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title

Visual support in camera control from a moving unmanned aerial vehicle

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De snelle ontwikkeling op het gebied van de vliegtuigtechnologie maakt het mogelijk om taakonderdelen die betrekking hebben op het vliegen van een Maritime Unmanned Aerial Vehicle (MUAV) in hoge mate te automatiseren. Eén van de belangrijkste taken van een MUAV operator wordt daarom het besturen van de sensoren aan boord van het platform. De meest gebruikte sensor is een video camera. Het beeld of de voetprint van een camera is afhankelijk van vele vrijheidsgraden, zoals de oriëntatie van de MUAV en de camera, vlieghoogte, en zoom-factor. Gecombineerd met de smalle bandbreedte die beschikbaar is voor communicatie met het moederschip—resulterend in een lage updatefrequentie van het camerabeeld—kan dit leiden tot ernstige problemen voor de operator. Bekende problemen betreffen het met de camera volgen van doelen, en de ruimtelijke oriëntatie.

Omdat de Koninklijke Marine de ontwikkelingen op dit gebied nauwkeurig volgt, wordt door TNO–TM in opdracht van de Koninklijke Marine onderzoek uitgevoerd naar de mogelijkheden om operators van MUAV's te ondersteunen. Dit rapport beschrijft twee experimenten waarin de mogelijkheden worden onderzocht om een operator te ondersteunen door het kunstmatig genereren en aanbieden van visuele bewegingsinformatie. Op basis van kennis over de positie en oriëntatie van platform en camera, de karakteristieken van het systeem, en de stuursignalen naar het platform en/of de camera is het mogelijk om op het moederschip een raster van aardvaste lijnen te genereren dat de bewegingen van het platform en de camera direct weergeeft. Deze lijnen kunnen in het camerabeeld weergegeven worden zonder gebruik te maken van het communicatiekanaal tussen platform en operator, en dus met een hoge updatefrequentie. Dit betekent dat de kunstmatige lijnen als het ware over een stilstaand plaatje bewegen als het buitenbeeld met een lage frequentie ververst wordt. Verwacht wordt dat deze kunstmatige visuele informatie de operator zal helpen in het waarnemen en onderscheiden van camera- en platformbewegingen, en de prestatie van de operator vergroot.

Bovenstaande hypothese is in twee experimenten getoetst. Het eerste experiment betrof een volgtaak, waarbij proefpersonen met de camera vanaf een bewegend platform een varend schip in beeld moesten houden, hetgeen grofweg neerkomt op het compenseren van translaties en rotaties van zowel het schip als het platform. De resultaten laten zien dat de kunstmatige visuele ondersteuning een positief effect heeft op de volgprestatie. Dit effect nam toe naarmate de opfrisfrequentie van het buitenbeeld afnam (de volgfout werd door het raster gehalveerd bij 0.5 Hz opfrisfrequentie). Het tweede experiment betrof een ruimtelijke oriëntatie taak. Hierin moesten de proefpersonen na 15 s de camera richten op de locatie waar eerder een schip te zien was geweest. Tijdens de 15 s werden er buiten de proefpersoon om translaties en rotaties aan het platform/camera systeem opgelegd. In dit experiment wordt een positief effect van de kunstmatige visuele ondersteuning aangetoond. De *relatieve* ruimtelijke ordening wordt verbeterd. Hoewel het niet geheel duidelijk is of in deze test een betere *absolute* ruimtelijke oriëntatie (ten opzichte van wereldcoördinaten) aangetoond wordt toont het experiment zonder meer de praktische toepasbaarheid van het principe aan.

De huidige experimenten zijn opgezet om de potentiële voordelen van kunstmatige visuele ondersteuning te onderzoeken. De resultaten zijn veelbelovend, en als zodanig aanleiding om de voordelen en toepassingen verder te onderzoeken. Zo kan het zinvol zijn om het principe ook te testen bij andere belangrijke taken van een operator, zoals het zoeken van doelen. Tevens zijn er potentiële mogelijkheden om het raster te verbeteren, zoals het introduceren van parallax door twee rasters op verschillende hoogte boven de zee te genereren. Een andere mogelijkheid is het invoeren van voertuigreferenties, zodat een operator direct rotaties van platform en camera kan onderscheiden.

Aankomende experimenten zullen gericht zijn op een nieuw ontwikkelde vorm van ondersteuning, waarin het huidige principe van een patroon loodrecht rasterpatroon gecombineerd wordt met een meer conventioneel head-up display. Bovendien zal er een andere ruimtelijke oriëntatie taak worden toegepast.

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SUMMARY

The rapid growth of aircraft technology enables to automate many subtasks related to platform control of a Maritime Unmanned Aerial Vehicles (MUAV). Therefore, one of the most important tasks of the operator('s) of a MUAV is operating the mission payload, which is usually a video camera. The footprint or image of the camera depends on numerous degrees of freedom, i.e. heading of the MUAV, heading and pitch of the camera, altitude, zoom factor. Combined with a limited bandwidth for communication with the mother ship —resulting in low update rates of the camera image—this may lead to several problems for operators, including loss of situational awareness and problems in tracking targets.
Because the Royal Netherlands Navy is closely monitoring the developments, the TNO Human Factors Research Institute is involved in several studies to explore possibilities to support operators. This report describes two experiments in which the operator of a MUAV camera is supported by synthetic visual motion information. On the basis of knowledge about the present position and orientation of MUAV and camera, system characteristics, and control inputs, an artificial grid of perpendicular lines in the camera image can be presented that specifies the various components of MUAV- or camera motion. This means that when the camera image is refreshed with lower update frequencies, the perpendicular lines move as it were over a static camera image. It is expected that this synthetic image augmentation will help the operator in perceiving and separating movements of MUAV and camera, and thus improves performance of the operator. This hypothesis was tested in two experiments. In the first experiment subjects had to track a moving target ship from a moving MUAV platform, which meant compensating for translations and rotations of both the ship and the MUAV. The results showed a significant positive effect of synthetic image augmentation. This effect became stronger in the conditions with low update frequencies: up to a factor two in the 0.5 Hz update rate conditions. The second experiment involved a situational awareness task. In this task subjects had to point the camera at the position of a previous depicted target ship after imposed translations and rotations during 15 s. This experiment too shows a significant positive effect of synthetic image augmentation, which increases in the conditions with lower update frequency. *Relative* situational awareness is improved. Although it is not clear whether the second experiment really indicates a improved *absolute* situational awareness in the presence of synthetic image augmentation, it does show the usefulness of the principle.
The present experiments were conducted to investigate the potential benefits of synthetic image augmentation in operating a MUAV. The results are promising, and ask for further exploration of the applications of synthetic image augmentation. Coming experiments will be designed to test a new developed form of synthetic image augmentation in which the present principle of the perpendicular lines is combined with a more conventional head-up display. Furthermore a different test for situational awareness will be applied.

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Visuele ondersteuning in camerabesturing van een bewegende MUAV

J.B.F. van Erp, J.E. Korteling en B. Kappé

SAMENVATTING

De snelle ontwikkeling op het gebied van de vliegtuigtechnologie maakt het mogelijk om taakonderdelen die betrekking hebben op het vliegen van een Maritime Unmanned Aerial Vehicle (MUAV) in hoge mate te automatiseren. Eén van de belangrijkste taken van een MUAV operator wordt daarom het besturen van de sensoren aan boord van het platform (meestal een video camera). Het beeld of de voetprint van een camera is afhankelijk van vele vrijheidsgraden, zoals de oriëntatie van de MUAV en de camera. Gecombineerd met de smalle bandbreedte die beschikbaar is voor communicatie met het moederschip—resulterend in een lage updatefrequentie van het camerabeeld—kan dit leiden tot ernstige problemen voor de operator. Bekende problemen betreffen het met de camera volgen van doelen, en de ruimtelijke oriëntatie.
Omdat de Koninklijke Marine de ontwikkelingen op dit gebied nauwkeurig volgt, wordt door TNO−TM in opdracht van de Koninklijke Marine onderzoek uitgevoerd naar de mogelijkheden om operators van MUAV's te ondersteunen. Dit rapport beschrijft twee experimenten waarin de mogelijkheden worden onderzocht om een operator te ondersteunen door het kunstmatig genereren en aanbieden van visuele bewegingsinformatie. Op basis van kennis over de positie en oriëntatie van platform en camera, de karakteristieken van het systeem, en de stuursignalen naar het platform en/of de camera is het mogelijk om op het moederschip een raster van aardvaste lijnen te genereren dat de bewegingen van het platform en de camera direct weergeeft. Deze lijnen kunnen in het camerabeeld weergegeven worden zonder gebruik te maken van het communicatiekanaal tussen platform en operator, en dus met een hoge updatefrequentie. Dit betekent dat de kunstmatige lijnen als het ware over een stilstaand plaatje bewegen als het buitenbeeld met een lage frequentie ververst wordt.
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De huidige experimenten zijn opgezet om de potentiële voordelen van kunstmatige visuele ondersteuning te onderzoeken. De resultaten zijn veelbelovend, en als zodanig aanleiding om de voordelen en toepassingen verder te onderzoeken. Aankomende experimenten zullen gericht zijn op een nieuw ontwikkelde vorm van ondersteuning, waarin het huidige principe van een patroon loodrecht rasterpatroon gecombineerd wordt met een meer conventioneel head-up display. Bovendien zal er een andere ruimtelijke oriëntatie taak worden toegepast.

1 INTRODUCTION

The rapid growth of aircraft technology has substantially expanded the existing possibilities for data registration and communication by unmanned air vehicles. In this connection the Royal Netherlands Navy is engaged in a program to investigate the prospects and weaknesses of applications of Maritime Unmanned Aerial Vehicles (MUAV). MUAV's are small air vehicles designed to carry out various (dangerous) maritime missions, which are supervised and controlled by a human operator from a control station on board a mother ship. This man-in-the-loop has to perform several tasks including planning the mission, controlling the MUAV status, and operate the mission payload. The most critical information needed for some of these tasks comes from the MUAV itself, for instance from a visual imaging device mounted underneath the vehicle. The present report concerns the characteristics, problems, and solutions related to such visual imaging devices and presents a study to test the feasibility of a new, simple principle for enhancement of the outside world image.

1.1 Limitations of imaging devices

Imaging devices are likely the most common form of UAV payload, providing prominent information required for information acquisition and vehicle guidance (Eisen & Passenier, 1991). As such, the quality of this information will be crucial to both tasks. During operation in which imaging sensors are indeed crucial (e.g., scouting or battle-damage assessment) one operator is typically engaged in visual search, detection, recognition, and identification. In these kinds of operations control of the imaging system is one of the most critical prerequisites for success. In addition, this same operator may employ the imaging device to adapt the flight profile to the mission plan, to potential threats and to the limitations of the platform and its sensor system.

Unfortunately, the outside world information is severely degraded relative to manned aircraft. While flying a manned aircraft the wide visual field provides the pilot an immediate indication of the slightest attitude change. Small translational accelerations of the aircraft are felt by the vestibular organs. The aerodynamic forces on the control surfaces are felt by the pressure and stretch receptors of the hands, arms, and legs. Speed can be inferred from aerodynamic noise or by the sound of the engine. All this *proprioceptive* information will be lacking in a normal teleoperated platform, making manual flight more difficult and likely more demanding.

These limitations all emerge from the fact that the operator is not located *in* the platform and thus has to interact indirectly with the environment via artificial devices. This may have serious drawbacks for the operator's *situational awareness*, i.e., the perception of orientation and position of the aircraft and/or the sensor in space and time together with an apprehension of the environmental (threat, targets), flight, and system conditions. Situational awareness problems are reinforced by additional limitations of the camera-monitor and data-link system. These limitations are caused by the need to limit the bandwidth of the data-link between MUAV and control station[1]. As a consequence of this limited data-link the quality of

[1] This is due to the requirement to digitize and code the image-signal in order to decrease vulnerability to disturbances and to prevent enemy jamming.

the payload image will not be comparable to the human eye, nor to the image of normal TV with an update rate of 30 Hz and 625 lines. Major possibilities to limit the data-link are amongst others: image compression, lower image resolution, and lower update frequency. Those three possibilities have been investigated before (see for example Swartz, Wallace, Libert, Tkacz & Solomon, 1992; Van Breda & Passenier, 1993; Agin, Hershberger & Lukosevicius, 1980), and they all have more or less serious consequences for the performance of the operator. The research of Swartz et al. showed that, with the same degree of data reduction, lower spatial resolution has less severe consequences for operator performance on a designation task than lower update rate. Swistak (1980) showed that lower update rate had no effects on detection and recognition, but spatial resolution did. However, Van Breda & Passenier, Agin et al., and Swartz et al. showed that lowering the update frequency of the image has severe consequences for operator performance in a ship tracking task.
The most important consequence of a low update frequency is that it may degrade the perception of object- and ego motion. To date, an update frequency of 1-4 Hz is feasible and a maximum of 5-6 Hz may be attained by 1996 (van Breda & Passenier, 1993). Since recommended update frequencies of 7.5 Hz or more are not feasible yet, it is wise to investigate other solutions which may help to overcome decrease of tracking performance by update limitations or other perceptual degradations in remotely controlled systems.

1.2 Resolving remote control problems

There seem to be various possibilities that may help to overcome the inherent human factors problems of remote control. The feasibility and quality of potential remedies depend on the mission and tasks of the system, technical possibilities, human capabilities, and human resource and logistic requirements. One of the most prominent issues concerns the allocation of labour between the operator and the machine. Automatization has the potential benefit of increasing the control *range* of the operator. However, by removing the man from the control loop, automatization always will degrade control *flexibility*. In some circumstances the ratio of control range *vs* flexibility may be increased by means of intelligent routines automatizing or linking subtasks and/or incorporating potential available data about the system in its task environment. In previous studies, conducted at the TNO Human Factors Research Institute, this approach has been successfully demonstrated (van Breda & Passenier, 1993; Korteling & van der Borg, 1994).

Coupled control

In the study of Van Breda and Passenier (1993) imaging-payload and UAV control were coupled such that one operator, who controlled and monitored both the platform and the imaging sensor at the same time, directly steered the sensor footprint, rather than acting indirectly upon it via separate sensor and vehicle commands. Computing intelligence must then allocate the requested footprint motions to UAV and payload commands. This solution, which proved to decrease task demand upon the operator while enhancing tracking performance, has the potential drawback of reducing the freedom of the operator. That is, the flight path around the target and viewing direction became to a certain degree dependent, which, for instance, reduces the possibilities of scanning around a target of interest.

Partial camera automation

The study of Korteling and van der Borg (1994), focused on an intelligent, semi-autonomous, camera control system for a camera operator of a simulated UAV. This interface used inherent system "knowledge" concerning UAV translations in order to assist a camera operator in tracking a moving truck. The semi-automated system compensated for the translations of the UAV relative to the earth by autonomously generating camera rotations that were intended to keep the "footprint" of the camera on the terrain stationary. The operator received feedback about these system interventions by autonomous joystick movements that corresponded with the compensatory camera rotations. In order to track the motion of the truck relative to the terrain, the operator had to superimpose camera control actions over these system actions. Consequently, the operator remained in the loop; he still had total control of the camera-motion system. The data showed that subjects performed substantially better with the semi-autonomous interface. Performance improvements appeared equal to the improvements resulting from an increase in the update frequency of the visual image from 2 Hz to 5 Hz.

Synthetic image augmentation

One promising way of solving situational awareness problems and improving perceptual capabilities of camera operators is *synthetic image augmentation*. Recent studies (Chavand, Colle, Gallard, Mallem & Stomboni, 1988; Mestre, Savoyant, Péruch & Pailhous, 1990) focused on spatial orientation problems in remote control situations. These problems arise by the fact that it is difficult for stationary operators, using a visual display as the main source of spatial information, to convert the visual transformations on the display, generated by the combined effects of platform and camera motion, into the proprioception (literally: self-perception) of translations and rotations of the platform and the rotations (viewing direction) of the camera. This lack of situational awareness may be compensated by providing augmented *visual* proprioceptive information concerning platform and camera motions. This would especially be helpful in missions with poor visual feedback (flying above sea, hazy weather) and/or when the camera operator has to fly a UAV by himself. A simple and well-known solution in such situations would be the presentation of an extra display on the status screen presenting indirect orientation information concerning platform and camera motion. An example of a display presenting indirect orientation information is a so called Horizontal Situation Indicator (HSI). This indicator presents in a compass like manner the viewing direction of the camera, the moving direction of the platform, and geographical north. In the present experiment this indicator is used as a starting-point. A potential drawback of this solution is that this extra display requires the operator to combine artificial and rather abstract orientation information with straightforward, concrete environmental information. Therefore a more direct solution to this disorientation problem may be provided by generating synthetic visual cues which are stationary relative to the world or to a target. A simple version of this was used by Agin et al. (1980), who added small symbols to the payload image, one for the movements of the image centre in real time, and one for the position of the image centre in the next frame. Since self-motion is normally specified by global visual transformations, we believe that a synthetic visual *grid* (pattern of lines) will be more suitable for enhancing spatial situational awareness.

Such a grid may be supposed to generate clear perspective optical transformations, termed optic flow or motion perspective. According to Gibson (1950, 1966, 1979) this kind of visual information is directly perceived and continuously available and utilized to control self-motion. Korteling (1994) argues that the nervous system is very efficient in combining this kind of information with other sources of environmental information. Accordingly, flow information does not pose any extra demands upon presumed limitations in information processing capacity, which are often merely due to a lack of information, rather than to a surplus. Optic flow transformations can be analyzed in a few basic components. These components independently specify UAV translations and UAV or camera rotations, whether or not in combination (e.g., Koenderink, 1986; Kappé & Korteling, 1995), and thereby enhance the separate perception of platform and camera attitude in an environment. When such a grid is positioned at a certain height above the ground, it may also be an aid in the perception of ground speed and altitude. In addition to a grid, *platform references* may be presented in the outside image. This artificial information may indicate the rotation and viewing direction of the camera relative to the platform. Hence, information is directly provided concerning viewing direction relative to the direction of platform translation. One of the most powerful advantages of this augmented synthetical information is that it can be presented *with a high update frequency, e.g. 30-60 Hz without any need for extra data-link capacity or platform payload*. Hence, the most significant part of the proprioceptive motion and camera information is continuously available to the operator.

1.3 The present experiments

The present experiments were undertaken to gain more insight in the feasibility and in the conditions under which this principle of *synthetic image augmentation* may be fruitfully applied in order to enhance tracking performance, and to overcome situational awareness problems related to the update frequency of the outside image in a MUAV. Since the feasibility of solutions always depends on the idiosyncrasies of the MUAV system and the operator's tasks, the present status quo of MUAVs utilized by the Royal Netherlands Navy is treated as a starting point for experimental tasks and scenarios. This means that matters concerning operating a rotary winged MUAV can be accurately and reliably automated. This includes guidance, stability, and navigation (Michelson & Patton, 1988; Bombardier, 1990). Therefore in the experiments controlling the MUAV was not part of the operator task.

Operator tasks

A MUAV typically is controlled by human operators at a remote location. This crew performs a number of basic functions which are common to most UAV missions, i.e., mission planning, navigation and platform control, payload (sensor) control, data analysis, launching and recovery, and communication. Depending on the kind of missions, mission payload, and task-allocation strategies these functions can be divided over one or several operators. In many existing systems these functions are carried out by at least three operators (Denaro, Kalafus & Ciganer, 1989). In case of a single operator and missions utilizing imaging payloads, primary operator tasks of interest are: detection, recognition, designation, and tracking. These tasks are complicated, partly because of the numerous degrees of freedom of the system: altitude, horizontal position, and yaw of the MUAV, and pitch, yaw, and field of view of the camera. Combined with constrains on spatial resolution and update rate (due to the restricted bandwidth), and constraints on the field of view this may result in serious problems for the operator. Previous research shows that target acquisition and tracking are the most critical tasks. Reported problems concerning operation of a MUAV, and interpretation of the camera image (e.g. Korteling & Van der Borg, 1994; Korteling & Van Breda, 1994) include:

- loss of situational awareness, and loss of the ability to discriminate between movements of the MUAV and movements of the camera,
- degraded perception of object and egomotion,
- disorientation because of the absence of direct visual feedback, and relative independence between the viewing direction and vehicle movements,
- degraded perceptual anticipation (Poulton, 1974), due to the low quality of the payload image,
- difficulties in operating and interpreting of the payload image due to restricted field, low resolution, and low update rate.

It is expected that synthetic image augmentation by a grid will reduce problems related to object and egomotion and thereby enhance situational awareness. The present study consists of two experiments to test the benefits of a grid on two different operator tasks, i.e., a tracking task and a spatial orientation task (situational awareness).

2 EXPERIMENT I: TRACKING A TARGET SHIP

Experiment I was designed to test the effects of synthetic image augmentation on tracking a moving target with a camera from a moving platform (MUAV). Starting point of this experiment was that the MUAV system has inherent knowledge about platform and camera at it's disposal. This knowledge will usually be presented to the operator by means of a Horizontal Situation Indicator (HSI), which displays geographical north, viewing direction, and flying direction, preferably in head-up mode. As has been argued in the Introduction, the main drawback of this rather abstract and indirect style of information presentation is that it does not directly specify the (high frequent aspects of) concrete motion information that is needed to track an object. This means that operators have to translate the HSI information into separate movements of camera and platform. The presentation of above mentioned inherent system knowledge in a more direct fashion (i.e., an artificial grid that continuously specifies motion information concerning the target as well as the camera/platform) was expected to improve tracking performance. It is furthermore expected that beneficial effects of this synthetic image augmentation will increase with the degree to which motion information is degraded, for example by a low update frequency of the monitor image.

2.1 Subjects

Eight payed male subjects (age 21−35 years, mean 26.3) participated in the experiment. All subjects had normal or corrected to normal vision, and some experience with similar tracking tasks.

2.2 Mock-up and instrumentation

The experiment was conducted in the TNO−TM RPV Research Simulator. This facility (see Fig. 1) is especially designed for simulating RPV missions (Korteling & Van Breda, 1994). The subject was seated in a chair in the middle of the operator table. The chair could be adjusted to personal comfort. The only control needed was a joystick (square type, RS type 162-732) placed on the operator table at a comfortable distance for the right or left hand. Joystick deflections resulted in changes of camera rotation and/or pitch (left and right deflections: horizontal rotations, forward and backward deflections: pitch). No deflection (2% range) resulted in a stationary camera. The monitor (Mitsubishi colour display monitor HL7955SBK) was placed at eye height at a distance of approximately 60 cm. All images and displays were generated by an EVANS & SUTHERLAND ESIG 2000 (600×800 pix., see Appendix 1 for technical details).
Further instrumentation consisted of computers for scenario and data storage (4 Hz sampling frequency), and for supervisory functions.

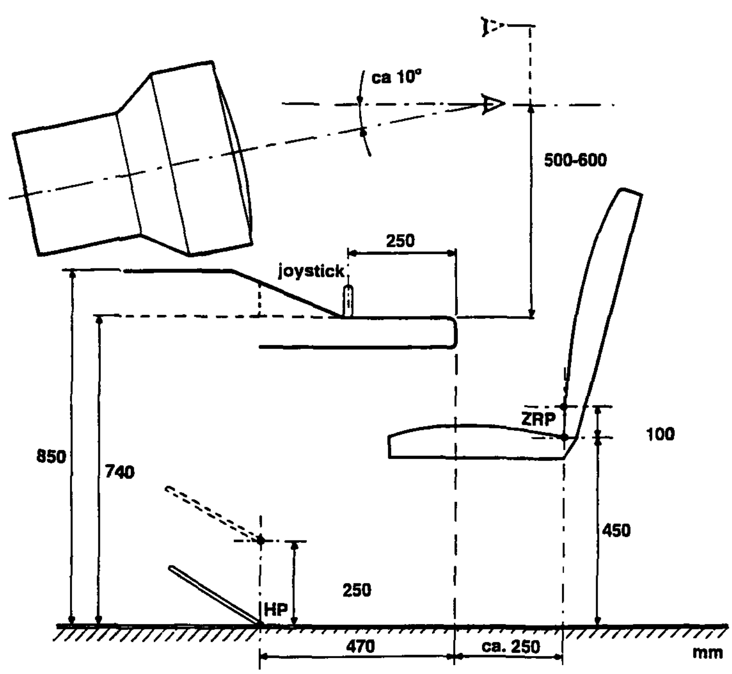

Fig. 1 Side view of the TNO−TM RPV research simulator.

2.3 Task

Subjects had to track a target ship, which meant keeping the stern of the ship as close as possible to a circle in the middle of the screen. The target ship sailed around by a route which was unknown to the subject. The same was true for the changes in speed of the target ship, and for the rotations, translations, and speed changes of the MUAV. At the beginning of a trial the target ship was in the middle of the screen. Initial distance between MUAV and target ship was 3000 m, altitude of the MUAV was always 600 m, thus initial vertical viewing angle (pitch) was 11.3°.
The MUAV flew above a further empty sea. The subject could only control the pitch and yaw of the camera, both by means of a joystick. The image was always view-up, which meant that the top side of the monitor indicated the heading direction of the camera. One trial lasted three minutes. After finishing of a trial the next trial would automatically start.

2.4 Image and displays

Camera image

The simulated camera image contained a sea, and the target ship. The synthetic image augmentation was depicted over the camera image (see Fig. 2). Field of view of the camera image was variable between 5° and 52°, in order to prevent that subjects completely lost track of the target. If the subject tended to lose the target ship the field of view was automatically enlarged, if the target ship was near the middle of the screen, the field of view was automatically narrowed. The camera image could be updated with different frequencies.

Horizontal situation indicator (HSI)

The HSI was presented as a Head-up Display (HUD) located in the middle of the screen near the bottom edge. The HSI was always view-up, and consisted of two indicators. One indicator (a line starting in the middle of the circle) for the flight direction of the MUAV (length equivalent with speed, maximum speed at the edge of the circle), and one to indicate the geographical north (a triangle on the edge of the circle). Both indicators were updated with 30 Hz, irrespective of the update frequency of the camera image.

Synthetic image augmentation

Synthetic image augmentation was provided by a grid which consisted of a pattern of parallel and perpendicular lines (100×100 lines). The grid was north-orientated and positioned at sea level. The distance between two parallel lines was 100 m, total surface 10×10 km. The grid was always updated with 30 Hz, irrespective of the update rate of the camera image. This was possible on base of the knowledge about the present status of the MUAV system (direction and speed of the MUAV, and direction of the camera), and output signals to platform and camera.

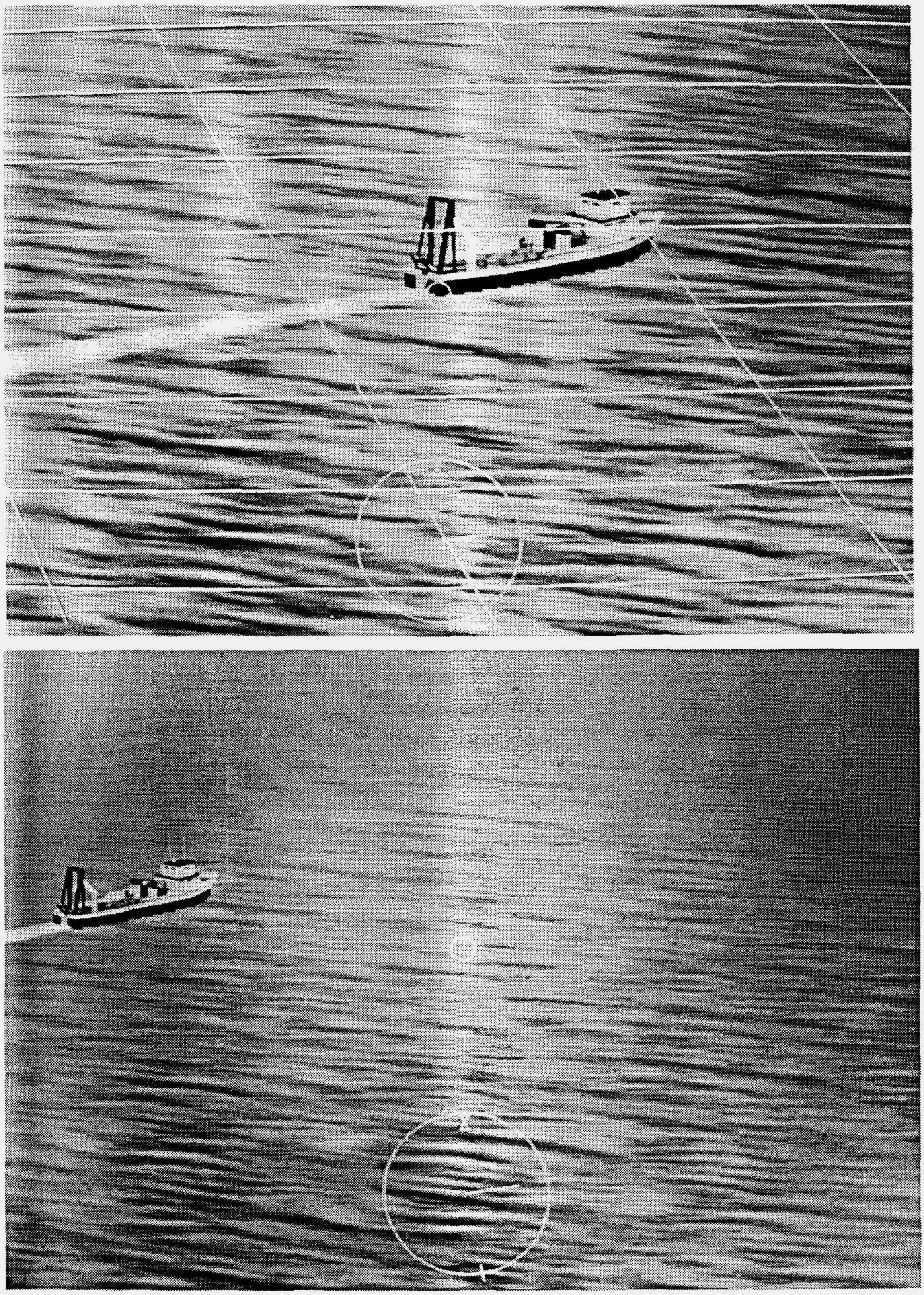

Fig. 2 Simulated camera image with grid (top) and without grid (bottom), and with different zoom factors.

2.5 Parameters of MUAV system and ship, characteristics of test scenarios

MUAV

The MUAV always flew at a altitude of 600 m, with a constant speed of 40 m/s. Maximum rotation speed was 2.16°/s. Maximum acceleration of rotation was .40°/s².

Ship

The target ship was a 70 m trawler. Speed of the ship was constant at 10 m/s. Maximum rotation speed was 2.16°/s, maximum acceleration of rotation was .32°/s².

Camera

Rotation speed of the camera (both pitch and yaw) depended on field of view (zoom-factor) and viewing distance. This was done to control the translation speed of the camera image across the monitor. Occurring maximum speed of camera yaw was about 7°/s, with maximum acceleration of about 4°/s². Occurring maximum speed of camera pitch was about 2.7°/s, with maximum acceleration of about 1.4°/s².

Test scenarios

Plots of the three minutes test scenario's are depicted in Appendix 2. Important characteristic of each scenario is the distance between ship and platform, which was limited between 2500 m and 3500 m.

2.6 Variables and statistical design

Independent variables

It was expected that synthetic image augmentation in the form of a grid would have an effect on tracking performance, and that this positive effect could compensate for the drawback of low update rate. Update rates below 4 Hz seem to be most critical (see Chapter 1). To test the hypotheses two factors were included in the experiment, with two and four levels each.

1 the presence of image augmentation by a grid:
   - present
   - absent
2 update frequency of payload image:
   - 0.5 Hz
   - 2 Hz
   - 4 Hz
   - 10 Hz.

All independent variables were varied within subjects, thus leading to 8 conditions for every subject.

Dependent variable

During the experiment the position and heading of the MUAV, the target ship and the heading and pitch of the camera were recorded with a sample frequency of 4 Hz. The position of the ship relative to the MUAV was calculated in terms of spherical coordinates (heading and pitch). These values were combined with the actual heading and pitch of the camera. The actual tracking error was the square root of the sum of the squared heading and pitch errors. RMS tracking error served as dependent variable and was calculated over the actual tracking errors for each run.

Statistical design

To exclude learning effects as a intervening variable, the eight conditions were order-balanced across subjects (Latin square, Wagenaar, 1967). In every condition the subject had to perform five scenarios of three minutes each. Because it is almost impossible to create scenarios of equal difficulty level, the testset for every condition consisted of the same five scenarios (order balanced within subjects). RMS was analyzed by a 8 (subject)×2 (display type)×4 (update rate) ANOVA with the statistical package STATISTICA®.

2.7 Procedures

After arrival at the institute subjects received a brief written explanation of the general nature and procedures of the first experiment. The instructor then showed the subjects the RPV mock up and explained the procedures, purpose and task in more detail. After this introduction the training began. The training consisted of one three minutes tracking scenario in each of the eight conditions (same scenario for all conditions). During the training the instructor always sat next to the subject and explained the working of both the HSI and the grid (if present). Furthermore the instructors showed possible strategies in using the grid (for example: in the low update frequencies try to compensate for platform movements by minimizing movement of the grid).
After the training the experiment would begin. The subjects received an extensive explanation of every oncoming condition. During the experiment the subjects had to track five three-minute scenarios in one condition (not including the training scenario). One subject completed one condition while the other subject rested.

3 RESULTS OF EXPERIMENT I

The RMS tracking data showed a main effect of synthetic image augmentation [$F(1,7)=31.6$, $p<0.005$]. As can be seen in Fig. 3, subjects were more accurate in tracking the ship in the conditions with a grid in the monitor image. Fig. 3 also indicates that RMS tracking error increased with low update frequencies [$F(3,21)=162$, $p<0.0001$]. A post-hoc Tukey test showed that only the RMS tracking error for the 0.5 Hz update frequency differed from the RMS tracking error for other update frequencies.

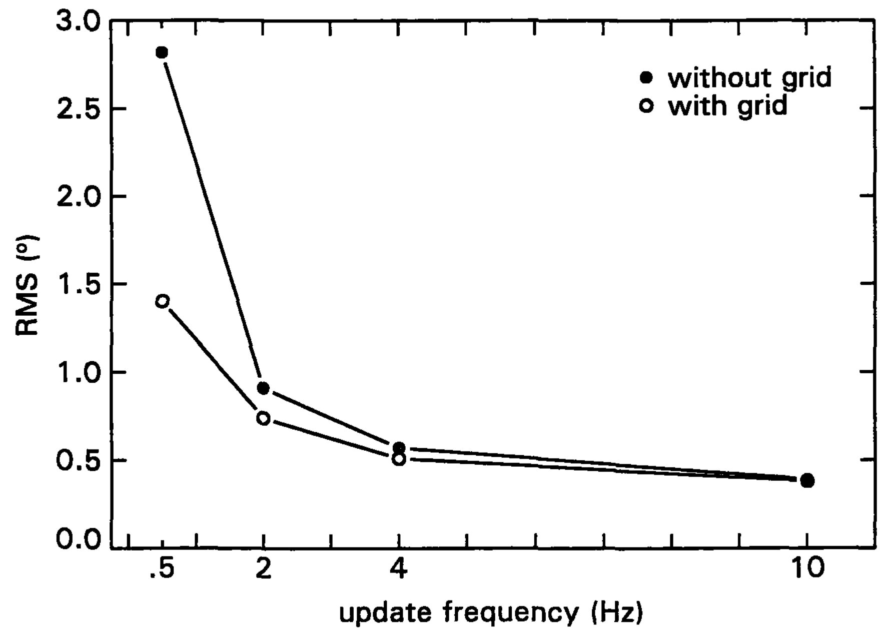

Fig. 3 RMS tracking error as effected by update frequency and image augmentation.

Fig. 3 also shows that the image augmentation effect interacted with update frequency [$F(3,21)=32.5$, $p<0.0001$]. This means that the grid was effective in reducing the RMS tracking error for low frequencies, and did not hinder tracking at higher update frequencies.

4 DISCUSSION EXPERIMENT I

Experiment I tested the effect on tracking performance of direct perceivable synthetic image augmentation, presented with a high update frequency. In the experiment, subjects had to track a moving object with a camera mounted underneath a moving platform. Performance in this task, keeping the target circle on the ship's stern, depends on the perception of the motion of the target ship as well as the motion of the camera. Camera motions result from platform rotations and translations and from the control actions by the subject (camera rotations). It was expected that low update frequencies would degrade the perception of changes in viewing direction due to rotations of the MUAV, as well as displacements of the target ship relative to the MUAV, and thus tracking performance. The results are in line with these expectations. In the low update rate conditions the subject perceives a series of static "snapshots" and the movements of camera and target ship have to be assessed by comparing static target positions. This makes it hard to discriminate between ship, camera, and MUAV motions. In addition, the subject did not receive immediate feedback of his control actions intended to keep the target on the centre of the monitor image.

In order to artificially enhance the various aspects of motion information that are degraded by low update frequencies an artificial grid was implemented in the sensor image that was updated with 30 Hz. On the basis of this high update frequency it was expected that the artificial grid would enable subjects to continuously monitor the MUAV and camera motions irrespective of the update frequency of the camera image. The potential advantage of the grid is that it enhances the critical visual information for tracking the target ship. Therefore, the grid was expected to improve tracking performance, particularly at low update frequencies of the simulated camera image, when motion information was degraded. This expectation was clearly substantiated by the data. Notice, however, that performance also decreased with lower update frequencies when the grid was present. This may be explained by the fact that the grid does not enhance perceptual anticipation (Poulton, 1974) of target ship motion. After all, the ship still was depicted "snapshot" like. When the image is of lower quality, perceptual anticipation will decrease, and predictions of shifts in the position of the target ship can only be made on the basis of cognitive anticipation (knowledge about characteristics of the target ship, and expectations about future positions).

In conclusion, on the basis of degraded perception of target and platform/camera motion, tracking performance was severely degraded by decreased update frequencies of the monitor image. This effect can be counteracted by providing augmented motion information by an artificial grid computed on the basis of inherent system knowledge and presented with a high update frequency.

5 EXPERIMENT II: SITUATIONAL AWARENESS

Experiment II was designed to test the potential beneficial effects of synthetic image augmentation on the subjects' spatial orientation or situational awareness, i.e., the perception of orientation and position of the aircraft and/or the sensor in space. Problems with the apprehension of this spatial information are supposed to be reinforced by low update frequencies of the monitor image. Like Experiment I, the presented synthetic image augmentation provided direct motion information by a grid consisting of perpendicular lines. Spatial orientation, however, may be less dependent on direct and continuous motion information than target tracking. In contrast to tracking, spatial orientation may benefit from pictorial status information as displayed by a Horizontal Situation Indicator (HSI) presenting geographical north, viewing direction, and flying direction. Therefore, in distinction from the previous experiment, this second experiment was designed such that—apart from synthetic image augmentation and update frequency of the monitor image—eventual HSI-effects could also be accounted for.

5.1 Subjects and apparatus

The same subjects of Experiment I participated in Experiment II. The mock-up, instrumentation, models, image and displays are the same as those described in Experiment I. The camera image had a standard field of view of 5°.

5.2 Task

In this experiment subjects had to watch a computer generated image for 15 s. The image was a simulation of the camera image of a MUAV flying above an empty sea. At the beginning of each trial an image was presented which contained a target ship (fixed position, in the middle of the screen, target distance 6000 m, vertical viewing angle 11.3°). The ship disappeared two seconds after the onset of the trial. Directly after the beginning of a trial the MUAV started to move (translation and rotation), and the camera started to rotate. All movements were unknown to the subject. After 15 s the image would freeze. The subjects task was first to move the camera (by means of a joystick) in such a way that it was pointed as accurately as possible at the location at which the ship had disappeared. After confirmation by pushing a button, the subject had to indicate the horizontal angle between the initial position of the target ship and the viewing direction of the camera at the moment the image froze. The subject had to write down this angle on a piece of paper and report it to the instructor, who started the next trial. Each condition consisted of six trials. Note that the ship disappeared 2 s after the beginning of a trial. This means that whenever the MUAV image contained the initial position of the ship after this 2 s, the ship was not depicted.

5.3 Variables and statistical design

Independent variables

Three factors were included in the experiment in order to test the effects of the synthetic image augmentation by the more traditional HSI, by a grid, and update frequency. Note that in Experiment I the HSI was always present. However, the utility of the head-up HSI solely could be relevant for spatial orientation tasks. On the basis of previous experiments it is expected that update frequencies below 4 Hz are most critical, so to limit the number of experimental conditions update frequency of 10 Hz is left out compared to Experiment I, thus leading to the next factors and levels:

1 Augmentation by means of a head-up HSI
   - present
   - absent
2 Augmentation by means of a grid
   - present
   - absent
3 Update frequency of payload image
   - 0.5 Hz
   - 2 Hz
   - 4 Hz.

All independent variables were varied within subjects, thus leading to 12 conditions for each subject.

Dependent variables

Two dependent variables were calculated in Experiment II:
- mean camera error
- mean reported heading error.

The camera error was the difference between the position of the target and the position of the camera footprint (resulting from heading and pitch) set by the subject in order to point at the target (both in spherical coordinates). The camera error was calculated as the square root of the sum of the squared pitch error and heading error. The mean camera error was calculated over the six scenarios in each condition.
The reported (horizontal) heading error was the absolute difference (in °) between the actual heading of the target relative to the final heading of the camera, and the subjects' verbal report of the heading of the target. The mean reported heading error was calculated over the six scenarios.

Statistical design

Conditions were order balanced across subjects (Latin square). In every condition the subjects had to perform six scenarios. To exclude effects of scenario difficulty, every subject performed the same six scenarios (order balanced) in every condition.
All measures were analyzed by a 8 (subject)×2 (HSI)×2 (grid)×3 (update frequency) ANOVA with the package STATISTICA®.

5.4 Procedures

The subjects first received written instructions concerning tasks, conditions, and procedures which they had to read carefully. Because all subjects had participated in Experiment I, they were familiar with the camera image, the synthetic image augmentation, and the joystick operation. Again subjects worked in pairs; one subject completed three conditions consecutively while the other one rested. After a short training, one scenario in each condition, the experiment began. The instructor always explained the oncoming condition to the subject. When the subject was ready the instructor started the first scenario. The subject watched the camera image, which would freeze after 15 s (indicated by a beep). Subsequently the subject could reposition the camera in the position of the initial position of the target ship. When the subject was satisfied with the aiming of the camera he conformed this by pushing a button. Finally, the subject had to indicate the horizontal angle between the position of the target ship and the viewing direction at the end of the 15 s scenario. After writing this down and reporting it to the instructor, the next scenario would start. One condition consisted of 6 scenarios.

6 RESULTS OF EXPERIMENT II

During the experiment, one subject indicated to have problems with the camera repositioning task, in spite of extensive additional instruction. In line with this, his mean camera repositioning error over all conditions differed more than 2 standard deviation from the overall mean camera error. Therefore this subject was excluded from further analysis.

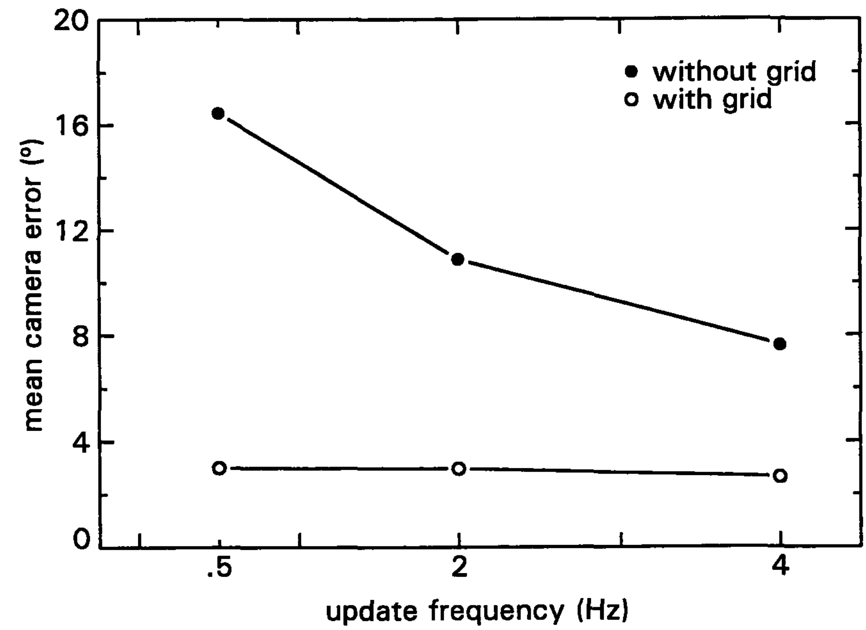

Fig. 4 Mean camera repositioning error as effected by update frequency and image augmentation.

Mean camera error data did not show an effect of the HSI; the subjects did not seem to use the information on the camera's viewing direction and the heading of the MUAV that was depicted in the HSI display [$F(1,6)=1.62$, n.s.]. The mean camera error was reduced when the visual information was augmented by means of the grid [$F(1,6)=12.7$, $p=0.012$]. As can be seen in Fig. 4, the subjects were more accurate in repositioning the camera when the grid was presented in the camera image. This figure also shows the effect of update frequency [$F(2,12)=3.9$, $p=0.048$], the subjects had a higher mean camera error for the lower update frequencies. Fig. 4 shows that image augmentation by means of a grid tended to interact with update frequency. Probably due to the high variance of the camera error data, this interaction just failed to reach significance [$F(2,12)=3.4$, $p=0.067$], but it does show that the presence of the grid resulted in a low mean camera error irrespective of the update frequency (post-hoc Tukey test shows significant differences between no-grid 0.5 Hz and no-grid 2 Hz *vs* all the grid conditions and between no-grid 0.5 Hz and no-grid 4 Hz).

With respect to the second dependent variable, providing a verbal indication of the heading of the ship relative to the viewing direction of the camera, the subjects reported severe difficulties. Most subjects were very uncertain about their answers and substantially overestimated the target's heading (about 10 to 20 times). In this task, all subjects were included in the analysis. In line with the reported difficulty of the task and the resulting high rate of error variance, the results did not show a significant effect on any of the independent variables.

7 DISCUSSION EXPERIMENT II

Experiment II was designed to test the potential beneficial effects of two forms of synthetic image augmentation on the subject's spatial awareness under different conditions of update frequency of the payload image. Upon an imposed motion pattern of the platform/camera the subjects had to reposition the camera in order to look in the direction of a previous visible target and to mention the direction of this target relative to the heading of the camera.
The presence of the horizontal situation indicator (HSI) did not show any effect on camera repositioning error. This might be explained by the fact that the interpretation of this display and the translation of the information into visuo-spatial knowledge or spatial awareness, may require more training than was provided during the experiment. This explanation is substantiated by the finding that subjects did not base their verbal reports concerning the heading of the target relative to the viewing direction of the camera on what they could read simply from the rude compass scale of the HSI. This means that subject did not use this abstract information, even not in conditions of highly degraded visual motion information.
Improved camera repositioning performance with image augmentation indicates that, as expected, the grid aided subjects to continuously and directly perceive orientation and position of the aircraft and/or the sensor in space. In addition, the positive effect of the grid may be explained by the fact that the subjects could use a simple heuristic to find the original position of the target. The grid enabled subjects to monitor the movements of camera and MUAV by observing the horizontal and vertical lines that passed (the centre circle of) the display. Consequently, the subjects could find the initial position of the target by reproducing these line passages in the opposite direction. That the subjects used this heuristic, is substantiated by the finding that the verbal reports on the targets heading did not show any effect of the presence of the grid. Overestimation of the camera rotation, and consequently the poor awareness of "compass space", is probably caused by the fact that the subjects were viewing a zoomed-in camera image. This point will be further addressed in the general discussion.
Camera repositioning performance decreased with low update frequency of payload image. In addition, as opposed to the data of Experiment I, a post-hoc Tukey test shows that the grid fully compensated for this performance decline with decreasing update frequency. This absence of an effect of image degradation when the grid was present suggests that the subjects completely relied on the synthetic grid in performing the repositioning task.

8 GENERAL DISCUSSION

The function of imaging devices, is to provide the operator with visual information for information acquisition and vehicle guidance. The quality of the visual information will be crucial to many tasks in which control of the imaging system is a prerequisite for success,

such as scouting, tracking, and battle-damage assessment. However, the quality of the visual information for MUAV operators may be severely degraded, which is partly due to the need to limit the data-link between the MUAV and the control station.
One major possibility to limit the amount of information that has to be transmitted by the data-link system of a MUAV is to decrease the update frequency of the payload image. The most important consequence of a low update frequency is that it may degrade the perception of object (target) and ego (platform/camera) motion is degraded. Therefore, in Experiment I, subjects had to track a moving target ship with a camera mounted underneath a moving platform under conditions of varying update frequencies of the payload image. Performance in this task depends both on the perception of the motion of the target ship, and the motion of the platform/camera. In line with our expectations, the data showed poor tracking performances in the conditions with low update frequencies. Under these conditions the subject perceives a series of static "snapshots" and the movements of camera and target ship have to be assessed by comparing static target positions. This makes it hard to distinguish whether the target moves relative to the aimpoint of the camera or the camera relative to the target. In addition this thwarts instantaneous visual feedback of control actions intended to keep the target in the centre of the monitor image.
In order to enhance the perception of egomotion it was conceived that an artificial grid could provide the most important cues for these motions. By using inherent system knowledge about the position and movements of the MUAV and the pitch and heading of the camera, the grid can be generated with a high update frequency, irrespective of data-link capacity. On the basis of its high update frequency it was expected that the grid would assist subjects to continuously monitor the platform and camera motions, which is especially relevant with low update frequencies and poor background textures (hazy sea). To a lesser extend, the motion of the ship relative to its environment would be enhanced. On the basis of the results it can be concluded that augmented motion information by this artificial grid is beneficial to tracking performance in conditions characterized by low update frequency of the payload image.
The kind of grid used in the present study enhanced the perception of the rotations of the camera or platform. These rotations generate translations in the camera image, and the presence of a grid with a high update frequency will enhance the perception of such translations. However, there is a problem in the perception of platform and camera movements with almost vertical viewing directions (large pitch angles). Under these conditions a small change in rotation can not be distinguished from a translation of the platform, since they both generate translations in the camera image. This problem can be solved by using a second grid that is positioned at some distance above the first grid. During a translation of the vehicle, the more proximal grid will move faster (motion parallax) than the grid at sea-level. However, in case the camera or platform rotates, both grids will translate at the same speed. This results in a clear distinction between the visual effects of translation and rotation.

Experiment II was designed to test the potential beneficial effects of synthetic image augmentation on the subjects' spatial orientation or situational awareness, i.e., the perception of orientation and position of the aircraft and/or the sensor in space. Also the apprehension of spatial orientation information may be supposed to be degraded by low update frequencies of the monitor image. As opposed to target tracking, spatial orientation may benefit from pictorial status information as displayed by a head-up Horizontal Situation Indicator (HSI) which displays geographical north, viewing direction, and flying direction. Therefore, in distinction from Experiment I, the second experiment was designed such that—apart from synthetic image augmentation and update frequency of the monitor image—eventual HSI-effects could be accounted for. Experimental task started with a brief presentation of a target ship, whereafter the camera and platform started to move randomly for 15 s. The subject's task was to reposition the camera in order to look at the initial position of a target and to mention the compass direction of the target relative to the heading of the camera.

The camera repositioning data and the verbally reported heading data jointly indicated that the HSI was not effectively used. In contrast, synthetic image augmentation clearly aided subjects to aim the camera at the previously seen target. Furthermore, as opposed to the data of Experiment I, the grid fully compensated for performance decline with decreasing update frequency. This absence of an effect of the quality of the outside image when the grid was present in combination with the poor verbal heading reports, even with the aid of a grid, demonstrates that the subjects completely relied on the synthetic grid in performing the repositioning task by using a simple heuristic. That is, the subjects could find the initial position of the target by reproducing line passages of the grid in the opposite direction.

With regard to the verbal direction estimations, subjects seriously overestimated the camera rotations and thereby misjudged the compass direction of the target. This was true for all task conditions. This poor awareness of "compass space", is probably caused by the fact that the subjects were viewing a zoomed-in camera image (without being told so). Normally, in everyday life, the translations generated by a rotation of the observer are directly related to the speed of rotation (Koenderink, 1986). Therefore, subjects can rely on the fact that the speed by which the visual image is translated is equivalent to the rate of rotation. However, When a camera is zoomed-in, the translation speed of the camera image depends on the speed of rotation multiplied by the zoom-factor. Therefore, zooming will increase the translation speed of information over the monitor. Since the exact zoom-factor was unknown to the subject, the magnitude of camera rotations could not be assessed from image velocity. However, it still may be regarded rather surprising that the subjects overestimated camera rotation in the presence of the grid, since the subjects could easily notice that the *orientation* of the grid lines did not change substantially during rotation. Modest grid rotations imply that the platform/camera only turns over small angles. Therefore, the overestimation of rotations shows that the subjects primarily relied on the translation speed of the camera image, ignoring the orientation information in the grid. Probably, subjects can be trained to use the orientation of the grid lines in order to improve their spatial awareness. The current results, however, show that the subjects normally tend to utilize the translation of the camera image in order to assess information on rotation. In our opinion, the starting point of the improvement of situational awareness should therefore be the correct representation of the rotational speed in the camera image. A future study may investigate how this should be accomplished.

The present experiments were focused at the potential benefits of synthetic image augmentation. Since the results are promising, a next step is to develop more sophisticated forms of synthetic image augmentation. Possible improvements of the present principle of earth fixed parallel and perpendicular lines for both the tracking and the situational awareness task are, amongst others:

- to introduce parallax by generating a second grid above sea level,
- to integrate the camera image and augmentation in a tactical display,
- to introduce platform references in the image to discriminate between rotations of the platform and of the camera,
- to introduce head-up information on camera pitch and heading,
- to generate perceptual correct grid information, irrespective of zoom factor.

Experiment I clearly demonstrated the benefits of the grid in a tracking task. This means that without any extra demands on the data-link, implementation of synthetic image augmentation results in better operator performance or the possibility to lower the update frequency without performance deterioration. This effect on tracking performance is even accomplished with a grid in its most simple form. Therefore oncoming experiments may be concentrated on performance in other tasks or missions.
Experiment II showed that a grid improved the subjects' abilities of pointing in the direction of a previously seen target. However, even with image augmentation, absolute spatial awareness (actually, awareness of "compass space") was far from optimal. Of the above mentioned improvements, presentation of a geometrically correct grid, independent of zoom-factor, probably is the most promising solution for improving awareness of compass space. To thoroughly test this, a dynamic test for situational or compass awareness has to be developed.

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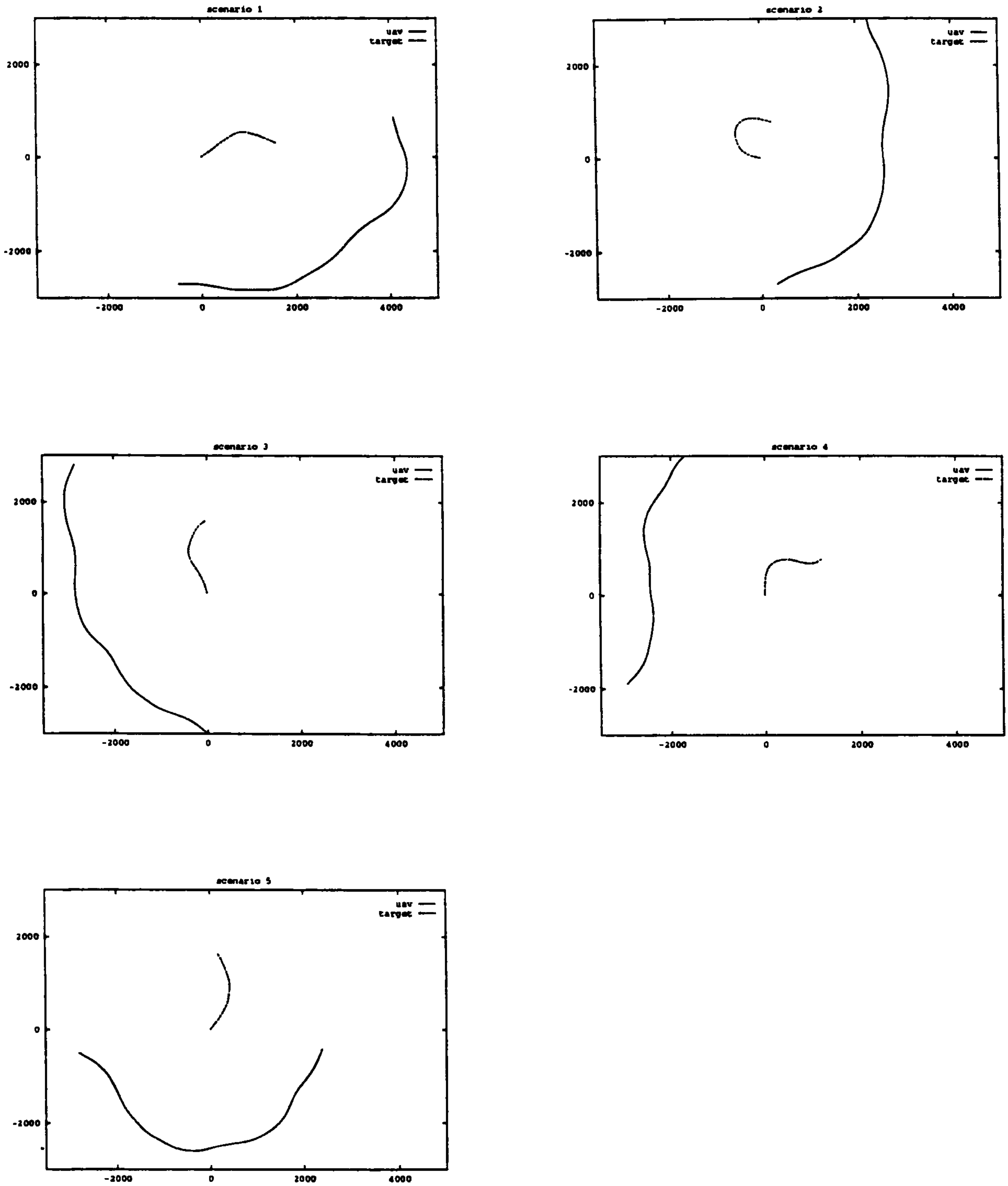
Soesterberg, 12 April 1995

Drs. J.B.F. van Erp

APPENDIX 1: Technical specifications ESIG-2000 image generator

Manufacturer:	Evans & Sutherland, type ESIG-2000
Principle:	computer generated images
Channels	maximum 4
Resolution:	1,0 M pixels per channel at 30 Hz (3 channels) 0,5 M pixels per channel at 60 Hz (3 channels)
Field of view	programmable
Number of polygons:	1500 to 2000 polygons/channel at 30 Hz, 1000 polygons/channel at 60 Hz
Colours:	1024 colours excluded texture and shading effects
Hidden surface removal:	Binary Separation Planes (BSP)
Shading:	smooth, flat, Gouraud shading
Anti-aliasing:	yes, not through transparent polygons
Moving objects:	maximum 252 independent objects
Lag time:	2½ update cycle+1 refresh cycle. At 30 Hz update and 60 Hz refresh: 100 ms, at 60 Hz update: 58 ms
Texturing:	maximum 256 (128×128) texture maps (4,2 Mtexel), dynamic texturing possible
Atmosphere:	day, night, dusk, lightning
Level of detail:	automatic, overload management
Light point:	yes
Line of sight ranging/ laser ranging:	yes
Collision detection:	yes
Terrain interaction:	yes, maximum 40 points
FLIR:	yes
Animation:	yes
Graphics overlay:	mixed in image by video-keying
Video-output:	programmable

APPENDIX 2: Plot of the five scenarios in the tracking task



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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

The rapid growth of aircraft technology enables to automate many subtasks related to platform control of a Maritime Unmanned Aerial Vehicles (MUAV). Therefore, one of the most important tasks of the operator('s) of a MUAV is operating the mission payload, which is usually a video camera. The numerous degrees of freedom of the image, combined with a limited bandwidth for communication with the mother ship may lead to several problems for operators, including loss of situational awareness and problems in tracking targets.
The TNO Human Factors Research Institute is involved in several studies to explore possibilities to support operators. On the basis of knowledge about the present position and orientation of MUAV and camera, system characteristics, and control inputs, an artificial grid of perpendicular lines in the camera image can be presented that specifies the various components of MUAV- or camera motion. This means that when the camera image is refreshed with lower update frequencies, the perpendicular lines move as it were over a static camera image. The hypothesis that this grid will enhance operator performance was tested in two experiments. In the first experiment subjects had to track a moving target ship from a moving MUAV platform. The results showed a significant positive effect of synthetic image augmentation. This effect became stronger in the conditions with low update frequencies: up to a factor two in the 0.5 Hz update rate conditions. The second experiment involved a situational awareness task. This experiment too shows a significant positive effect of synthetic image augmentation, which increases in the conditions with lower update frequency.
The present experiments were conducted to investigate the potential benefits of synthetic image augmentation in operating a MUAV. The results are promising, and ask for further exploration of the applications of synthetic image augmentation. Coming experiments will be designed to test a new developed form of synthetic image augmentation in which the present principle of the perpendicular lines is combined with a more conventional head-up display. Furthermore a different test for situational awareness will be applied.

16. DESCRIPTORS Data Transmission Human Performance Image Interpretation Target Tracking UAV	IDENTIFIERS Situational Awareness

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