply to decisions in the tactical time domain as a late decision in this domain may result in a time-critical conflict. At automation levels 7-9 the operator is taken out of the direct control loop and moved up to the role of supervisor. This corresponds to automated directional control. Note that it does not necessarily mean that the operator cannot override the system when he questions the quality of the decision made by the automation. Following the preceding arrangement, automation levels 7-9 apply to decisions in the time-critical domain. Level 10, in which the operator has no influence at all, applies to the innermost control loop in which vehicle and payload stability are guaranteed.

Concept Demonstrator

Based on the preceding discussion we propose an operator environment functionality and implementation as presented in Table 2. We suggest using perspective displays (denoted as 3D) for awareness in the tactical and time-critical domain and orthographic displays (denoted as 2D), such as a plan-view display (PVD) and vertical profile display (VPD) in the strategic domain. Manual control applies to both the outer- and directional loop whereas automated control applies to the directional and inner-loop.

In order to demonstrate the potential of SV-technology for UAV operator support to the RNLN, a concept demonstrator was implemented. This was achieved through modification of existing software components of an SV research system, which is developed at the Delft University of Technology.

Implemented Operator Environment

As shown in Figure 3 the realized operator environment consists of two types of perspective displays, a PVD and a Multi-Function Display (MFD).

The Perspective displays[5] provide a tactical overview of the situation from various adjustable points of view. As mentioned before, short-term conflict avoidance/resolution is likely to require a multi-dimensional approach. The center display corresponds to an SV primary flight display (PFD) and presents an ego-centered point of view. It displays the intended trajectory, terrain, traffic, threat zones, restricted areas and target areas. The required state symbology (e.g., roll, pitch, heading, speed and altitude indications) depends on the operator's primary task. Whereas an aircraft pilot focuses on control of the instantaneous vehicle state (such as attitude), the UAV operator should concentrate on tactical and strategic mission aspects. For tactical aspects, limited symbology (only speed, altitude and heading) is sufficient while strategic aspects require no current state indications at all. Therefore the attitude, track, speed and altitude readouts can be toggled on or off. Additionally, the PFD is integrated with the simulated imagery of a nose-mounted sensor to provide real-time visual data. The limited field of view and ego-centric reference frame prevent the PFD from providing adequate strategic information. Therefore the other perspective displays present an exo-centered, vehicle-slaved point of view, depicting the trajectory of the aircraft in the context of surrounding terrain and integrated with the required information described earlier. The points of view as well as

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[5] Figure 3 shows a total of five perspective displays, as used in the original set-up of the SV research system that served as a starting-point for the UAV concept demonstrator.

the fields of view of the displays can be adjusted individually using a touch-screen multi-function display. The ability to select multiple points of view is intended to contribute to an increase in the level of awareness about the environment.

Table 2. Subset of Elements in the Proposed Operator Environment

Element	Function	Visualization 3D	Visualization 2D
Ownship symbol	Represents ownship position.	wire frame aircraft	arrowhead
Waypoint	Describes the trajectory, these can be moved and inserted by means of the touch-screen PVD (horizontal plane) and MFD vertical profile plot, as an example of outer-loop control.	-	star
Stored Trajectory	Represents the planned trajectory (forcing function).	white line	white line
Intended Trajectory	Represents a preview of the intended replanning actions. The operator will be warned if he tries to (re)plan the trajectory into dangerous areas.	-	magenta dotted line
Heading / Flight-path angle Marker	Represents the track/flight-path angle that will be followed temporarily when a direct-to is executed. This enables manual directional control, used for temporarily deviations from the planned trajectory.	-	magenta dotted line
Terrain Warnings	Enables the operator to evaluate the current and proposed plan and ensure their effectiveness in producing a trajectory free of terrain conflicts.	red zones	red zones
Traffic	Supports separation assurance by providing an estimate of the location of other traffic	wire frame aircraft	TCAS: diamond (non-directional) ADS-B: arrowhead (directional)
Threat	Represents hazardous volume of space, which the UAV should avoid (weather/hostiles). Threats might appear in each of the three defined timescales.	yellow cone	yellow circle
Target Area	Represents the area of interest. The UAV should fly over these entire regions in a stable flight so imagery can be collected.	orange box	orange rectangle
Sensor Picture	Represents real-time imagery of a nose-mounted camera payload. Used to demonstrate the tasking aspects (location FOV, imaging quality) of the mission plan.	Integrated in ego-centered display. Might also be useful as a projection in the exo-centric displays	Projected onto the horizontal plane.
Predefined Action Library	Enables quick reaction to (near) time-critical conflicts (manual directional control).	-	-
Viewpoint Actions	Enables adjustment of the positions, orientations and fields of view of the synthetic cameras.	-	-

Figure 3. Display Setup with Perspective Displays (upper row), PVD (lower left) and M

The touch screen Plan-View Display provides a more strategic overview of the situation and serves as a (re-)planning tool. The PVD displays obstacles, beacons, intended trajectory, traffic, terrain, threat and target data and integrates these on a digital map. The obstacle and beacon data can be toggled on or off to prevent information cluttering. The PVD also presents basic heading, altitude and speed readouts. The operator can alter the flight plan simply by dragging waypoints to the desired 2D position. The desired altitude and speed at the waypoints can be altered numerically. The operator may also insert extra waypoints by means of the drag and drop principle to support retasking actions. Besides the outer-loop control of waypoint positioning, the PVD also supports directional control tasks, such as heading commands. Before sending the intended commands to the UAV, the PVD automatically shows warnings along the route concerning terrain conflicts. This previewing capability provides an extra validity check before actual implementation of the actions. It is currently limited to terrain conflicts.

The touch-screen Multi-Function Display provides a 2D orthographic vertical profile plot to assess ground clearance and to enable both vertical outer-loop and vertical (manual) directional control. Additionally, the MFD contains controls to alter the points and fields of view of the exo-centered displays to improve SA. Furthermore the MFD contains a command library for essential predefined actions and maneuvers (evasive maneuvering, countermeasures, terrain following and search/loiter patterns) to enable manual directional control. Currently the MFD is still limited to viewpoint controls.

Demonstrated Scenario

In order to obtain initial feedback, an RSTA scenario containing a planned trajectory and three unexpected events was demonstrated. The objective of the UAV was to fly over the assigned target area to collect video imagery (by means of a simulated camera). The planned trajectory led past two known hostile Anti-Aircraft Artillery (AAA) sites, both with a danger zone of 6 km in diameter. Figure 4 shows a screenshot of the scenario on the PVD. The trajectory is flown counter-clockwise; the pop-up threat has already appeared.

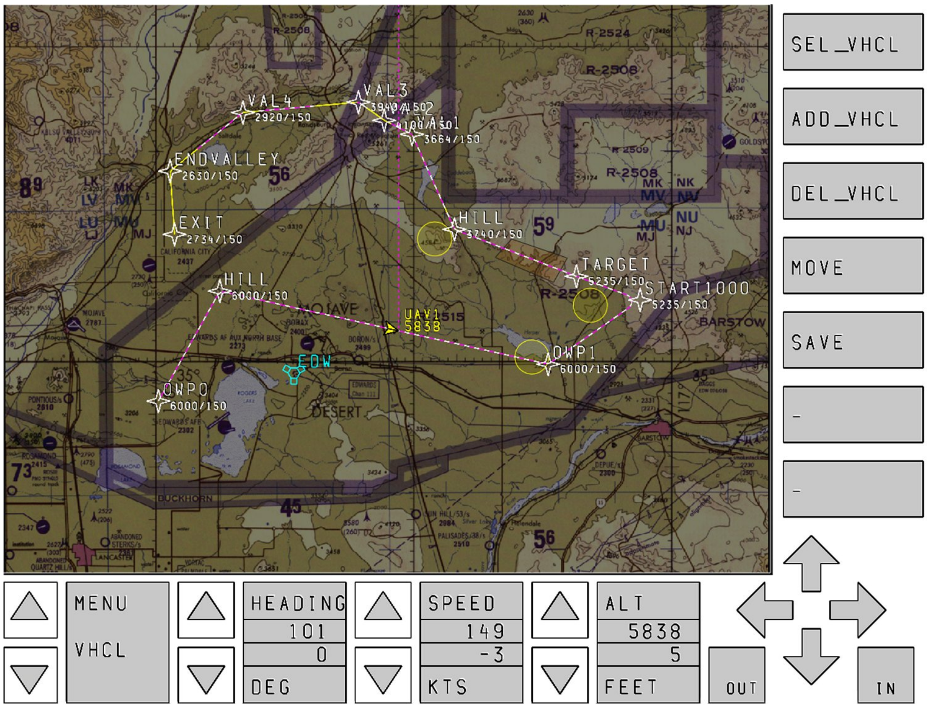

Figure 4. Plan-View Display with Demonstrated Scenario

First, an ATC-vectoring was simulated, demonstrating the ability of using manual directional control to resolve a separation conflict in the tactical domain. Thereafter, the operator could disengage the direct-to mode after which the UAV would automatically intercept and resume the planned trajectory (automated directional control). Next, a pop-up threat appeared along the trajectory. This event also belonged to the tactical time domain, giving the operator sufficient time to move some waypoints in a way to prevent the UAV from entering the threat's lethality zone. Changing the route should neither endanger the mission objective, nor lead the UAV into other danger areas. The preview capability of the PVD supports the operator in carefully planning his actions. Finally, while over the target area, the operator was ordered to retask the UAV to a target area some 30 km northeast. This entails waypoint insertion and, since the new track leads through a valley, terrain warnings on proposed trajectory changes.

Because at the time of the demonstration sessions the preplanned action library and corresponding levels of automation were not yet implemented, time-critical conflicts were not yet included.

Conclusions and the Way Ahead

For commercial aviation SV is regarded as a means to compensate for a lack of visual information, while at the same time improving the level of pilot SA. The commonality in information requirements between navigation of manned and unmanned aircraft formed the basis for the idea to investigate the feasibility of SV-technology for UAV operator support. The first implementation phase employed existing SV-software components to create a basic concept demonstrator. Using this concept demonstrator, more detailed functional requirements have been identified. Although the current implementation of the concept demonstrator does not yet have the full functionality as proposed in Table 2, operational and combat system design experts of the RNLN acknowledged the potential of this concept, and provided recommendations for further enhancements and refinements. To further demonstrate the operational value, we suggest the following recommendations and guidelines for future research:

First of all, full functionality based on the indicated information requirements should be implemented, including:

- Vertical profile to enhance vertical navigation;
- Time-on-Target indication (e.g., ghost or time-box along route);
- Endurance indication, taking into account weather and performance;
- Likelihood of detection: information about UAV's ESM-profile/coverage diagram; line-of-sight determination taking into account terrain features and weather;
- Time and mission phase dependent constraints (ROEs, EMCON), restrictions and failures;
- Integration of sensor imagery in exo-centric perspective displays and PVD;
- Dynamic threats and targets; implementation of Bell's search area method [3] to provide additional operator support regarding these objects;
- Control over multiple UAV's to demonstrate coordination support and (non-ATC) separation assurance;

Furthermore, the context-dependency of autonomy and authority should be thoroughly studied and Sheridan's authority questions applied to a specific scenario. Taking into account task priorities, this should ultimately result in a task-based autonomy allocation in which effects of time delay and communication loss are included. Subsequently, the required replanning actions should be identified and implemented in a predefined action library to fully support both manual and automated directional control. Finally, to actually prove the value of the thus achieved prototype, it should be tested and compared with a conventional operator interface. This requires definition of appropriate performance criteria.

References

[1] Draper, M.H., H.A. Ruff, 28 April 2000, Multi-Sensory Displays and Visualization Techniques Supporting the Control of Unmanned Air Vehicles, IEEE International Conference on Robotics and Automation, San Francisco, IEEE.

[2] Hogan, J., E. Pollak, M. Falash, May 2002, Enhanced Situational Awareness for UAV Operations over Hostile Terrain, AIAA's 1st Technical Conference and Workshop on Unmanned Aerospace Vehicles, AIAA 2002-3433.

[3] Bell, B., J. Clark, 2002, Bringing Command and Control of Unmanned Aerial Vehicles Down to Earth, 0-7803-7367-7/02 7.E.1, IEEE.

[4] Sarter, N.B., D.D. Woods, 1992, Pilot Interaction With Cockpit Automation: Operational Experiences With the Flight Management System, The International Journal of Aviation Psychology, 2(4), Lawrence Erlbaum Associates, pp.303-321.

[5] Theunissen, E., R.M. Rademaker, T.J. Etherington, October 2002, Synthetic Vision: A Prototype Display Concept for Commercial Aircraft, IEEE AESS Systems Magazine, pp.13-18.

[6] Tadema, J., August 2002, Beschrijving UAV's en Mogelijke Missies, Preparation for a M.Sc. Thesis Project in Electrical Engineering, Delft University of Technology, in Dutch.

[7] Pritchard, D.E.R., March 2000, Dynamic Route Replanning and Retasking of Unmanned Aerial Vehicles, AFIT/GAE/ENY/00M-10, Air Force Institute of Technology.

[8] Lopez, R., 2002, Avoiding Collisions in the Age of UAVs, Aerospace America June 2002, pp.34-38.

[9] Young, S.D., S.D. Harrah , M. Uijt de Haag, 2002, Real-Time Integrity Monitoring of Stored Geo-Spatial Data Using Forward-Looking Remote Sensing Technology, 0-7803-7367-7/02 11.D.1, IEEE.

[10] Theunissen, E., K. Dobler, G. Sachs, 2000, Systematic Design of Synthetic Vision Displays, Proceedings of the International Symposium on Precision Approach and Landings Systems (ISPA), pp. 395-402, Munich, Germany.

[11] Lasswell, J.W., C.D. Wickens, May 1995, The Effects of Display Location and Dimensionality on Taxi-way Navigation, Technical Report ARL-95-5/NASA-95-2, Urbana, Aviation Research Laboratory, Institute of Aviation University of Illinois.

[12] Aretz A.J., 1990, Cognitive Requirements for Aircraft Navigation, Urbana, Graduate College of the University of Illinois

[13] Wickens C.D., J.G. Hollands, 2000, Engineering Psychology and Human Performance, New Jersey, Prentice-Hall Inc.

[14] Ellis, S.R., M.W. McGreevy, R.J. Hitchcock, 1987, Perspective Traffic Display Format and Airline Pilot Traffic Avoidance, Human Factors 29(4), Human Factors Society Inc, pp. 371-382.

[15] Theunissen, E., 1998, Spatial Terrain Displays: Promises and Potential Pitfalls, 0-7803-5086-3/98 E46, IEEE.

[16] Sheridan, T.B., 1991, Automation, Authority and Angst – Revisited, Proceedings of the Human Factors Society 35th Annual Meeting, pp. 2-6.

[17] Breda, L. van, 1999, Anticipating Behaviour in Supervisory Vehicle Control, Delft, Delft University Press.