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title

Specification and evaluation of the functional requirements of a UAV crew trainer

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Om de mogelijkheden te onderzoeken voor de inzet van low-cost simulatoren in militaire trainingen, is een onderzoeksproject gestart, getiteld ELSTAR (European Low-cost Simulation Technology for the ARmed forces), in opdracht van de Ministeries van Defensie van de vijf participerende landen van Research Technology Project (RTP) 11.8, te weten: België, Duitsland, Frankrijk, Griekenland en Nederland. Dit project bestaat uit 5 werkpakketten. In het eerste werkpakket zijn 4 trainingsgebieden geselecteerd uit een verzameling van 100 militaire taakdomeinen, op basis van een aantal criteria die relevant zijn voor low-cost simulator onderzoek, ontwikkeling en applicatie. Deze trainingsgebieden zijn: rijvaardigheidstraining, staf training, training in het gebruik van optische hulpmiddelen, en UAV operator-team training. In werkpakket 2 zijn huidige (van de plank verkrijgbare) en toekomstige simulator technologieën geïnventariseerd. In het huidige werkpakket 3 van het ELSTAR project zal een uitgebreide taak- en trainingsanalyse moeten leiden tot een meer gedetailleerde beschrijving van de trainingssystemen.

Het huidige rapport omvat een taak en trainingsanalyse van een UAV team, die de basis vormde voor the functionele specificaties van een UAV team trainer. De kostbare elementen van dit trainingssysteem zijn geïdentificeerd om te bepalen welke systeem configuratie meest kosten-efficiënt is. De effecten van gedegradeerde configuraties op de trainingseffectiviteit van het systeem zijn geëvalueerd in een experimentele studie.

De resultaten van de taak- en trainingsanalyse laten zien dat het UAV team voornamelijk visuele informatie gebruikt bij de taakuitvoering. Het zwaartepunt van de functionele specificaties ligt daarom bij het beeldsysteem, beeldgeneratiesysteem en de visuele database. Voorts is gebleken dat de visuele database de kosten-drijvende factor in de ontwikkeling van het UAV trainingssysteem is. De ontwikkeling van deze database is tijd- en kostenintensief omdat de gesimuleerde wereld zowel groot als zeer gedetailleerd moet zijn.

In de evaluatiestudie zijn twee gedegradeerde database configuraties getest: in beide configuraties was een zeer gedetailleerd doelgebied gespecificeerd, terwijl het omringende gebied niet of met een lage detaillering werd gepresenteerd. De trainingswaarde van het systeem is geëvalueerd door UAV training experts. Uit de resultaten blijkt dat de experts beide configuraties als goed beoordelen. Hun aanvullende opmerkingen kwamen erop neer dat zij nog wel ruimte voor verbeteringen zien.

De databaseconfiguraties waarvoor in deze evaluatiestudie was gekozen kunnen de ontwikkelingskosten van een UAV trainingssysteem verlagen, maar er is een meer uitgebreide taak- en trainingsanalyse noodzakelijk om de vereiste eigenschappen van de database te definiëren. De evaluatie kan worden gezien als een eerste poging de trainingswaarde van diverse configuraties van de simulator-deelsystemen te bepalen. In een later stadium van dit project zou de trainingswaarde kunnen worden bepaald door meer objectieve metingen en deze te vergelijken met alternatieve trainingsmethoden.

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SUMMARY

To investigate the possibilities for application of low-cost simulators within military training courses, the research project called ELSTAR (European Low-cost Simulation technology for the ARmed forces) is carried out under the contract of the Ministries of Defence of the five participating countries of Research Technology Project (RTP) 11.8, viz. Belgium, France, Germany, Greece, and The Netherlands. This project consists of 5 work packages. In the current work package 3 of the ELSTAR project, an elaborate investigation of the task- and training requirements of the selected training areas, must render more detailed descriptions of four selected training systems.

The current report includes a task- and training analysis of a Unmanned Aerial Vehicle (UAV) crew, which formed the basis for the functional requirements of a UAV crew trainer. In order to determine low-cost solutions for this trainer, the cost driving requirements of the system were identified. The effects of degrading these requirements on the training value of the UAV crew trainer were evaluated in a experimental study.

The results of the task and training analyses show that visual information is the most important source of information for the UAV crew to perform its tasks; therefore, the focus of the functional specifications is on the image system, with its image generator, display system, and visual database. In the development of a UAV simulator, it seems that the visual database is the major factor in the costs. This database needs to be large and very detailed, which causes the development to be time-consuming and expensive.

In the evaluation study two degraded database configurations were tested: both configurations involve the definition of a high detail target area within the database, while the surrounding area is either left out or displayed with a lower level of detail. The results show that the UAV experts evaluated both simulator configurations as having a high training value. Nevertheless, their additional remarks show that they see room for improvement.

This evaluation experiment can be seen as a first attempt to define the value of specific configuration of subsystems of the simulator for training. In a later stage of this project, training value will be determined by objective measurements against alternative training methods.

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Specification and evaluation of the functional requirements of a UAV crew trainer

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SUMMARY

To investigate the possibilities for application of low-cost simulators within military training courses, the research project called ELSTAR (European Low-cost Simulation technology for the ARmed forces) is carried out under the contract of the Ministries of Defence of the five participating countries of Research Technology Project (RTP) 11.8, viz. Belgium, France, Germany, Greece, and The Netherlands. This project consists of 5 work packages. In the current work package 3 of the ELSTAR project, an elaborate investigation of the task- and training requirements of the selected training areas, must render more detailed descriptions of four selected training systems.

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TNO Technische Menskunde
Soesterberg

Specificatie en evaluatie van de functionele eisen van een UAV trainer

A.S. Helsdingen

SAMENVATTING

Om de mogelijkheden te onderzoeken voor de inzet van low-cost simulatoren in militaire trainingen, is een onderzoeksproject gestart, getiteld ELSTAR (European Low-cost Simulation Technology for the ARmed forces), in opdracht van de Ministeries van Defensie van de vijf participerende landen van Research Technology Project (RTP) 11.8, te weten: België, Duitsland, Frankrijk, Griekenland en Nederland. Dit project bestaat uit 5 werkpakketten. In het huidige werkpakket 3 van het ELSTAR project moet een uitgebreide taak- en trainingsanalyse leiden tot een meer gedetailleerde beschrijving van de trainingssystemen.

Het huidige rapport omvat een taak en trainingsanalyse van een onbemand vliegtuig (Unmanned Aerial Vehicle: UAV) besturingsteam, die de basis vormde voor the functionele specificaties van een UAV team trainer. De in verhouding dure elementen van dit trainingssysteem zijn geïdentificeerd om te bepalen welke systeemconfiguratie het meest kosten-efficiënt is. De effecten van gedegradeerde configuraties op de trainingseffectiviteit van het systeem zijn geëvalueerd in een experimentele studie.

De resultaten van de taak- en trainingsanalyse laten zien dat het UAV team voornamelijk visuele informatie gebruikt bij de taakuitvoering. Het zwaartepunt van de functionele specificaties ligt daarom bij het beeldsysteem, beeldgeneratiesysteem en de visuele database. Voorts is gebleken dat de visuele database de kosten opdrijvende factor in de ontwikkeling van het UAV trainingssysteem is. De ontwikkeling van deze database is tijd- en kostenintensief omdat de gesimuleerde wereld zowel groot als zeer gedetailleerd moet zijn.

In de evaluatiestudie zijn twee gedegradeerde databaseconfiguraties getest: in beide configuraties was een zeer gedetailleerd doelgebied gespecificeerd, terwijl het omringende gebied niet of met een lage detaillering werd gepresenteerd. Uit de resultaten blijkt dat UAV experts beide configuraties als goed beoordelen. Hun additionele opmerkingen tonen echter aan dat zij nog ruimte voor verbeteringen zien.

De evaluatie kan worden gezien als een eerste aanzet om de trainingswaarde van diverse configuraties van de simulatorsystemen te bepalen. In een later stadium van dit project zou de trainingswaarde kunnen worden bepaald door meer objectieve metingen en deze te vergelijken met de resultaten van alternatieve trainingsmethoden.

1 INTRODUCTION

1.1 Background

The EUCLID program focusses on the European development and production of cost-effective systems that can fulfill future military needs. One of the Research Technology Projects (RTP) within EUCLID is RTP 11.8, entitled: ***Low-cost Simulators***. Low-cost simulators are defined as a new family of training devices that, through the use of commercially available and emerging technologies, provide superior benefit-to-cost ratios when compared to full fidelity simulators. The present research project, which is carried out under contract of the Ministries of Defence of the five participating countries of RTP 11.8 (Belgium, France, Germany, Greece, & The Netherlands), is called ***ELSTAR***, an acronym for: ***European Low-cost Simulation Technology for the ARmed forces***.

The ELSTAR approach for developing low-cost training simulators is to identify and select those critical task elements that can be easily simulated with high fidelity. The approach involves three steps:

1) selection of military task domains that are suitable for cost-effective simulator training
2) aggregation of (sub)tasks and critical cues that can be easily simulated with high-fidelity in combination with the elimination of the (sub)tasks that are difficult to simulate, and
3) careful integration of simulator training into the curriculum, taking into account the opportunities and limitations of low-cost training simulators.

As a first step, military task domains were selected that may be conceived as the most promising for application of simulation technology and for the generation of relevant knowledge, see Korteling, Van den Bosch, and Van Emmerik (1997). For this purpose a military task taxonomy, called the ELSTAR taxonomy of military tasks, was constructed, consisting of about 100 task domains. With this taxonomy, judgments from training- and simulator experts were obtained on each task domain and on 15 different criteria which reflected prospects for low-cost simulation and generation of relevant knowledge.

On the basis of the expert-judgments, many domains were considered very appropriate for further investigation. In order to narrow the potential number of subjects, a concise set of 9 military training areas was defined that represented the selected task domains. These are the short descriptions of these training areas (Korteling, Van den Bosch & Van Emmerik, 1997):

1 Wheeled vehicle control (Driving)
2 Air platform navigation (APN or Navigation)
3 Image intensifier and thermic infrared equipment (II/IR)
4 Manoeuvring unmanned platforms (Unmanned Aerial Vehicle: UAV)
5 Within visual-range, guided, fire-and-forget, single-unit operated weapon systems (Stinger)
6 Within visual-range, guided, fire-and-forget, co-ordinated weapon systems (FAC)
7 Beyond visual-range, non-guided, fire-and-forget, single-unit weapon systems (M109)
8 Fault diagnostics and maintenance of complex composite systems (Maintenance)

9 Mission planning and implementation (Mission management).

On these training areas more detailed data were acquired with respect to task- and cost-utility information (Helsdingen, Korteling & Van den Bosch, 1997, 1998). Subsequently, these data were analysed in the global training- and cost-utility analyses of work package 1c (Van den Bosch, Korteling & Van Winsum, 1997). The training analyses identified and described the *critical* knowledge and skills to be trained and the critical cues and task elements (with regard to training and to simulation) of the most representative subtasks of each selected training area. The cost-utility analysis compared training utility and cost reduction potentials which provided indications with respect to selection of further research candidates. These analyses were used to verify whether, and to what degree, the selected task domains are indeed interesting for low-cost simulator development and application. These data were also used for the final part of work package 1, that is: the selection of 4 training areas for further research. This selection method involved all relevant information available and attained so far. This included the consideration of the scores on the military task taxonomy (WP1.a), the field inventory (WP1.b), the training- and the cost-utility analyses (WP1.c), and expert-judgments (WP1.d). In this final phase of work package 1 also global functional descriptions of generic training simulators that could be developed for training programmes were provided. These simulators will be the focus of further research, which ultimately (after 4 subsequent work packages) aims at a handbook comprising methods and guidelines for low-cost simulator development, acquisition, and its application.

In work package 3 of the ELSTAR project, an elaborate investigation of the task- and training requirements of the selected training areas, must render more detailed descriptions of the selected training systems. For that purpose, the information collected in work package 3, will be combined with the results from work package 2 (analysis of low-cost technology). That way, more detailed requirements for low-cost training systems will be specified.

This report describes the task analysis, training requirements and the functional specifications of the UAV crew training simulator that resulted from the task and training analysis. Furthermore, an evaluation study was undertaken and reported here, to investigate the effects of degrading the functional specifications. For this evaluation study, the functional specifications and the results from WP2 were combined in order to identify the cost-driving elements of the UAV crew trainer. These cost-driving elements were then evaluated to determine how they could be further degraded in order to save money.

1.2 Outline of the report

In chapter 2 the methodology and the results of the task analysis, training requirements and functional specifications are described. Chapter 3 includes a study into the effects of degradation of the functional specifications on the training effectiveness of the UAV crew training simulator. A general discussion on the results of the functional specifications and degradation study is incorporated in chapter 4.

2 SPECIFICATIONS FOR A UAV CREW TRAINER

This chapter reports the functional specifications of the UAV crew trainer. In § 2.1 the context of the training area is described, then the methodology is shortly presented in § 2.2. A list of tasks and the training requirements are incorporated in § 2.3, the functional specifications are briefly described, and a discussion on these results is given in § 2.4.

2.1 Context of the training area

The current responsabilities of the armed forces include peace enforcement and peace keeping operations. These tasks demand that the armed forces are able to operate in unfamiliar terrain that is difficult to access. Peace enforcement and peace keeping operations involve a.o. border patrol, surveillance of territory, reconnaissance, and fast, accurate information exchange. Unmanned, remotely controlled vehicles (RPV: Remotely Piloted Vehicles) can support these tasks, and can be deployed for military operations in unknown or dangerous areas.

A typical RPV (either for land, air, or ground based tasks) includes a moving platform, a ground control station and a ground data terminal. The RPVs are often equipped with a sensor that records and sends information to the ground control station. This makes the RPV suitable for surveillance, reconnaissance and target acquisition tasks.

As a basis for the UAV crew task- and training-analysis, a medium range UAV system was selected. Medium range UAV systems are deployed for reconnaissance and surveillance tasks. Reconnaissance and surveillance typically involves target detection and identification by means of infrared or CCD cameras, from a height of 1000−1500 metres. The UAV can fly according to a preprogrammed route, but at medium altitude, manual control of the UAV should also be possible.

A typical UAV crew consists of three operators: the mission planner, the navigator, and the image analyst. All three work at their own workstation in the ground control station (GCS). The mission planner predefines the mission of the UAV: its flight plan, transmission plan, and Rules Of Safety plan (predefined procedures for emergencies). The Navigator and Image analyst work in direct relation to the operating UAV; the navigator monitors and controls the flying platform and the image analyst controls the camera’s on board this platform.

Training the UAV crew focuses mainly on training the individual operators, and to a lesser extent the training of the operators as a crew. Co-operation between members of the UAV crew only involves rerouting tasks. The UAV is rerouted when the image analyst orders the navigator to deviate from the predefined route, or in case of system failures or enemy threat, when the navigator asks for permission from the higher ranking officer in the GCS (mission planner) to reroute or abort the flight of the UAV.

2.2 Methodology

Both the task and training analyses and the functional specifications are based on expert knowledge (TNO-HFRI) about prototypical UAV systems that are controlled by a crew (> one operator) at the ground control station (GCS). When appropriate, the data acquired in ELSTAR Work package 1b is used.

For the three operators of the UAV crew, separate task analyses are made (Appendix B). This separation will be maintained for both the training requirements and functional specifications, on the understanding that when requirements or specifications for different operators overlap, the requirements or specifications are described only for one operator. Thus, for other operators references will be made to that description.

The operating environment of the UAV crew is degraded in the sense that they do not have direct sensory information from the flying platform, but rather indirect information through the limited capacity data-link between the GCS and the UAV. Therefore, the operating environment can be simulated with high physical fidelity, at low cost. However, it is not necessary to copy the complete operating environment, since not all tasks of the UAV crew are relevant for training in a simulator. Thus training requirements are the basis for determining what has to be specified, but since the operating environment is degraded, the specifications themselves are for a great part equal to the specifications of the operational systems. The specifications that are provided are functional; the technical means to acquire the functional level is not specified. For example, the resolution of the display systems is given, without specifying how this resolution should be attained.

2.3 Results

2.3.1 Task list

1. Mission planner
1.1 Mission planning
    1.1.1 Create flight plan
    1.1.2 Check flight plan
    1.1.3 Link transmission plan
1.2 Mission monitoring (see navigator)
1.3 Mission control (see navigator)

2. Navigator
2.1 Start mission
2.2 Monitor mission
2.3 Mission control
    2.3.1 Change flight parameters
    2.3.2 Choose alternative routing
2.4 UAV emergency actions

3. Image analyst
3.1 Detect targets
3.2 Identify targets
3.3 Track targets
3.4 Transfer data to fire support centre
3.5 Analyse stored images

2.3.2 Training requirements

Mission planner

The main task of the mission planner is to enter flight data into the mission planning system. The mission planner is only involved during the mission flight of the UAV in case of emergencies, when the navigator asks for permission to reroute or abort the flight. Since this permission has to be given by a higher-ranking officer and the mission planner and the image analyst are usually equal in rank, this involvement is not crucial for the mission of the UAV. There is little involvement of the mission planner in the flight of the UAV, or interaction between the mission planner and the other crewmembers. Furthermore, training the mission planner in his mission-planning task doesn’t contain significant chances of injuries, casualties or system damage, nor does it yield any practical problems, or high costs. Therefore, training this task doesn’t constitute an opportunity for (low-cost) simulation. In the specification of functional requirements for the UAV crew trainer, the tasks of the mission planner are not considered.

Navigator

The navigator mainly monitors the programmed flight of the UAV. In case of unforeseen problems, or when the image analyst requires so (for the purpose of tracking or identifying a target), the UAV can deviate from its predefined route. The navigator does this rerouting. The navigator selects either a new predefined route from the flight plan that was downloaded into the UAV, or directly manipulates the UAV through low-level flight inputs (speed, altitude, pitch, roll), or high level flight inputs (such as fly an orbit, fly the footprint of the camera).

The main training goals for the navigator involve training of procedures of rerouting, skills in map-reading, and cognitive skills such as interpreting failure warnings from the system, and translating position-orders or rerouting requests from the image analyst into low- or high-level flight commands for the UAV. Since training with the real system involves a high risk of damage for the UAV, and yields practical problems and high costs, there is a high need for a training simulator.

The navigator mainly uses information from a cartographic display, on which the UAV and its flight plan, airspace management information, safety flight areas, and tactical information is presented. Furthermore, information concerning altitude, UAV attitude, and status of the engine will have to be presented on graphic displays.

Image analyst
The image analyst controls the camera-movements, and manipulates aspects of the images, such as selecting the type of sensor images (e.g., IR or TV), and field of view. His tasks involve target detection, identification, classification, and tracking. The image analyst's workstation includes a video monitor on which the (black-and-white) outside images of one UAV are presented, with additional co-ordinate information, as well as feedback on camera position and settings.

The training of the image analyst focuses on training target detection and identification/-classification skills. Extensive knowledge on military targets is required for these tasks, as well as skills in interpreting patterns in (infrared) images to distinguish between relevant targets and noise. A second topic in training is skills in camera control, orienting in the environment and communication with the navigator.

2.3.3 Functional requirements

Visual information is the most important source of information for the UAV crew to perform its tasks; therefore, the focus of the functional specifications is on the image system, with its image generator, display system, and visual database. Besides this visual system, the dynamic vehicle model (UAV and camera behaviour) is important for training the navigator and image analyst to correctly control respectively the flying platform and the camera. But functional specification for this vehicle model can, at this stage in the project, not be more detailed than that it should mimic UAV and camera movements of the real system, and specify the sum of the vehicle and camera movements for the resulting camera image to be presented. This will vary considerable between different UAV systems.

The functional specifications are reported in detail in Appendix C. Below, a summary of the functional specifications is given, separate for both the navigator and image analyst.

Navigator

The navigator performs his tasks supported by a cartographic display, on which tactical information, airspace management information, terrain information, and route information (way points, flightlegs) are presented. Information on UAV behaviour, such as pitch, roll, heading, speed and altitude, is presented on graphical displays next to the cartographic screen. The image generator has to generate a digital map, with both static and dynamic symbolic objects, graphical and numerical information, dialogue windows, and dynamic indicators.

For presentation of this information, a 19" colour computer screen (or bigger) can be used, with a typical resolution of 1280×1024 pixels, and an update/refresh rate > 60 Hz. This type of display is usually found in the operational environment, and since it can be acquired of-the-shelf, at low cost, it is suitable for a low-cost simulator.

In the visual database for the navigator, digital maps are stored, as well as visual characteristics of the following attributes: symbolic objects, way points, tactical information, air management data, and displays that provide information of altitude, attitude and status information on engines.

For platform control task, the navigator uses a flight control panel, on which rotary buttons for manipulation of pitch, roll, speed and altitude are presented, and push buttons for selection of different flight modes. This control panel can be easily, and at low cost, built for the simulator.

Image analyst

For the image analyst, a high-resolution video screen will be required, on which simulated outside video or IR images can be presented. The image generator has to provide realistic, dynamic sensor images with a high level of detail (typical resolution about 800×600 pixels), static and dynamic objects in the environment, and continuous zoom capabilities.

The camera images are often black and white, but a coloured overlay may be presented on which extra information is presented (co-ordinate axes, cross hair). This support should also be presented in the training environment, and therefore, a colour video screen can be required. On the other hand, if this overlay can be accomplished by contrast differences, a black and white screen may be sufficient.

The visual database should contain the camera images of the outside environment, including terrain characteristics, tactical information (own troops, enemy troops), and landmarks (rivers, bridges, houses, trees). Based on performances of typical UAV sensors that are deployed for surveillance and reconnaissance tasks, at the prototypical heights, the minimum level of detail of the terrain should be around 2×2 cm per pixel.

The image analyst needs two control panels: one keyboard for image analysis of stored images after the mission is terminated, and a camera control panel for manipulation of the camera. This control panel will include a joystick for manipulation of the camera position, buttons and rotary knobs for selection of sensor images, contrast enhancement, zooming, field of view. This panel can be easily built for the simulator at low cost.

2.4 Discussion and conclusion

The functional specifications for the UAV crew trainer have been derived almost completely from specifications of a prototypical operational environment. The operational environment of the UAV crew is degraded in such a degree that the operators do not receive direct sensory information from the controlled system and its immediate surroundings, but only indirect information through camera images and attitude displays. These hardware systems of the operational environment can be copied for the simulator.

Functional specifications for simulating the mission planner task environment are not reported, since he is not directly and interactively involved during the flight of the UAV, and his tasks can be easily trained on the actual system. Furthermore, mission planning tasks are very similar to the rerouting tasks of the navigator, and are performed in an environment that is also very similar to the navigator's operational environment (digital map, keyboard), thus, training of the mission planner can take place also on the navigators training system.

Training a UAV crew on the actual system raises practical, financial, didactic, and legal problems. Practical problems include finding a suitable location for practice, positioning targets in the environment, and realizing critical conditions. The financial problems arise due to the high amount of personnel needed to set up an exercise, and the high risk of damage to the system. Didactic problems involve a.o. the difficulty in performance measurement and feedback. Finally, legal problems are for example the restrictions for UAV deployment, such as obtaining flight authorization.

Use of a simulator can provide the means to overcome the abovementioned problems that are related to UAV crew training in a real environment. Development of the simulator mock-up, with its displays and data-entry devices will not constitute a major problem: the control panels can easily be built at low-cost, and joysticks and displays can be acquired of-the-shelf. The research and development challenge for the UAV crew trainer is to develop realistic tactical scenario's for training, and the simulation of realistic, dynamic camera images derived from a large database (area of operation).

3 DEGRADATION STUDY

In this chapter, first a short introduction into the specific problems related to UAV simulator development are discussed, followed in § 3.2 by a description of the current RPV simulator at TNO-HFRI that was adapted to the functional specifications of chapter 2. In § 3.3 specific database development problems are described. The experiment is shortly introduced in § 3.4.

The methodology and the results are reported in §§ 3.5 and 3.6, respectively. A discussion on these results is included in § 3.7.

3.1 Introduction

The functional requirements for a UAV crew simulator show that most of the required hardware is not the critical factor in the procurement of a simulator. Most hardware can be acquired off the shelf, or even the operational equipment can serve as a simulator console. The research challenge in developing a UAV crew trainer is to generate realistic tactical scenarios and realistic daylight or infrared camera images. In order to achieve a low cost simulator configuration, one should focus on simplifying these parts and thereby reducing costs, while maintaining sufficient training value of the simulator. In order to define what can and what cannot be simplified while preserving the simulator training value, the effect of degradation of these critical simulator parts on the tasks that need to be trained in the simulator has to be determined.

In the development of a UAV simulator, it seems that the visual database constitutes the major cost component. The choice for a database affects the configuration of both the image generator and the host computer, since the image generator should be capable of showing the information from the database and the host computer should have enough processing power to subtract data from the database. The choice for a database is dependent on the specific missions that the UAV crew has to be trained for. For initial training, it might be sufficient to have a rather small database, but as training progresses, or for mission rehearsal, it might be necessary to implement larger training databases or even databases of the actual terrain of the intended mission.

3.2 The TNO-HFRI RPV research simulator

Operating an unmanned vehicle differs to a great extent from operating a manned vehicle, in which the operator is inside the vehicle. Specific human factors problems, related to the control and manipulation of a RPV, can be attributed to the absence of direct perceptual information from the vehicle and its surroundings. In this respect, Korteling and Van Breda (1994) identified the most important problems:

- Disorientation (related to manoeuvring) because of the relative independence of sensor viewing direction and vehicle movements and the absence of proprioceptive information of these movements.
- Steering problems for an operator who has to control both the vehicle and sensor platforms simultaneously.
- Bad perception of vehicle attitude because the haptic and vestibular systems do not receive mechanical movement information.
- Vehicle control problems related to the absence of force feedback on the controls.
- A limited instantaneous field of view, resolution and update frequency of the outside images that impairs steering of the sensors and interpretation of the images.

- Disorientation (related to navigation) caused by unfamiliarity with the area of operation and the limited viewing capabilities.
- The absence of binocular disparity impairs operations at a short distance (tele-manipulation).

TNO-HFRI has developed a RPV research simulator to expand the knowledge related to the abovementioned human factors problems (Korteling & Van Breda, 1994).

The standard configuration of the RPV research simulator includes a console for two operators, a 19" colour video monitor, a control monitor, a passive and an active joystick, a gas and a brake pedal, and a headset with microphone. Computer generated outside images are displayed on the video monitor, with a resolution of 800×600 pixels and an update frequency of 30 Hz. The control monitor is used for the integrated presentation of tactical, navigational, and situational information (e.g., vehicle attitude). The RPV or the sensors are manipulated by means of the active and/or passive joysticks; the gas and brake pedal are available for simulation of remotely piloted ground vehicles. The headset with microphone are used for communication between the operators, and between the operator and the session leader.

Several computer systems operate the RPV simulator. Each system is dedicated to a specific task, such as scenario generation, calculating RPV dynamical behaviour, collection and storage of performance data. The standard configuration of the RPV simulator can be expanded with a Taskomat system (Spoelstra, 1993) that generates additional tasks for the operator in order to measure his workload. Moreover, a head mounted display can be added to present the simulated camera images, with a head tracker that compensates for the operator’s head movements. For stereoscopic images, the graphical processor can be configured such that a stereo display is activated.

3.3 Database Problems

One of the major problems in the development of a UAV simulator is the visual database. If a UAV is flying at a typical height of 1000 metres, the distance to the horizon is 113 kilometres. If there are no obstructions (e.g., mountains) in the line of sight, and the camera is positioned horizontally, this horizon should be visible. This means that, for simulation, a very large area has to be specified in the visual database. Also, the sensor images of outside world of the UAV have to be simulated with a high level of detail, since typical UAV sensor systems can provide images in which one pixel displays an area of 2×2 cm (required for target identification).

Thus, the visual database has to contain an area that is both very large and very detailed. This constitutes the main problem for simulation, and building this database is the cost-driving factor in the development of the simulator. To solve this problem, the database can be degraded by defining a target area within the visual database of the simulated area. A target area is where the target could be, and thus, target detection and identification can only be performed in that area. The area surrounding the target area can be left out, or be presented with a lower level of detail, which poses less difficulty and costs for the development of the database. Leaving out the surrounding area all together might affect the situational awareness of the operators in the simulator, which can deteriorate platform or camera control tasks. Whether presenting the surrounding area with less detail influences target detection and identification will have to be established. Presenting this low-detail surrounding area might enhance the face validity of the simulator, thus minimising the effect of database degradation on platform or camera control tasks.

3.4 The experiment

In the experiment that is described in the following paragraphs, it was investigated what arethe effects of solutions to overcome the problems with the database development on training value of the simulator. Two experimental conditions are investigated for their effect on training value. The first condition involved defining an area of interest in the visual database with a high level of detail (high resolution), while the surrounding area has a lower level of detail (low resolution). The second experimental condition involved only the presentation of images of the area of interest with a high level of detail and not displaying the surrounding area.

The RPV (remotely piloted vehicle) simulator of TNO-HFRI is adapted, according to the functional requirements of a UAV crew simulator (chapter 2). The simulator consists of two operator workstations: one for the navigator and one for the image analyst. The navigator workstation includes a digital map, on which the UAV and its flight plan, and tactical information is displayed. Furthermore, information concerning altitude, UAV attitude, and status of the engine are presented on graphic displays. The image analyst workstation consists of a video monitor on which the simulated camera images are presented.

The training value is determined by subjective evaluations by UAV training experts. These experts are considered to be able to estimate the training value of the simulator configurations because of their training expertise. The experimental simulator configurations are not tested against a full fidelity simulator configuration with a large database in which the whole simulated world has a high level of detail. This would generate too much complexity and high costs for this exploratory phase of our research. The experience of the subjects with real UAV systems (Crecerelle and Sperwer UAV systems manufactured by SAGEM and operated by respectively the French and Dutch Armed forces) is expected to enable them to compare the experimental simulator configuration with the operational equipment, and this comparison can be viewed as the comparative test against a full fidelity simulator configuration.

The subjective evaluations concerning the training value of the simulator configurations are derived by having the subjects rate a number of aspects of the simulator (e.g., realism of air vehicle behaviour, realism of camera images) on a scale of 1 (= poor) to 5 (= excellent) for both experimental conditions. It is expected that subjects will attribute a higher training value to the high resolution area of interest combined with low resolution surroundings, compared to the high resolution area/no surroundings condition, since the former method of presentation is expected to have a better face validity and overview, thereby improving the operator's situational (system) awareness.

This effect is expected to show up in higher ratings on especially the questionnaire regarding the image analyst workstation, and specifically questions that deal with realism of the total image, detection performance, having an overview of the whole simulated world, and realistic air vehicle attitude. The evaluation of the navigator workstation will probably not be influenced that much from changing configurations, since this workstation does not include presentation of the camera images. However, the navigator is able to look at the display of the image analyst, and therefore, might use this information in addition to the information from his digital map and UAV status displays.

3.5Method

3.5.1 Subjects

Four military officers that had experience with unmanned air vehicles participated in this experiment.

3.5.2 Task

The task was a UAV crew task in which one subject acted as navigator and one subject acted as image analyst of the UAV. The navigator had to monitor the pre-programmed flight of the UAV and was instructed to deviate from this pre-programmed route to follow a specific road, or when the image analyst requested him to do so. The navigator could control the air vehicle manually by means of a joystick. The image analyst controlled the line of sight of the daylight camera, searching for tanks in the terrain. As soon as he had found one, the image analyst had to ask the navigator to deviate from the pre-programmed route and fly around the tank in order to identify this tank. Two tanks were present in the simulated environment. Also, the image analyst had to track a road, the road that the navigator was instructed to follow.

3.5.3 Navigator Workstation

The navigator workstation included a Silicon Graphics Indigo system for generating the digital map, and displaying UAV attitude (pitch, roll), altitude, speed, vertical speed, and engine status, according to the flight model. The flight model parameters are presented in Table I. The information was presented on 19" colour monitors, with a resolution of 1280×1024 pixels. The navigator display had an update frequency of 30 Hz. The display was positioned vertically on eye height, and the subjects were seated at a distance of 50 cm from the screen.

Table I Flight model parameters and values

Parameter	**Value**	**Maximum deflection**

Pitch	5°/s	30°
Roll	50°/s	60°
Yaw	12°/s	–
Ground speed	15m/s (fixed)	–

The digital map was a still image of the visual database from an altitude of 10,000 metres. The map consisted of 2000×2000 pixels, but only 620×724 pixels were displayed at once. When the air vehicle symbol reached the end of the displayed map, within 0.03 seconds a new map of 624×724 pixels was drawn. The pre-programmed trajectory of the air vehicle was displayed by white crosses (way points) on the map. The navigator could edit these way point by selecting "move way point", or "delete way point" or "add way point" functions from a pull down menu above the digital map. The air vehicle was represented by a round symbol on the map, and missile sites (diamond symbol) could be entered in the map according to the same procedures as for way points.

3.5.4 Image analyst workstation

A Silicon Graphics Octane system, with Performer visualisation software, generated the simulated camera images from the visual database. The images were presented on a 19" display, with a resolution of 1280×1024 pixels. The images were updated with a frequency of 20 Hz. The display was positioned vertically at eye height (centre screen); the subjects were seated at a distance of 50 cm from the screen.

The simulated world consisted of an area of interest of 5 by 5 kilometres, in which the terrain resolution was 3 metres per pixel, and a surrounding area with a far lower resolution. For objects (such as houses, trees or mountains) photo texture was used to enhance the physical fidelity of the simulated world. The tanks were positioned in the area of interest, two types were used: a ZSU24 and a YPR PRAT. The line of sight of the camera could be controlled by a spring return joystick; the camera movement was linear function of the joystick deflection. The yaw was 20°/s, with unlimited deflection, the pitch was 20°/s, with a maximum deflection of –1°. There were two field of view conditions: camera opening 5°, and camera opening 20°.

Fig. 1 Navigator workstation (right) and Image analyst workstation (left)

3.5.5 Independent and dependent variables

In the evaluation session, one independent variable was manipulated within subjects: camera field of view. The field of view was either 5˚ or 20˚: with a field of view of 5˚, the presented images were only of the target area, with a high level of detail. With a field of view of 20˚, images included both the target area with the same high level of detail, and the surrounding areas with a lower level of detail.

The measured, dependent variables were the opinions of the subjects on several aspects of the simulator. The subjects' opinions included ratings on the questionnaire, and remarks with respect to the task and simulator.

The ratings were scores between 1−5, according to the following scheme: 1: poor, 2: mediocre, 3: reasonable, 4: good, 5: excellent. The navigator questionnaire consisted of 15 questions; the image analyst questionnaire included 13 questions. The scores of all subjects on each question were added and the mean and standard deviation of all scores were calculated for both viewing conditions. To determine the effect of viewing condition, the difference between mean scores was submitted to a t-test.

3.5.6 Procedure

The subjects participated in teams, thus two teams were formed. The total evaluation included 8 trials; thus every subject performed both navigator tasks and image analyst tasks in both camera field of view conditions. The teams were fixed, the order of tasks was balanced between subjects, and the order of viewing conditions was fixed. Each trial lasted about 10 minutes after which both the navigator and image analyst had to fill in the questionnaire (see Appendices D and E).

3.6Results

3.6.1 Scores on the Navigator Questionnaire

In Table II, the average and standard deviations of the scores on all the questions of the navigator questionnaire are presented. There was no difference in scores between the viewing conditions, subjects reported not to be affected by the viewing conditions in their task as navigator, and gave equal scores for both conditions Therefore, only mean scores and standard deviations are calculated. The answers on question 7 ("What part of the total display has proved to be the best support during performing the task of the navigator?"), three subjects answered that both the digital map and the integrated air vehicle display were most supportive, whereas one subject only mentioned the integrated air vehicle attitude display.

Table II Means and standard deviations of the scores on all questions of the navigator questionnaire

Question	Mean score	S
1.1 Speed reaction	3.5	0.6
1.2 Accuracy reaction	3.8	0.5
1.2 Synchroneity	4.3	0.6
2. Realistic speed	4.0	0.0
3. Realistic altitude	4.3	0.6
4. Transition automatic-manual	4.0	1.0
5.1 Drawn symbols on map	4.5	1.0
5.2 Drawn terrain on map	4.3	.5
5.3 Use of colour in map	4.0	.8
5.4 Realism of the map	3.3	1.7
6.1 Use of colours status disp.	4.5	.6
6.2 Legibility of information	4.0	.8
6.3 Type of information	3.8	1.3
8. Communication I.A.	4.3	.5

The speed and accuracy of the air vehicle reactions to the navigator's manipulations are judged to be reasonable to good. Synchroneity between the information presented on the digital map and information presented in the vehicle attitude displays is found to be good. The realism of the vehicle model, with respect to altitude and speed, is considered good. Also, the subjects found that transition between manual and automatic control, and vice versa, went well. The digital map is judged to be good with respect to use of colour, drawn terrain, and drawn objects. The realism of the map is found to be reasonable. The displays are considered to be good in terms of use of colours, information presented, and legibility. Communication with the image analyst went well.

3.6.2 Additional Remarks

The subjects gave some additional remarks regarding the simulator navigator workstation.

- Separate presentation of outside camera images for navigator
- Footprint of camera displayed on digital map
- Replace round symbol for air vehicle (on digital map) with triangle, pointed in flying direction
- Make use of military maps
- Provide zoom capability or extra window with map of the whole area (smaller scale) to enhance overview
- Use numbers for way points.

3.6.3 Scores on the Image Analyst Questionnaire

In Table III, the average and standard deviations of the scores on all questions of the image analyst questionnaire are presented for both conditions. The averages on questions number 2, 7,8, and 9 are equal for both the wide view and narrow view condition. The average score for questions number 1.2, 3, 4.1, 4.2, 4.3, 4.4, and 6 are higher for the narrow view condition than for the wide view condition. Average scores on questions number 1.1, 4.1, and 5 are higher in the wide field of view condition than in the narrow field of view condition. Only one difference in scores is statistically significant: the score on question number 4.2 is higher for the narrow view condition than for the wide view condition. Level of detail of the camera images is judged to be better in the narrow field of view condition than in the wide field of view. The difference in scores between narrow and wide view for question 6 shows no variance, and can therefore be seen as a true difference. Identification performance is judged to be better in the narrow view condition than in the wide field of view condition.

Table III Mean scores on the questions of the image analyst questionnaire for both viewing conditions, and corresponding p-values

Question	**Wide view** Mean score (m_w)	**Narrow view** Mean score (m_n)	**P ($d=m_w-m_n=0$)**
1.1 Reaction speed	4.5	4.3	$p>0.05$
1.2 Accuracy	4	4.3	$p>0.05$
2. Realistic speed	4	4	$p>0.05$
3. Realistic altitude	3.8	4	$p>0.05$
4.1 Update frequency	4.3	4.5	$p>0.05$
4.2 Detail	3.8	4.8	$0.01<p<0.05$
4.3 Realism objects	4	4.8	$p>0.0$
4.4 Realism image	4	4.8	$p>0.05$
5. Detection	4.3	4	$p>0.05$
6. Identification	3.3	4.3	$p<<0.01$
7. Following	3.8	3.8	$p>0.05$
8. Overview	3.8	3.8	–
9. Communication	4.5	4.5	$p>0.05$

For both viewing conditions, the following scores apply. The speed and accuracy of the camera reactions to the image analysts' manipulations are judged to be good. The realism of air vehicle model with respect to altitude and speed is found to be good. The update frequency, use of colours, realism of objects and realism of the total image of the camera is scored good. Target detection and identification, as well as following the road is conducted reasonably to good, according to the subjects' own perception. Communication with the navigator went good to excellent.

3.6.4 Additional Remarks

The subjects added a few remarks regarding the simulator, on their questionnaire:

- Add more (artificial) objects in the simulated world that obstruct the camera line of sight
- Implement a zooming option for the image analyst
- Narrow view makes the task more difficult than wide view
- With a narrow view it is difficult to have a good overview on the simulated world
- Target detection is more easy in the simulator than in real world because there is such a difference in colour and texture, and consequently, the target has a high contrast with its surroundings
- For more realistic target detection, tracks of vehicles should be drawn
- Indicate flying direction of the aeroplane on the display
- Provide co-ordinate information for camera cross hair.

3.7 Discussion

3.7.1 Navigator Workstation

The scores on the questions of the navigator questionnaire are high and equal for both viewing conditions of the simulated camera images. This means that the subjects were satisfied with the configuration of the navigator workstation, and that the camera view configuration did not have an impact on their task performance and/or evaluation of training value. They judged the user interface (displays, digital map), controls, and realism of air vehicle attitude to be good to excellent, while keeping in mind the training purpose of the simulator as a whole.

All the additional remarks that were made concerning the navigator workstation, have to do with enhancing the situational awareness and overview of the navigator. The experts suggested that the digital map should be similar to military maps, with the footprint of the camera displayed on this map, numbers for the way points, the direction of the air vehicle indicated, and zoom capabilities or another method to be able to view the whole area at once. These possibilities are all present in the UAV systems with which the experts were familiar. It doesn't require superior technologies to implement those in the simulator.

3.7.2 Image Analyst Workstation

The results show that the average scores of two questions of the image analyst questionnaire are significantly different: both the level of detail of the image and the ability to identify targets were judged to be better in the narrow view condition than in the wide view condition. This may be explained by the absence of distracting surrounding information in the camera images, thus enabling the image analyst to focus more on the targets. All other questions do not show any difference in scores for the viewing conditions, indicating no difference in training value between either the 5° or 20° field of view.

The additional remarks made by the subjects have to do with enhancing the realism of the simulated camera images [e.g., add more (artificial) objects, draw vehicle tracks], providing extra support to the image analyst (e.g., implement camera zoom option), and to facilitate co-operation and communication between the image analyst and the navigator by providing extra information (e.g., indicate flying direction of the air vehicle, provide co-ordinates of camera cross hair). These requirements all add to the cost of the simulator, but will also enhance training effectivity.

4 GENERAL DISCUSSION

The functional specifications for the UAV crew trainer are almost completely derived from specifications of a prototypical operational environment. This prototypical operational environment formed the basis for the adaptation of the TNO RPV simulator to the UAV crew simulator. An important consideration in database development is the choice for either a geotypical or a geospecific database. A geotypical database is a database of a typical area such as a mountainous area, a coastal area, or urban area. Many typical elements of such an area have to be concluded in the database. In a geospecific database a specific area is drawn, such as the north of France, the southern part of the Alps, or the city and surroundings of Amsterdam. For initial training, a small (geotypical) database may suffice, but for further training or mission rehearsal, geospecific database might be needed, to prepare the operators for the specific area of operation. But since UAVs are very often deployed for reconnaissance in unknown areas, mission rehearsal with the use of geospecific databases might not be possible.

Besides the higher cost of development for the geospecific database, it also requires more processing power of the image generator. The database will contain lots of specific landmarks and other objects that have to be presented. Furthermore, the navigator station requires a digital map of the operational area. When using a geospecific database, existing maps can be used, but for geotypical databases, digital maps will have to be manufactured. Using a geotypical database of, for example, a typical north-western European area, means that many objects present in the simulated world (houses, trees, roads) and terrain elevation contours will have to be drawn on the map. This is a time-consuming and therefore expensive task.

The database for the evaluation study was a geotypical database, degraded by defining a target area within the database. The problem of drawing a digital map of the geotypical database was solved by making a still image of the total database from above. This method of database and digital map development can lower the development costs of a UAV training system, but an extensive task and training analysis is needed to determine the required features of the database as well as of the maps.

In the degradation study the subjects have evaluated the simulator configuration as having a high training value, for both the configuration in which a target area is displayed with high resolution and the surrounding environment with a lower resolution, and for the configuration in which only a high resolution target area is displayed.

The subjects' scores are very high, which might give the impression that they judge our simulator to be excellent. Nevertheless, their additional remarks show that they see room for improvement. In a later stage of this project, training value will be determined by objective measurements against alternative training methods. This evaluation experiment can be seen as a first attempt to define the value of specific configuration of subsystems of the simulator for training. Cost information for the specific configurations cannot be given, since the visual database is the determining factor in the costs of any configuration, and this visual database is dependent on the operational system, and the missions that a UAV crew has to be trained for.

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APPENDIX A Abbreviations

ADT	Air Data Terminal
APN	Air Platform Navigation
ELSTAR	European Low-cost Simulation Technology for the ARmed forces
FAC	Forward Air Controller
FTA	Forward observer Tactical Computer
GCS	Ground Control Station
GDT	Ground Data Terminal
Hz	Hertz
IA	Image Analyst
IAP	Image Analyst Panel
IAS	Image Analyst Station
II	Image Intensifiers
IR	Infra Red
ISS	Image Storage System
ITS	Information Transfer System
LOS	Line Of Sight
MMI	Man-Machine Interface
MPS	Mission Planner Station
NP	Navigator Panel
NS	Navigator Station
ROS	Rules Of Safety
RPV	Remotely Piloted Vehicle
RTP	Research Technology Project
TPDB	Transmission Plan Data Base
TV	TeleVision
UAV	Unmanned Aerial Vehicle
WP	Work Package

APPENDIX B Task and training analyses UAV crew

1. The Mission planner

1.1 Mission planning

Description task: A mission is typically composed of a GCS (Ground Control Station) site, a GDT (Ground Data Terminal) site, a radio transmission plan, and a set of flight plans. The mission planner initializes, and is able to change parameters of these components of the mission. Information is retrieved from the GCS chief station, through ITS (Information Transfer System), and data previously stored in several databases.

1.1.1 Create flight plan

Description task: A flight plan is generally composed of a launch point and its characteristics, a primary trajectory and its recovery site, from zero up to seven rerouting trajectories and their recovery sites, a ROS (Rules Of Safety) plan, an occurrence window, an UAV identifier, its parameters and its payload configuration. The mission planner can both initialize and change these flight plan components.

- Input
  - Digital map with area of interest indicated
  - Information on tactical situation (ITS)
  - Airspace management data (ITS)
  - Weather forecasts / information
  - Orders and information from higher control
  - Knowledge on UAV capabilities and payload
  - ROS plan
  - Interface with MPS (Mission Planner Station)
- Operations
  - Initialize attributes (precise location, antenna height) of GDT site
  - Initialize attributes (precise location) of GCS site
  - Initialize UAV identifier, parameters (mass, fuel load) and payload configuration
  - Initialize occurrence window (earliest time of launch, latest time of recovery)
  - Define Launch point
  - Define Line Of Sight (LOS) of GDT
  - Define way points (type, coordinates, altitude, payload order)
  - Define ground speed for each flight leg
  - Define orbit flight pattern (number of cycles, radius, turn way)
  - Define hippodrome flight pattern (number of cycles, radius and turn way)
  - Define primary trajectory and its recovery site
  - Define rerouting trajectories and recovery sites
  - Link ROS plan
- Output
  - GCS and GDT are indicated on cartographic background
  - The UAV identifier, parameters and payload configuration are correctly represented on a cartographic background
  - The launch point, and way points with attributes are represented on a cartographic background, within the LOS area
  - Recovery point is indicated on cartographic background
  - The payload order (for example, TV and IR/TV only/IR only) for each way point is determined
  - Flight legs with attributes are indicated on cartographic background
  - Specific tasks (orbit, hippodrome) are indicated on cartographic background
  - ROS plan is linked to flight plan
- Critical conditions
  - Lack of information
- Critical task elements
  - Correct digital map of area
  - Knowledge on enemy threats

  - Access to information stored at GCS chief station (flight pan, mission data, frequency plan, ROS plan)

1.1.2 Check flight plan

Description task: Before the flight plan can be executed, all its components (way points, flightless, launch and recovery) will have to be checked whether the UAV is capable to execute it in terms of endurance, speed, altitude, fuel consumption etc. and whether the UAV will not enter enemy threat areas, violate airspace management regulations, etc. For most UAV systems, checks are performed by the system, that will give warning signals or more specific indications to the mission planner when a trajectory is problematic or impossible.

- Input
  - Data on tactical situation (ITS data)
  - Flight plan information
  - MMI with MPS
- Operations
  - Check if flight leg does not cross enemy threat missile zones
  - Receive information from system checks
  - Change flight leg and/or plan if leg crosses threat zone
  - Change flight leg and/or plan if system indicates a problematic, dangerous or impossible route
- Output
  - All flight legs of all trajectories of flight plan do not cross enemy threat missile zones
  - All flight legs of all trajectories of flight plan are correct according to altitude, UAV capabilities, safety flight areas, fuel consumption, etc.
- Critical conditions
  - Lack of information
  - System failures
  - Critical task elements
  - Link with ITS
  - Operator has to be able to interpret the tactical situation

1.1.3 Link transmission plan

Description task: A transmission plan will not be used in peace-time mode. The frequencies used in peace-time are directly configurated in the GDT and ADT (Air Data Terminal) equipment. A transmission plan is typically composed of the operational platoon frequency domain, the scrambling mode information, and the hopping mode information. A platoon frequency domain is includes a number of frequency sub-domains: for both UAVs that can be under control of the GCS a sub-domain for control actions data and a sub-domain for system monitoring data, and one sub-domain for sensor data. The mission planner can modify all components of the transmission plan from the transmission plan database.

- Input
  - Transmission plan database (TPDB)
  - Number of platoon that operates in the same area (mission parameter)
  - Transmission user number (mission parameter)
- Operations
  - Select elementary channels of the operational platoon frequency domain
  - Define scrambling mode ON/OFF
  - Define hopping mode ON/OFF
  - Generate scrambling mode information
  - Generate hopping mode information
  - Define one elementary channel per operational platoon frequency sub-domain
  - Incorporate predefined platoon frequency domain from the TPDB
- Output
  - Definition of the platoon frequency domain
  - Definition of scrambling mode
  - Definition of hopping mode
  - Scrambling mode information

    - Hopping mode information
    - Definition of Rendez-vous frequency (one elementary channel per operation platoon frequency sub-domain)
  - Critical conditions
    - The transmission plan is only defined in war-time
    - System failures
    - Critical task-elements
    - Information from the transmission plan database
    - The operation frequency domain has to be compliant with the defined mission parameters

1.2 Mission monitoring (see navigator)

1.3 Mission control (see navigator)

2. The Navigator

2.1 Start mission

Description task: The predefined mission with its flight plan, ROS plan, GCS site and GDT site determined, and transmission plan, are stored at the MPS station. These missions can now be opened at the Navigator Station (NS) and from there downloaded into the UAV for execution.

Input
  MMI with NS
  Cartographic screen
  Preflight checklist
  Mission data from MPS
  Link with launch-site
  Orders from GCS mission planner
  Navigator panel (NP)
Operations
  Select UAV
  Establish link with UAV
  Select mission
  Select monitoring session on UAV
  Assign flight plan to UAV
  Perform pre-flight check (by system or manually with checklist)
  Download mission to UAV
  Choose cartographic screen settings
  Approve launch
Output
  Flight plan, transmission plan and ROS plan are downloaded into the selected UAV
  The NS provides information on the UAV under control
  Pre-flight check is performed, either manually or (when data link with launch point is established) by system
  The navigator has selected suitable screen settings for the cartographic display (zoom, grid, vector themes)
  The operators at the launch site have approval for launch
Critical conditions
  No datalink between GCS and launch site is established
  System failures
Critical task elements

2.2 Monitor mission

Description task: The navigator will usually be able to select the fully automatic execution of the flight plan, or control some parameters of the flight himself. In the fully automatic mode, he has to check and monitor the execution of the flight plan and intervene when something is not according to the flight plan.

Input
  MMI with NS
  Altitude display
  Attitude display
  Cartographic screen
  NP
Operations
  Check whether flight mode is automatic
  Check launch
  Check altitude (both) UAV(s)
  Check whether (both) UAV(s) follow predefined paths
Output
  UAV flight is automatic
  Altitude UAV(s) is above safety height

  - UAV(s) fly according to flight plan
- Critical conditions
  - UAV system failures
  - GCS system failures
  - UAV altitude is below safety height
  - UAV deviates from predefined flightpath
  - Loss of data-link
- Critical task elements
  - Altitude information
  - UAV attitude information

2.3 Mission control

Description task: When the image analyst requests to deviate from the predefined path, or when unforseen problems ask for a rerouting, the navigator can control the UAV and alter its flightpath. This can be done by manipulating specific parameters of the flight (altitude, speed, etc) or by entering a new route.

2.3.1 Change flight parameters

- Input
  - MMI with NS
  - Attitude display
  - Altitude display
  - Cartographic screen
  - Flight plan displayed on cartographic screen
  - Airspace management data
  - Weather forecast
  - Information on tactical situation
  - LOS area displayed on cartographic screen
  - Orders/requests from image analyst
  - NP
- Operations
  - Select UAV
  - Select operator control mode
  - Manipulate speed
  - Manipulate heading
  - Manipulate altitude
  - Manipulate roll
  - Select orbit flight-mode
  - Select fly-the-footprint mode
  - Select recovery mode
- Output
  - UAV under control deviates from predefined path and flies according to the heading, altitude, and roll defined by the navigator
  - UAV under control can fly an orbit around target location
  - UAV under control can follow the camera footprint
  - UAV under control can land on a location different from the predefined location in the flight plan
- Critical conditions
  - GCS system failures
  - UAV system failures
  - Enemy missile threat
  - Bad weather conditions
  - Loss of data-link

2.3.2 Choose alternative routing

- Input
  - MMI with NS
  - Altitude display
  - Attitude display

  - Mission data
  - Flight plan displayed on cartographic screen
  - Airspace management data
  - Information on tactical situation
  - Weather forecast
  - Information on UAV: fuel load, endurance
  - LOS area displayed on screen
  - NP
  - Orders/requests from image analyst
- Operations
  - Select alternative route from flight plan
  - Move a way point from the UAVs current trajectory
  - Modify way point attributes (speed, altitude) of a current trajectory
  - Select another way point (from current or other trajectory) as the next way point
  - Define new landing (recovery) point
- Output
  - UAV flies an alternative route that was predefined during mission planning
  - UAV flies to another way point
  - Speed or height for a way point is altered during flight
  - UAV lands at a new location
- Critical conditions
  - New route, way point or landing point is outside the safe flight area
  - New route, way point or landing point is beyond LOS area
  - New route should is not compliant with UAV capabilities
  - New altitude is below safety height
- Critical task elements
  - Information on safe flight areas, LOS area, UAV capabilities and safety height
  - Altitude display
  - Attitude display
  - The operator has to be able to interpret the tactical situation

2.4 UAV emergency actions

Description task: In case of loss of data-link or problems with altitude, safety flight areas, airspace management regulation etc. the system automatically executes actions to overcome these problems. Still, some emergency actions will have to be performed by the navigator.

- Input
  - MMI with NS
  - Information on tactical situation
  - Altitude display
  - Attitude display
  - Status display on engine UAV, heading, transmission, ground data transmission station, pilot, and ground control station system.
  - Live video image
  - Enemy threat
  - NP
- Operations
  - Detect UAV mission failure
  - Diagnose failure (wrong altitude, outside safety area, deviates from route, no data-transmission, no transmission of payload data)
  - Wait for data-link to recover
  - Decide to reroute UAV
  - Decide to land UAV
  - Decide to perform emergency recovery
- Output
  - Datalink is restored
  - Failure is put right (UAV is at right altitude, route or within safety area)
  - UAV is rerouted

- UAV is landed

Critical conditions

- Systems provide contradictory information
- UAV lands in enemy threat area

Critical task elements

- Navigator has to interpret failure messages from systems
- Navigator has to decide on cause of failure

3. Image analyst

3.1 Detect targets

Description task: The image analyst searches the area of interest for possible targets. He can manipulate the camera or select auto search mode, in which the system will detect spots or patterns in the image. Only type of image (e.g., video or infrared) from one of the two possible UAVs can be transmitted to the ground control station.

- Input
  - Live video images
  - Live infrared images
  - Image Analyst Panel (IAP)
  - Co-ordinate information
  - Information on AV location
  - MMI with Image Analyst System (IAS)
- Operations
  - Select UAV
  - Select images (video or infrared)
  - Control camera-position
  - Manipulate camera focus
  - Manipulate camera field of view
  - Select contrast for video images
  - Select infrared polarity
  - Search area of interest
  - Select autosearch mode
  - Set search algorithm (black centroid, white centroid, correlational)
- Output
  - Camera is in position
  - Focus and field of view are set
  - Contrast is set
  - Polarity is set
  - Image analyst performs visual search of area of interest
  - System detects black spots, white spots or patterns in image
- Critical conditions
  - Clouds
  - Bad weather
  - Equal temperature for everything in the area
- Critical task elements
  - Image analyst should be able to orientate
  - Polarity has to be chosen correctly
  - Image analyst has to estimate distances

3.2 Identify targets

Description task: After detection of a target, the image analyst has to decide on the type of target, and whether it is a friend or foe. This can be done on line, or later on at the image analysis. To be able to identify on line, the image analyst can request from the navigator to reroute the UAV and fly over the target (once) more. The system can provide the image analyst with some possibilities to determine the position and speed of the target.

- Input
  - Live video images
  - Live infrared images
  - Image Analyst Panel (IAP)
  - MMI with IAS
  - Co-ordinate information
  - Information on UAV location
  - Information on tactical situation
  - Information on possible types of targets

Operations
- Zoom in on target
- Determine position of target
- Decide to track target
- Order/request orbit flight around target
- Order/request for rerouting of UAV
- Provide navigator with co-ordinates of target
- Decide to store image in database for analysis later on
- Estimate measures of target
- Determine speed of target
- Define type of target
- Classify target (friend or foe)

Output
- Target is located
- UAV is rerouted (orbit flight) for better view on target
- Target images is stored for analysis later on
- Target will be tracked for analysis
- Target is identified and classified

Critical conditions
- Bad weather conditions
- Clouds
- Noise in image

Critical task elements
- Knowledge of type of targets
- Knowledge of tactical situation
- Ability to orientate
- Ability to estimate distances

3.3 Track targets

Description task: The image analyst can track a dynamic target for better identification or surveillance purposes. Tracking can be done either manually or automatic, in case of automatic tracking, the image analyst has to monitor the systems performance.

Input
- Live video images
- Live infrared images
- IAP
- MMI with IAS
- Co-ordinate information
- Information on UAV location
- Information on tactical situation
- Information on target

Operations
- Manipulate camera position
- Select autotrack mode
- Select tracking algorithm (white centroid, black centroid, correlation)
- Order/request fly-the-footprint mode from navigator

Output
- Target is tracked manually
- Target is tracked automatically
- UAV follows camera position

Critical conditions
- Clouds
- Bad weather conditions
- Target enters enemy threat area
- Noise in image

Critical task elements
- Image analyst has to check autotrack performance

Image analyst has to predict target path for good tracking performance

3.4 Transfer data to fire support centre

Description task: When the image analyst has identified a target that should be eliminated, he has to determine the position of the target, and provide co-ordinate information to a fire support centre. This is usually done by means of a Forward observer TActical Computer (FTAC).

Input
  Target
  MMI with IAS
  IAP
  Keyboard
  MMI with FTAC
Operations
  Determine precise position of target (point crosshair)
  Enter co-ordinates into FTAC
Output
  Request for firing/fire support is completed
Critical conditions
  System failure
Critical task elements
  The image analyst has to read complex numerical information from te screen and enter this in the FTAC.

3.5 Analyse stored images

Description task: The image analyst can usually store images during a mission, and these images can than be analysed after the mission is terminated. This still image analysis should be done on a system that provides many possibilities to the analyst through for example, a window-based environment.

Input
  MMI with Image Storage System (ISS)
  Stored images
  Co-ordinate information of stored images
  Cartographic screen with performed flight indicated
  Knowledge on tactical situation
  Knowledge on types of targets
Operations
  Open stored image
  Determine location of target in relation to tactical situation (use stored information on position and time of detection)
  Measure size of target
  Define type of target
  Classify target
  Define possible goal/mission of target
  Estimate threat of target
  Decide for further actions (no actions, inform, destroy)
  Measure distance between target and artillery station
  Provide information on target to higher control or artillery station
Output
  Target is located in relation to the whole tactical situation
  Target is identified
  Target is classified
  Mission/goal and threat of target is estimated
  Higher order control is informed
  Artillery station receives target information
Critical conditions
  System failures
  Stored images lost

Critical task elements

- Knowledge on military targets, tactics
- Image analyst should be able to determine possible mission and threat of target

APPENDIX C UAV crew trainer; specification of functional requirements

1. Display system

1.1 Display Navigator

High resolution computer colour screen (e.g., 1280 × 1024 pixels, 19")

- Update frequency/refresh rate: > 60 Hz

1.2 Display Image analyst

Colour video screen, for example 800 lines (resolution 800 × 600), ⌀333 mm

- Update frequency / refresh rate: > 60 Hz

2. Image generator

2.1 Image generator for display Navigator:

- Digital map
- Discrete zoom (digital map), e.g., 1:12, 1:8, 1:4, 1:2
- Static symbolic objects
- Dynamic symbolic objects (current position UAV, predicted position)
- Graphic information (airspace management data, safety flight area)
- Numerical information (coordinates, altitude, height, elevation)
- Dialogue windows
- Dynamic indicators (altitude, speed, heading, wind speed and direction, pitch, roll, engine RPM, fuel)
- Height display with prediction (0-X minutes) and safety altitude corridor (graphic)

2.2 Image generator Image analyst

- Animation
- Dynamic objects
- Anti-aliasing
- Black and white or colour images
- Graphic colour overlay (head up display)
- Terrain textures
- Weather phenomena: fog, rain
- Night and daylight conditions
- Continuous zoom
- Camera-movements: azimuth: 360°, elevation: [ca. +20°, –120°]

3. Visual database

3.1 Visual database Navigator

- Digital maps (scale e.g., 1:100.000, 1:250.000, 1:500.000), attribute:
  *Terrain elevation
- Symbolic objects (about 5−10 types)
- Dialogue windows
- Way points with attributes:
  *Altitude
  *Speed
  *Time and distance to recovery
- Tactical information, such as:
  *Enemy troops and missile sites
  *Own troops and missile sites
- Air management data
  *Safety flight areas
  *Corridors.

3.2 Visual database Image analyst

- 3D objects, such as: trucks, tanks, missile launch stations, bridges, trees
- Terrain features such as: elevation, texture, soil, roads, rivers
- Co-ordinate information for every position in visual database
- Resolution of terrain: see Table A.C1, min: 2,1 × 2,0 cm per pixel; max: 86,0 × 82,4 cm per pixel (the altitudes are proto-typical for surveillance and reconnaissance tasks; the Field Of View (FOV) values are representative for a regular UAV sensor system).

Table A.C1 Size of terrain (in centimetres) that has to be presented in one pixel, for 4 different altitudes of the UAV and 4 different field of view values of camera.

FOV	Alt. 500 m	Alt. 1000 m	Alt. 1500 m	Alt. 2000 m
1,8° × 1,35°	2,1 × 2,0 cm	4,3 × 4,0 cm	6,5 × 6,0 cm	8,6 × 8,0 cm
7,2° × 5,4°	8,5 × 8,2 cm	17 × 16,4 cm	25,5 × 24,6 cm	34,0 × 32,8 cm
12,6° × 9,45°	15,0 × 14,4 cm	30,0 × 28,8 cm	45,0 × 43,2 cm	60,0 × 57,6 cm
18° × 13,5°	21,5 × 20,6 cm	43,0 × 41,2 cm	64,5 × 61,8 cm	86,0 × 82,4 cm

4. Dynamic model

- Correct behaviour of flying platform as determined by atmospheric conditions and flight inputs
- Correct behaviour of sensor as determined by air platform motion, sensor stabilization, and sensor steering inputs
- Sum of camera movements and settings (zoom) and vehicle movements define video images.

5. Data-entry devices

5.1 Data-entry devices Navigator

- Keyboard (qwerty)
- Flight control panel with push buttons, knobs, rotary knobs, or joysticks for the following functionalities:
  *Air vehicle N
  *Fly the footprint
  *Autonomous flight
  *Manual flight
  *Select heading control
  *Select roll control
  *Select pitch control
  *Heading
  *Roll
  *Pitch
  *Altitude
  *Speed.

5.2 Data-entry devices for Image analyst

- Payload control panel with push buttons, knobs, rotary knobs, or joysticks for the following functionalities:
  *Air vehicle N
  *Sensor select
  *Change discrete zoom value IR images
  *Change polarity for IR images
  *Lock position
  *Camera in default position
  *Continuous zoom for TV images
- Keyboard (for entering co-ordinate information).

APPENDIX D Questionnaire navigator

Read the questions in this questionnaire carefully before you start with your task. Answer the questions after you have performed your task. You have to score each question according to the following scheme:

1: poor
2: mediocre
3: reasonable
4: good
5: excellent.

1 What do you think of steering the air vehicle, with respect to
  1.1 speed of reaction of the air vehicle to your manipulations
  1.2 accuracy of the air vehicle reaction to your manipulations
  1.3 synchroneity of the information presented in the status displays and the information presented on the digital map.

2 Does the air vehicle have a realistic speed?

3 Does the air vehicle have a realistic altitude?

4 What do you think of the transition between automatic flight and manual control?

5 What do you think about the digital map, with respect to:
  5.1 drawn symbols
  5.2 drawn terrain
  5.3 use of colour
  5.4 realism of the map (does it resemble a “real map”?)

6 What do you think of the status displays, with respect to:
  6.1 use of colour
  6.2 legibility of the information
  6.3 type of information that is presented

7 What part of the total display has proved to be the best support during performing the task of the navigator?

Integrated air vehicle attitude display/separate height/altitude display/engine status display/digital map *

8 How did the communication with the image analyst go?

* Cross out the options that are not applicable

APPENDIX E Questionnaire image analyst

Read the questions in this questionnaire carefully before you start with your task. Answer the questions after you have performed your task. You have to score each question according to the following scheme:

1: bad
2: mediocre
3: reasonable
4: good
5: excellent.

1 What do you think of manipulating the camera, with respect to:
  1.1 speed of reaction of the camera to your manipulations
  1.2 accuracy of the reactions of the camera to your manipulations

2 Does the air vehicle have a realistic speed?

3 Does the air vehicle have a realistic altitude?

4 What do you think of the camera images with respect to:
  4.1 update frequency
  4.2 level of detail
  4.3 realism of the objects (size, colour, shape)
  4.4 realism of the total image

5 Were you able to detect the targets?

6 Were you able to identify the targets?

7 Were you able to follow the road with your camera?

8 Did you have a good overview on the simulated world?

9 How did the communication with the navigator go?

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15. **ABSTRACT (MAXIMUM 200 WORDS (1044 BYTES))**

To investigate the possibilities for application of low-cost simulators within military training courses, the research project called ELSTAR (European Low-cost Simulation technology for the ARmed forces) is carried out under the contract of the Ministries of Defence of the five participating countries of Research Technology Project (RTP) 11.8, viz. Belgium, France, Germany, Greece, and The Netherlands. This project consists of 5 work packages. In the current work package 3 of the ELSTAR project, an elaborate investigation of the task- and training requirements of the selected training areas, must render more detailed descriptions of four selected training systems.

The current report includes a task- and training analysis of a Unmanned Aerial Vehicle (UAV) crew, which formed the basis for the functional requirements of a UAV crew trainer. In order to determine low-cost solutions for this trainer, the cost driving requirements of the system were identified. The effects of degrading these requirements on the training value of the UAV crew trainer were evaluated in a experimental study.

The results of the task and training analyses show that visual information is the most important source of information for the UAV crew to perform its tasks; therefore, the focus of the functional specifications is on the image system, with its image generator, display system, and visual database. In the development of a UAV simulator, it seems that the visual database is the major factor in the costs. This database needs to be large and very detailed, which causes the development to be time-consuming and expensive.

In the evaluation study two degraded database configurations were tested: both configurations involve the definition of a high detail target area within the database, while the surrounding area is either left out or displayed with a lower level of detail. The results show that the UAV experts evaluated both simulator configurations as having a high training value. Nevertheless, their additional remarks show that they see room for improvement.

This evaluation experiment can be seen as a first attempt to define the value of specific configuration of subsystems of the simulator for training. In a later stage of this project, training value will be determined by objective measurements against alternative training methods.

16.	**DESCRIPTORS** Simulation Training Unmanned Aerial Vehicle		**IDENTIFIERS**

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