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Visual support in target search from a simulated unmanned aerial vehicle

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Bij het op afstand besturen van Maritime Unmanned Aerial Vehicles (MUAV's) wordt de stuurtaak van de operator bemoeilijkt door de geringe hoeveelheid, en slechte kwaliteit, van de beschikbare visuele informatie. Bijvoorbeeld, door de beperkte bandbreedte van de downlink, kan het door de camera geregistreerde beeld slechts met een lage update frequentie en een bescheiden resolutie worden doorgezonden. Dit hindert met name het zoeken en volgen van targets, aangezien de operator daarbij op basis van het videobeeld moet sturen. In dit verband is bij TNO Technische Menskunde een nieuw principe voor operator ondersteuning ontwikkeld, waarmee, zonder de downlink verder te belasten, stuurtaken kunnen worden ondersteund (Van Erp, Korteling & Kappé, 1995). Het principe is gebaseerd op een aardvast Computer Gegenereerd Grid (CGG) dat met een hoge update frequentie op het camerabeeld wordt afgebeeld. Het grid wordt gegenereerd op basis van de operator input naar het platform en kennis van de systeem eigenschappen. Hierdoor zijn camera en MUAV bewegingen goed zichtbaar, onafhankelijk van de update frequentie van het camerabeeld.

In het huidige experiment werden de effecten van een CGG op de operator's 'target search' prestatie onderzocht, en vergeleken met een meer traditionele manier van operator ondersteuning. In een zoektaak moesten de proefpersonen vijf schepen lokaliseren in een vooraf bepaalde volgorde. Informatie over de positie van de schepen werd door middel van een gesimuleerd radarbeeld gepresenteerd.

De proefpersonen konden op twee manieren worden ondersteund: door middel van een aardvast CGG en met twee lineaire kwantitatieve indicatoren die de heading en pitch van de camera aangaven. Als basisconditie was een standaard methode voor operator ondersteuning, een pictorale 'Combined Heading and Pitch Indicator' (CHPI), aanwezig.

De informatie die door het CGG wordt gegenereerd is fundamenteel verschillend van de informatie die door de indicatoren wordt aangeboden. Volgens Gibson (1950) wordt de 'optic flow' van het CGG als gevolg van camera en MUAV bewegingen 'direct' waargenomen, zonder dat dit veel aandacht vereist. De meer traditionele methoden, zoals de kwantitatieve indicatoren, vergen meer aandacht, omdat de toestand van de MUAV moet worden 'gereconstrueerd' aan de hand van de aangeboden abstracte informatie.

Om meer inzicht te krijgen in de potentiële voordelen van een CGG werd de zoektaak onder verschillende condities uitgevoerd. De MUAV kon een vaste positie hebben of een cirkelbeweging uitvoeren, en de MUAV kon centraal in het radarbeeld zijn gepositioneerd of excentrisch. Een cirkelbeweging bemoeilijkt de zoektaak aangezien de relatieve positie van het target verandert; een excentrisch geplaatste MUAV hindert het vaststellen van de heading van het target.

De resultaten laten duidelijk zien dat het CGG een effectieve methode is om de 'situational awareness' van MUAV operators te verbeteren: de proefpersonen zochten sneller, en hadden minder camerabewegingen nodig om de targets te lokaliseren. De meer gebruikelijke methode van operator support, indicatoren die heading en pitch aangaven, bleek daarentegen geen significante effecten op te leveren.

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Visual support in target search from a simulated unmanned aerial vehicle

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

SUMMARY

In steering Maritime Unmanned Aerial Vehicles (MUAV's) and controlling its camera movements, the operator's task is complicated by a limited quantity and quality of the available perceptual information. For example, the outside image is presented with low update rate and a narrow field of view due to the limited bandwidth of the data-link between platform and operator. The reduced amount of visual information may hamper visual search, target tracking, and control performance. In this connection the TNO Human Factors Research Institute has developed a new principle of visual support of which some of its potential benefits were demonstrated in a previous experiment. (Van Erp, Korteling & Kappé, 1995). This principle involves an earth-fixed Computer Generated Grid (CGG) consisting of parallel and perpendicular lines, depicted with a high update frequency over the (slower updated) camera image. The current experiment focused on the benefits of the CGG in improving target search performance, and compared its performance with other methods of operator support. In a search task, subjects had to locate five target ships on a, further empty, sea as fast as possible. Information on the location of the MUAV and the target ships was presented on a simulated radar image.

The subject could be assisted by two different types of visual support: an earth-fixed CGG at sea level, or two head-up linear quantitative indicators adjacent to the camera image, indicating camera pitch and compass heading. As baseline, all conditions included a standard method of operator support by means of a pictorial combined heading and pitch indicator (CHPI).

The information provided by the CGG is fundamentally different from the information provided by the indicators. Gibson (1950) assumes that the information provided by the CGG may be picked-up directly by the visual system, without demanding substantial visual attention. The more traditional methods of operator support all require the operator to use some kind of cognitive strategy to infer the MUAV attitude from the presented abstract information.

In order to gain more insight in the potential beneficial effects of the two types of operator support, the MUAV could have a fixed position in the air, or could fly a circular flight path. It was expected that a circling MUAV would complicate perception and discrimination of camera and MUAV motions. Also, the MUAV could be positioned central or eccentric in the radar display. Only when the position of the platform is in the centre of the radar image the quantitative indicators and the CHPI provide straightforward information. In an eccentric

position, subjects have to calculate in order to determine the correct heading of the camera by using the compass scale.

The results clearly substantiate the effectiveness of the CGG in improving the operators search performance: search time and total camera-heading and pitch movement were significantly reduced when the CGG was presented. Supporting the operator by means of quantitative indicators, depicting camera heading and pitch, did not reach significance on any of the dependent variables.

Visuele ondersteuning bij het zoeken van doelen met een gesimuleerd unmanned aerial vehicle

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

SAMENVATTING

Bij het op afstand besturen van Maritime Unmanned Aerial Vehicles (MUAV's) wordt de stuurtaak van de operator bemoeilijkt door de beperkte hoeveelheid, en slechte kwaliteit, van de beschikbare visuele informatie. Bijvoorbeeld, door de beperkte bandbreedte van de downlink, kan het door de camera geregistreerde beeld slechts met een lage update frequentie, en een beperkte resolutie, worden doorgezonden. Dit hindert met name het zoeken en volgen van targets, aangezien de operator daarbij op basis van het videobeeld moet sturen. In dit verband is bij TNO Technische Menskunde een nieuw principe voor operator ondersteuning ontwikkeld, waarmee, zonder de downlink verder te belasten, stuurtaken kunnen worden ondersteund (Van Erp, Korteling & Kappé, 1995). Het principe is gebaseerd op een aardvast Computer Gegenereerd Grid (CGG) dat met een hoge update frequentie op het camerabeeld wordt afgebeeld. Hierdoor zijn camera en MUAV bewegingen goed zichtbaar, onafhankelijk van de update frequentie van het camerabeeld.

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De proefpersonen konden op twee manieren worden ondersteund: door middel van een aardvast CGG en met twee lineaire kwantitatieve indicatoren die de heading en pitch van de camera aangaven. Als basisconditie was een standaard methode voor operator ondersteuning, een pictorale 'Combined Heading and Pitch Indicator' (CHPI), aanwezig.

De informatie die door het CGG wordt gegenereerd is fundamenteel verschillend van de informatie die door de kwantitatieve indicatoren wordt aangeboden. Volgens Gibson (1950) wordt de 'optic flow' van het CGG als gevolg van camera en MUAV bewegingen 'direct' waargenomen, zonder dat dit teveel aandacht vereist. De meer traditionele methoden, zoals de indicatoren, vergen meer aandacht, omdat de toestand van de MUAV moet worden 'gereconstrueerd' aan de hand van de aangeboden abstracte informatie.

Om meer inzicht te krijgen in de potentiële voordelen van een CGG werd de zoektaak onder verschillende condities uitgevoerd. De MUAV kon een vaste positie hebben of een cirkelbeweging uitvoeren, en de MUAV kon centraal in het radarbeeld zijn gepositioneerd of

excentrisch. Een cirkelbeweging bemoeilijkt de zoektaak aangezien de relatieve positie van het target verandert; een excentrisch geplaatste MUAV hindert het vaststellen van de heading van het target.

De resultaten laten duidelijk zien dat het CGG een effectieve methode is om de zoekprestatie van MUAV operators te verbeteren: de proefpersonen zochten sneller, en hadden minder camerabewegingen nodig om de targets te lokaliseren. Daarentegen bleek de meer gebruikelijke methode van operator support, kwantitatieve indicatoren die heading en pitch aangaven, geen significante effecten op te leveren.

1 INTRODUCTION

In modern warfare, success and failure become increasingly dependent on technological developments and applications of intelligent and (semi) autonomous systems such as unmanned vehicles. In this connection, the Royal Netherlands Navy is especially interested in Maritime Unmanned Aerial Vehicles (MUAV's). Potentially, these systems may contribute to many tasks, such as intelligence, target acquisition, battle-damage assessment, communication relays, radar observation, etc. However, several technological problems have to be solved before these goals can be reached. From a human-factors point of view, one of the main problems is related to the images provided by the imaging devices, the most common MUAV payload. These imaging devices, e.g., video or infra-red cameras, have two principal limitations: a low update-rate and a limited and zoomed-in field of view. These limitations may become critical when the operator would need manual control of MUAV and/or camera movements, for instance when tracking a target or in battle damage assessment.

The low update rate of the payload image is mainly due the restricted capacity of the data link between MUAV and operator, in order to decrease vulnerability to enemy jamming. The current state of technology allows a maximum update rate of 4 Hz, combined with low spatial resolution, limited field of view, and image compression-decompression. These image degradations have serious consequences for operator performance. Reported difficulties include: loss of situational awareness, degraded perception of object motion and platform-camera attitude, degraded perceptual anticipation, and performance loss in MUAV-control (cf., Van Erp, Korteling & Kappé, 1995).

However, even with an optimal update frequency, the camera's field of view is limited. Due to the large minimum following distance (2000 m, NATO (1990)), the camera needs to zoom-in on targets, resulting in a recorded field of view of only a few degrees. Such limited field of view does not allow the operator to develop a sense of spatial awareness, i.e., knowing the position and direction of translation of the MUAV, knowing the viewing direction of the camera with respect to the orientation of the MUAV, or knowing the position of the different sites of interest with respect to the MUAV (cf. Van Erp et al., 1995, Korteling & Van der Borg, 1994).

In order to solve these principal limitations of imaging devices, a previous experiment introduced a new principle for operator support (Van Erp et al., 1995). This principle allows the operator to control the MUAV relatively independently of the update frequency of the camera and may circumvent the problems of the limited field of view.

The new method presents the operator with an earth fixed Computer Generated Grid (CGG), consisting of parallel and perpendicular lines, that may be superimposed on the camera image. One of the major advantages of using a CGG is that this method does not consume any down-link capacity: the CGG is generated at the control station. Using current MUAV status and attitude (updated at a low frequency), and a MUAV model running on a computer at the control station, the CGG may be updated at a high frequency. Thus, the grid allows the optic flow generated by MUAV and camera motions to be smooth and continuously visible, even when the camera image is updated at (very) low frequencies.

The ability of the operator to use the optic flow generated by camera and MUAV movements is of fundamental importance. Normally, this information allows us to navigate ourselves through complex environments, and build a sense of spatial awareness. The visual system has evolved to make use of the information contained in optic flow, and may pick-up this information without effort (Gibson, 1950). This makes the information contained in optic flow fundamentally different from the pictorial (e.g., map-like) or numerical (e.g., position, heading and speed) information on the status of the MUAV that is usually presented to the operator. The latter kind of information requires the operator to perform some kind of cognitive processing in order to build a mental model of the MUAV's status. Obviously, such cognitive processing requires attention, and may hamper the operator in performing additional tasks.

In a previous experiment we tested the efficiency of the CGG in both a tracking and situational awareness task. In the first task subjects had to track a moving ship from a moving MUAV under different update frequencies of the camera image (see Fig. 1). A very significant positive effect of a CGG on the RMS tracking error was found, in particular at lower update frequencies (factor 2 at 0.5 Hz). In the second task subjects that had to reposition the camera to the target position after 15 seconds of 'random' platform and camera movements, and had to verbally report the horizontal angle between the camera heading after 15 s, and the initial target position. The results again demonstrated a positive effect of the CGG on operator performance. Due to its high update frequency, the grid allowed an optimal perception of MUAV and camera movements. Also, the subjects could use a simple heuristic to reposition the camera, i.e., counting the number of horizontal and vertical lines that passed during the 15 seconds.

However, in spite of the accurate repositioning of the camera, the subjects' verbal reports on the position of the target with respect to the 'self' showed a substantial overestimation of the camera rotation. These results indicated that the subjects had a poor 'situational awareness', e.g., they did not know the target's position in respect to the current viewing direction of the camera. This effect is probably caused by the fact that subjects watched a zoomed-in camera image. A zoomed-in camera image increases the magnitude of translational optic flow generated by camera rotations, resulting in overestimation of camera rotation.

Improving target search performance

The current experiment was designed to explore the effects of a CGG on the operators target search performance, and to compare its performance with a more traditional method of operator support. The subjects' task was to search for target ships as fast as possible, in a predetermined order. A simulated radar image provided information on the position of the MUAV and the targets. Point of departure in the present experiment was a high quality camera image. If a positive effect of visual support can be demonstrated for such images, these effects may be even more pronounced in with degraded camera images.

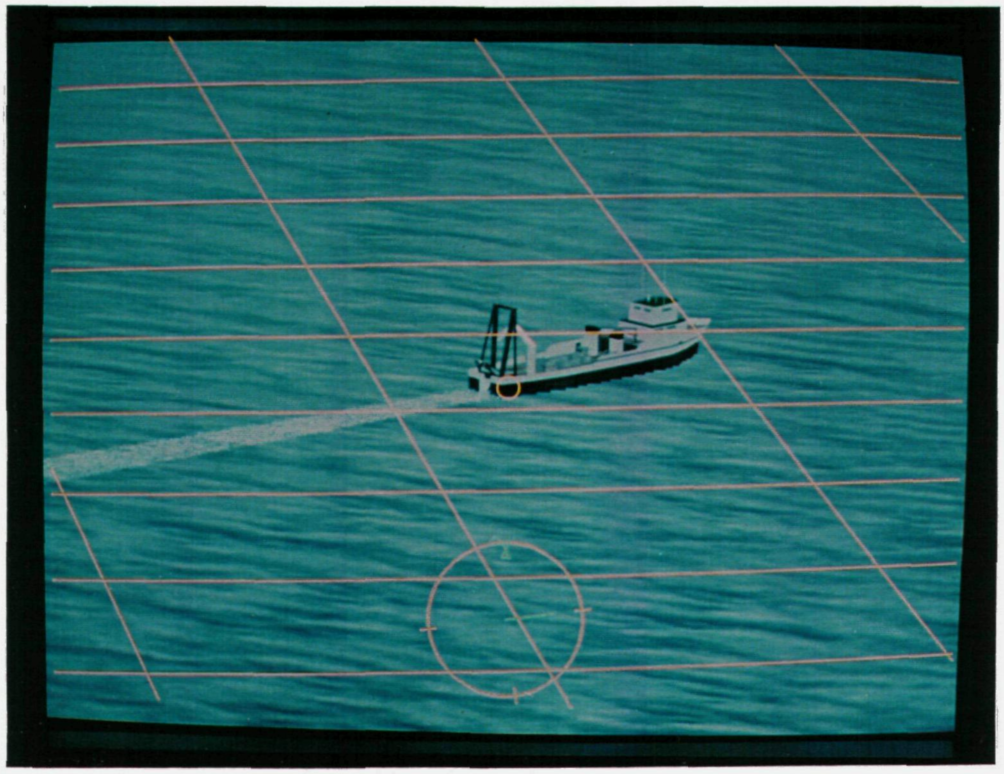

Fig. 1 The Computer Generated Grid (CGG) used in the previous experiment.

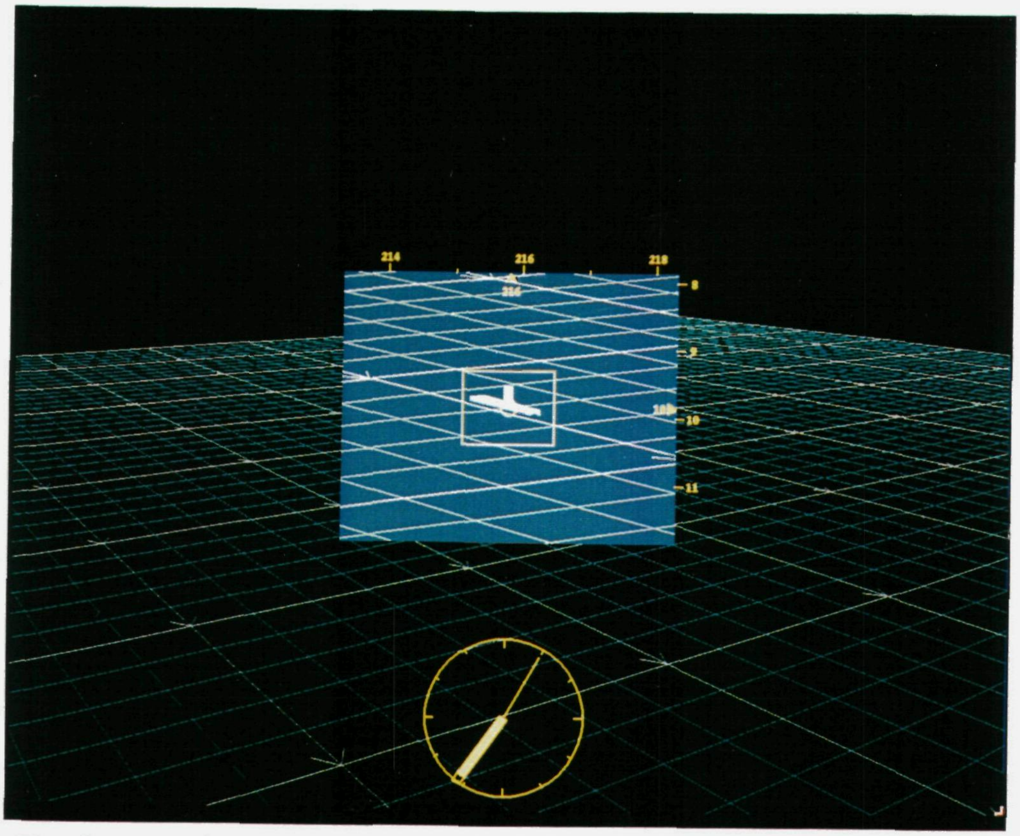

Fig. 2 The Computer Generated Grid (CGG), the camera image, and the Combined Heading and Pitch Indicator (CHPI) used in the current experiment.

Besides the zoomed-in grid that was presented in the previous experiment, we used a perspectively correct presentation of the grid, independent of the zoom factor of the camera. The grid was presented around the camera image, as if the operator was looking from the MUAV onto the CGG (Fig. 2). The hypothesis was that such a grid would prevent overestimation of camera rotation, and would allow operators to develop a good sense of spatial awareness, resulting in an improved target search performance.

Apart from the CGG, a more traditional method of operator support could be presented to the observer. This method consisted of a set of head-up linear quantitative indicators on the top and right side of the camera image, indicating heading and pitch angles of the camera. The indicators provide the operator with accurate numerical information on the status of MUAV and its camera. Obviously, this type of information can only be used when the operator actively estimates target position, and adjusts the camera heading and pitch accordingly.

In the experiment, these two methods of operator support were combined in a full factorial design. Such a design includes a condition without CGG and quantitative indicators, which would make the search task impossible to accomplish. Therefore, a third type of operator support was introduced, that was always present in the display.

The so called Combined Heading and Pitch Indicator (CHPI) was always present in the display. The CHPI presented the operator a pictorial, clock-like, head-up display that depicts camera and MUAV status (see Fig. 2) The specifications of the CGG, the quantitative indicators and the CHPI are given in the method section.

Both CGG and traditional types of operator support have different benefits and weaknesses. One may expect that the CGG provides a strong cue for the perception of camera and/or MUAV motion, but is less accurate in determining the exact heading and pitch of the camera. On the other hand, the indicators are exact indicators of heading and pitch, but are less useful in perceiving MUAV motions. Also, the indicators may be less useful when the MUAV is not positioned in the centre of the radar image. Now, the operator can no longer read the targets' heading directly from the radar image, but has to transpose the relative position of the MUAV in order to estimate heading.

In order to investigate these possible effects four different MUAV flight paths were generated: stationary or moving (along a circular track) and positioned at the centre of the radar image or eccentric.

Note that all three indicators (CGG, pictorial, indicators) do not directly indicate required pitch. When the MUAV is flying at a fixed altitude, the subject will have to develop a concept about the relation between distance on the radar screen, and required pitch.

2 METHODS

2.1 Subjects and task

Subjects

Eight higher educated, male subjects (age 21−31 years, mean 24, sd 3 years) participated in the experiment. All subjects had normal or corrected to normal vision. The subjects were payed for their participation, and had no experience with similar operator tasks.

Task

Subjects had to locate five target ships, in a fixed order, as fast as possible by operating a camera from a MUAV. The camera image simulated the image recorded by a movable camera located underneath a MUAV. The camera was controlled by means of a joystick, controlling the MUAV was not part of the subjects' task.

After locating the actual target, subjects had to track it for 2 s (so called target-locking). Target-locking was introduced to be sure that the subject really located the target, and to avoid accidental hits. After target locking, the screen would freeze and turn green for five seconds, after which the subject could proceed with the next target. At the beginning of each trial the camera was aimed at the first target ship, which was visible in the camera image. This means that the initial camera heading and pitch were known to the subject. After two seconds (target-locking) the image would turn green, and the subject could begin the search for the first of the five real targets.

On the basis of pilot studies the maximum search time per target was limited to 90 s. If the subject failed to locate the current target within this 90 s. the camera screen would turn red, and the computer would take over the control of the camera and point it at the current target. Again, after locking, the screen would turn green, and the subject could take over the control and begin the search for the next target.

Subjects came in pairs, and completed four scenarios in succession, each scenario consisting of five targets. The completion of four scenarios never lasted longer than 20 minutes, after which the subject could rest, while the other subject completed four scenarios.

2.2 Image and displays

Subjects had three images at their disposal: a radar image, a camera image, and the heading and pitch indicator combined with a factorial combination of the two types of visual support. Please note the difference between camera image, and the camera screen (camera image plus indicators).

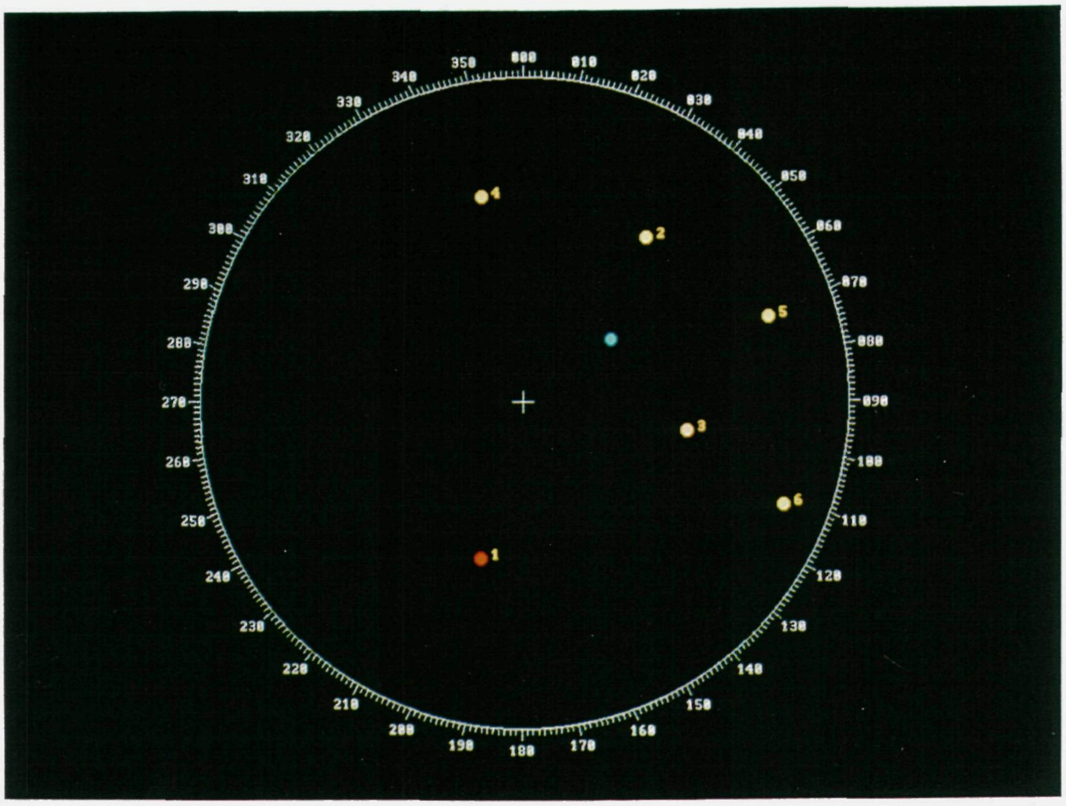

Fig. 3 The simulated radar image.

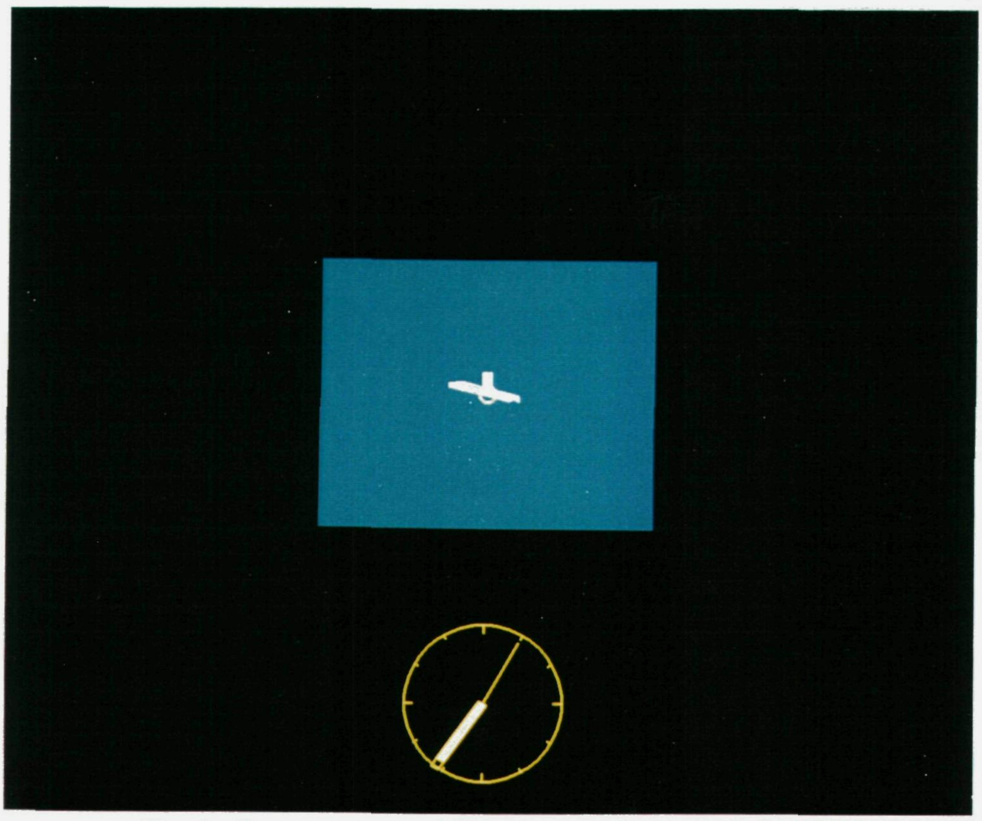

Fig. 4 Camera screen with the camera image and the CHPI.

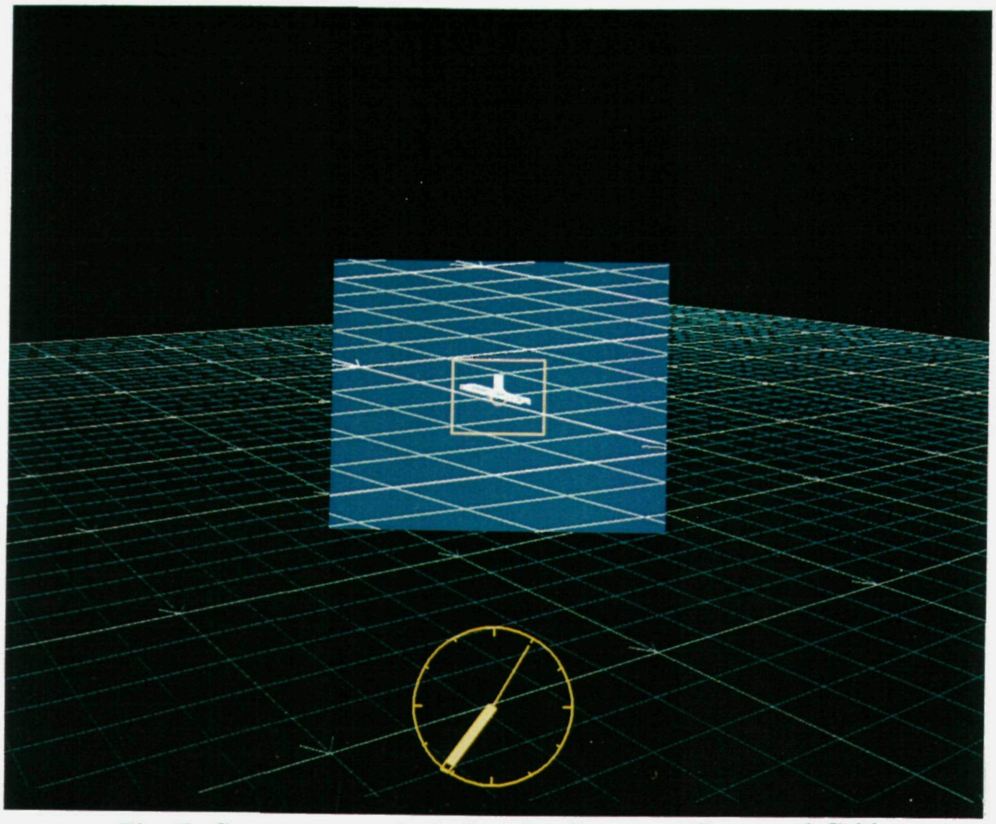

Fig. 5 Camera screen including the Computer Generated Grid.

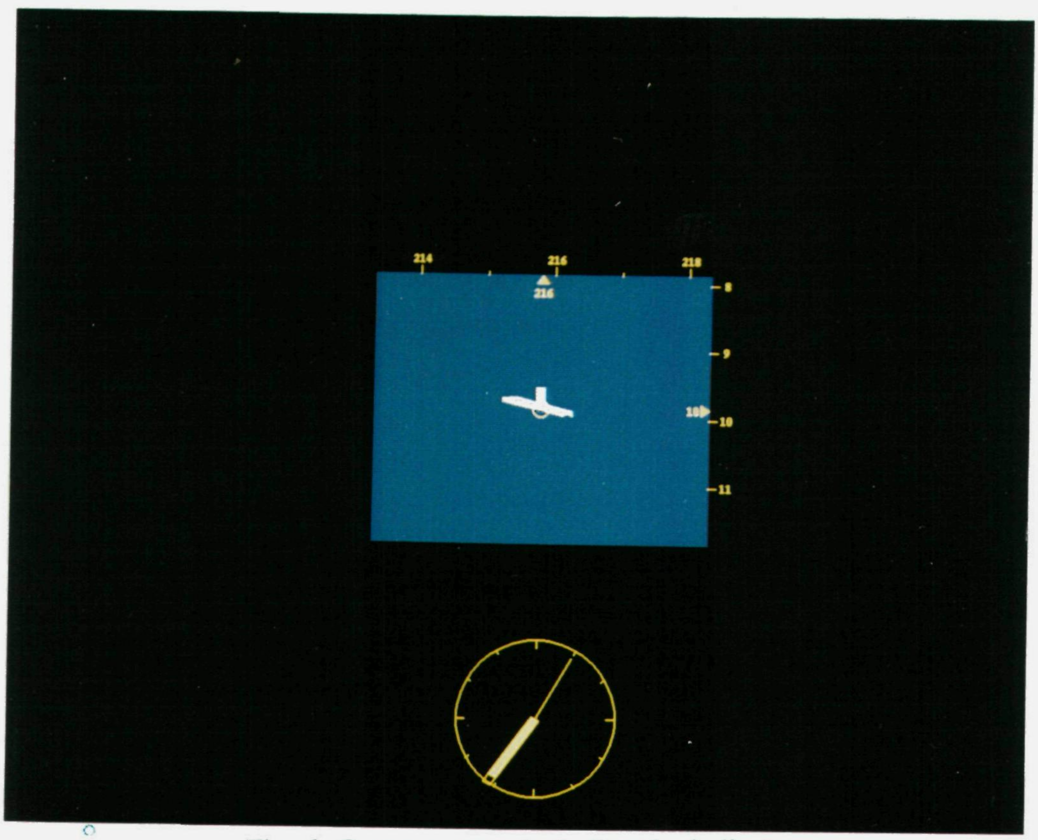

Fig. 6 Camera screen including the indicators.

Radar screen

The radar screen displayed a simulated radar image generated on board the mothership (see Fig. 3). The image was north-up, and depicted information about the position of MUAV and target ships. Information about the location of the target ships was presented by means of numbered dots, numbers indicating the search order. The colour of the actual target ship was red, all others were yellow.
The current location of the MUAV was indicated by means of a blue dot, the position of the mothership (always in the centre) with a white cross.
Around the radar image a north-up compass scale was depicted, with markers every degree, and values every ten degrees.

Camera image

The simulated camera image, which displayed a sea, and, when in sight, the current target ship, was depicted in a 12 cm × 9 cm window in the centre of the camera screen (exactly one third of the total camera screen, see Fig. 4).
Apart from the current target, no other ships were shown. Field of view of the camera image was 5°, zoom factor was 10.2. The horizon was simulated by a transition from light (sky) to dark blue. In the conditions without CGG, 500 dots were randomly positioned at sea-level to simulate the slight texture of an empty sea. The camera image was updated at 30 Hz.

Computer Generated Grid

The CGG consisted of a pattern of parallel and perpendicular lines. The CGG was north-orientated (north indicated with arrows at the intersection of grid lines), and positioned at sea level.
The distance between two parallel CGG lines was 100 m, over a total surface of 10 × 10 km. The CGG was updated with 30 Hz. The CGG was both depicted in the camera image, and around the camera image on the camera screen (remember that the camera image was only a window in the centre of the camera screen). The camera image, and thus the CGG in the camera image, was zoomed-in (factor 10.2, fixed). The CGG around the camera image was perceptually correct, which means that it was depicted at the correct size when viewing directly from the MUAV (zoom factor 1.0).

Linear quantitative indicators

Indicators could be presented head-up along the top and right edge of the camera image. These indicators depicted respectively the camera heading and pitch (see Fig. 6).
The indicators consisted of a moving line with values at every degree marker, and a fixed triangle in the centre of the scale with the accompanying value (digital, round at 1 degree). The indicators indicated the heading and pitch values of the zoomed-in camera image, correct in respect with the zoom factor of 10.2.

Combined heading and pitch indicator (CHPI)

The CHPI was presented as a head-up display located in the horizontal centre of the camera screen between the camera image and the bottom edge (see Fig. 4). The CHPI was always oriented north-up, and consisted of three indicators. A partially hollow bar indicated the heading of the camera. The hollow bar was filled to a certain extent, indicating camera pitch (no filling indicated 90° pitch, completely filled indicated 0° pitch, or pointing the camera to the horizon). The third indicator was a thin line, which indicated the heading direction of the MUAV. All indicators were updated with 30 Hz.

2.3 Mock-up and instrumentation

The experiment was conducted in the TNO-TM RPV Research Simulator, see Fig. 7. This facility is specially designed for simulating RPV missions (Korteling & Van Breda, 1994). The subject was seated in a chair in the centre of the operator table. The chair could be adjusted to personal comfort. The only control handle 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 in camera rotation and/or pitch (left/right deflections: left/right rotations, fore- and backward deflections: pitch). No deflection (5% range) resulted in a stationary camera in relation to the MUAV. Rotation and pitch speed were linear dependent on joystick deflection. Full deflection resulted in the maximum rotation speed of 30 °/s in each direction.

The two monitors were placed at eye height at a distance of approximately 60 cm. The camera screen, right in front of the subject (Mitsubishi colour display monitor HL7955SBK, 38 cm × 27 cm, 1024 pix × 1024 pix), depicted the simulated camera image, the CHPI and the CGG and/or the indicators when present. These were all generated by a SILICON GRAPHIC IRIS image generator. The camera image was depicted in a window in the centre of the camera screen (12 cm × 9 cm, 340 pix × 340 pix). The visibility (visual angle and contrast) of the target ships was such that they could always be detected when they appeared on the camera screen.

The radar screen (MAGIC VIEW 14′ DIGITAL) was placed next to the camera screen, and depicted the simulated radar image. This super VGA image was generated by a 66 MHz 486 personal computer.

The instructor sat in a control room with direct intercom contact with the subject, and had the same images at his disposal. Further instrumentation consisted of computers for scenario and data storage (5 Hz sampling frequency), and for supervisory functions.

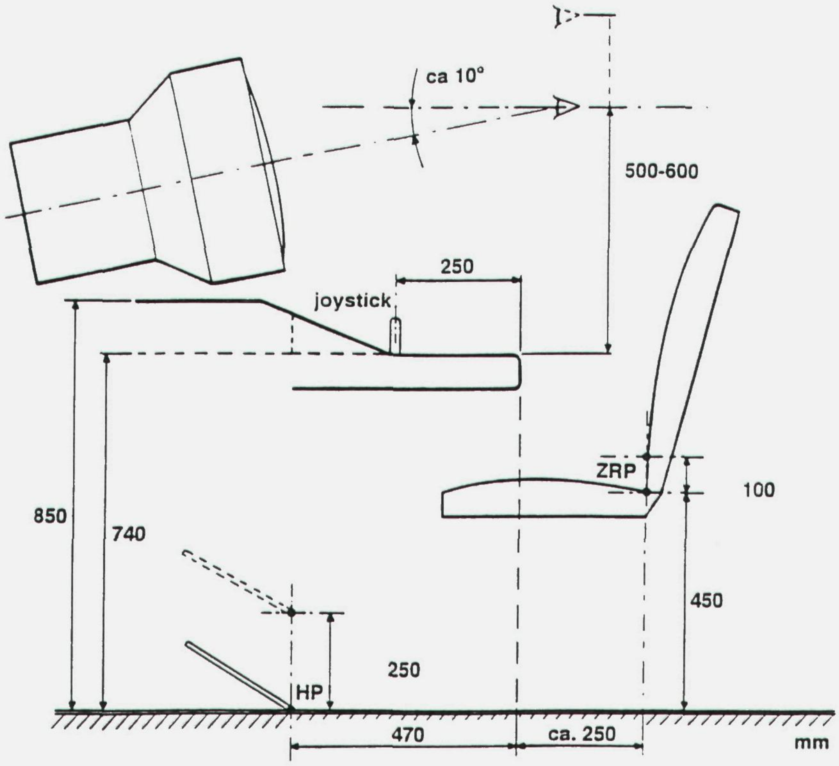

Fig. 7 Schematic side view of the TNO RPV research facility.

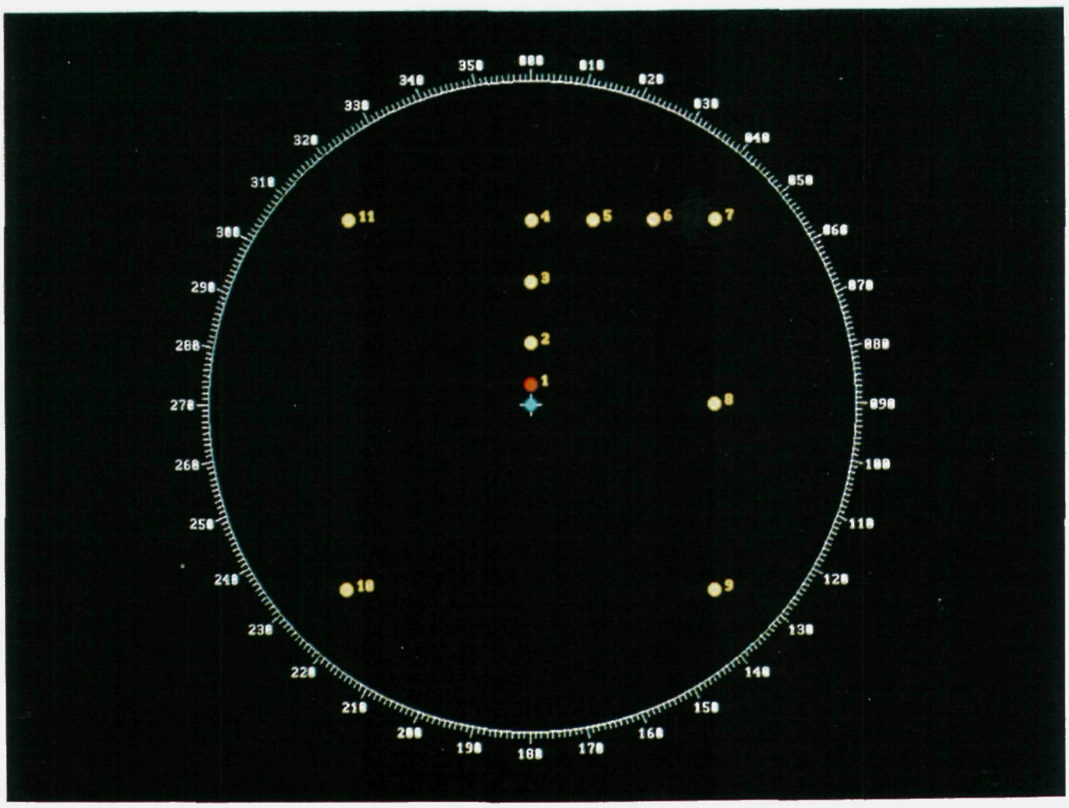

Fig. 8 Training scenario.

2.4 Parameters of MUAV system, target ships, and test scenarios

MUAV

The MUAV always flew at an altitude of 600 m. In the circular flight path conditions, the MUAV flew a circle with radius 1.0 km, at a constant speed of 43.6 m/s, around a point which was located 1.5 km north and 1.5 km east of the middle of the radar image.

Target ships

The target ships were trawlers (70 m long), positioned at a fixed location.

Scenarios

The 64 scenarios which were used during the experiment were randomly generated under the following conditions: distance between the initial position of the MUAV and each of the target ships was between 1900 and 4900 m. Distance between two successive target ships was at least 1000 m separate in both the north-south and the east-west direction. The ship at which the camera was pointing at the beginning of each scenario was located 2500 m north of the initial position of the MUAV.
Location of the target ship would never coincide with the intersection of two grid lines (when present).

2.5 Variables, statistical design, and procedures

Independent variables

Independent variables were actually classified into those concerning the visual support, and those concerning the MUAV flight path. Each group is again divided into two variables with two levels each, leading to four variables with two levels each.

Type of synthetic visual support:	
1 **CGG**, with levels:	- **CGG** *absent*
	- **CGG** *present*
2 **indicators**, with levels:	- **indicators** *absent*
	- **indicators** *present*
MUAV flight path:	
3 MUAV **motion**, with levels:	- *fixed position* (no motion)
	- *circling*
4 MUAV **position**, with levels:	- *central* in the radar image
	- *eccentric*.

Note that the CHPI was not an independent variable, but was present in all conditions. All independent variables were varied within subjects, thus leading to 16 conditions for each subject.

Dependent variables

Three dependent variables were used: search time, total heading movement, and total pitch movement. Search time indicates search effectiveness: the time it took to locate the target. Total heading and pitch movement indicates search efficiency: larger values for these variables mean that subjects required more camera movements to locate the target, indicating a decreased search efficiency. These effects do not depend on the speed of the movements, which is directly related to search time.

Since it is expected that different kinds of synthetic visual support could have different effects on the quality of pitch and of heading estimations, total heading and total pitch movement were analysed separately. Thus, from the recorded data three dependent variables were calculated:

a **search time (s)**, defined as the time elapsed between the beginning of the search for a new target till the locking of the target (minus the 2 seconds it took to actually lock the target). When the maximum search time of 90 s passed without the subject locking the current target, camera control was passed onto the computer. Depending on the actual heading and pitch error, the computer located the target between 1 and 20 s. This final search time (including the first 90 s) was taken as score.

b **total heading movement (rad)**, the integral of camera heading during target search.

c **total pitch movement (rad)**, the integral of camera pitch during target search.

Statistical design

Each dependent measure was analysed by a 8 (subject) × 3 (**session**) × 2 (CGG) × 2 (**indicators**) × 2 (**motion**) × 2 (**position**) ANOVA with the statistical package STATISTICA®. Each cell consisted of five observations, one for each of the five targets in a scenario.

Procedures

After arrival, subjects received a brief written explanation of the general nature and procedures of the experiment. The instructor explained the controls, images, procedures, purpose and task in more detail.
The training consisted of a scenario with five targets positioned at regular distances in the north-south direction, five targets at regular distances in the east-west direction, and four random positioned targets (see Fig. 8). This was in required to teach subjects the relation between positions and distances in a certain direction and accompanying heading and pitch.
During the training the instructor always sat next to the subject and explained the experimental condition, and the images (the radar and camera image, and the CHPI and the synthetic visual support, if present). This same training scenario was performed under different conditions of synthetic visual support (none, or both **CGG** *present* and **indicators** *present*), and different conditions of MUAV flight path (*fixed/centre*, or *circling/eccentric*). This resulted in four training scenarios for each subject.

The experiment would begin when both subjects had finished their training. The subjects were informed about the oncoming condition. During the experiment the subjects had to track five scenarios in one condition. Total number of conditions is 16 (2 (CGG) × 2 (indicators) × 2 (position) × 2 (motion)). Every subject performed three sessions, each consisting of all 16 conditions. Each session was split in four blocks with the same combination of visual support. Each of these blocks consisted of four scenarios, one for each MUAV flight path. After completion of one block, the subject could rest. Type of support was order balanced across subjects, MUAV flight path was order balanced within type of support. Scenarios were balanced across all subjects in such way that every scenario was flown an equal number of times within each level of MUAV flight path, and within each level of visual support.

3 RESULTS

Analyses were executed for each dependent variable separately. First, for each dependent variable the effect of training was tested. Results were treated per independent variable: concise results are presented below, detailed results are presented in the Appendix.

3.1 Effects of practice

In order to measure possible learning effects, every independent variable was tested against the effect of session (three levels). Both the total heading and total pitch movements showed no effect of factor session, only search time did [$F(2,14)=11.50$, $p=.001$]. A post-hoc Tukey test revealed a significant difference between the first session and both the second and the third. This indicates that subjects reached their final performance level during the first session. Since both total heading and total pitch movements did not show a learning effect, we included the first session in the analysis.

3.2 Effects of operator support: CGG and quantitative indicators

CGG (*absent/present*) showed significant effects on all three dependent measures: search time [$F(1,7)=10.14$, $p=.015$], total heading movement [$F(1,7)=6.78$, $p=.035$], and total pitch movement [$F(1,7)=14.46$, $p=.010$]. All effects pointed in the same direction: lower scores, and thus better performance, in the CGG *present* conditions (see Fig. 9). Largest effect was found on total pitch movement, in the CGG *present* conditions the total pitch movement to locate the target was reduced with more than 50%. There were no interactions of CGG with any of the other manipulated factors.

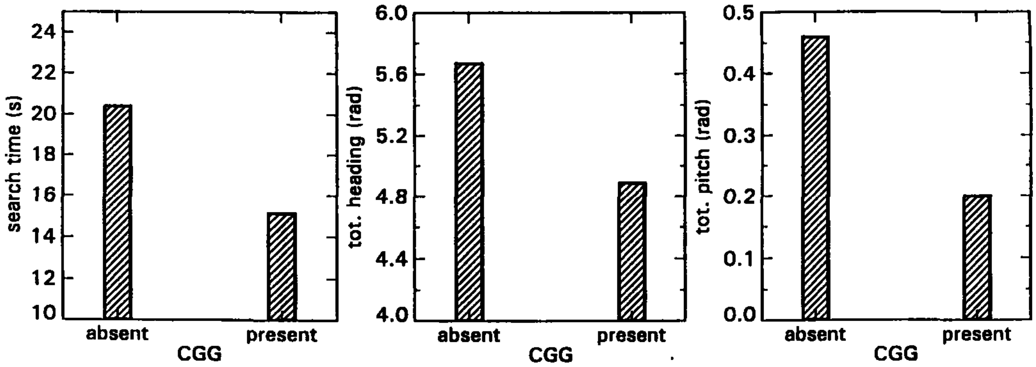

Fig. 9 The effect of **CGG** on search time, total heading movement, and total pitch movement.

Indicators (*absent/present*) did not produce significant main effects on any of the dependent variables, nor did any of the interactions of **indicators** with **CGG** or MUAV **position** or **movement**. There was however a significant interaction of **indicators** with **session** [$F(2,14) = 5.06$, $p = .022$]. A post-hoc Tukey test revealed a decreased effect of **indicators** with successive sessions.

3.3 Effects of MUAV flight path: position and movement

Position of the MUAV (*central/eccentric*) did not show an effect on any of the three dependent variables.

Movement of the MUAV (*fixed/circling*) showed an effect on search time [$F(1,7)=28.58$, $p<.01$], and on total pitch movement [$F(1,7)=5.59$, $p=.05$]. Both effects showed a performance decline of more than 20% in the conditions with a *circling* platform (see Fig. 10). Total heading movement was in the same direction, but this effect did not reach significance.

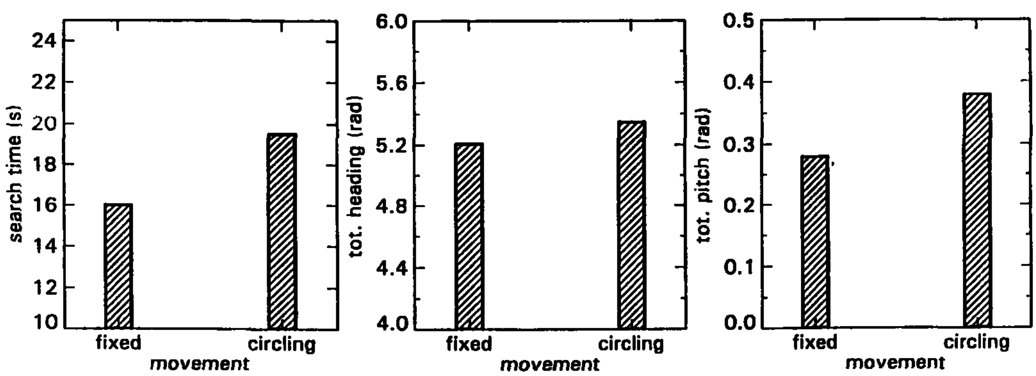

Fig. 10 The effect of MUAV movement on search time, total heading movement, and total pitch movement.

4 DISCUSSION AND CONCLUSIONS

The current experiment was designed to test the effects of a Computer Generated Grid (CGG) on target search performance of operators of Maritime Unmanned Aerial Vehicles (MUAV's), and to compare performance with a traditional method of operator support by means of linear quantitative indicators depicting camera heading and pitch. For this aim a visual search task was introduced, in which operators had to locate target ships on the basis of a camera and radar image. Point of departure was a simulated, high quality camera image (30 Hz update frequency, 340 pix × 340 pix) and a pictorial indicator for camera heading and pitch. The update rate of the simulated camera image is above the present state of technology, and one may expect that effects are more pronounced when update frequency is lower.

Grid and indicators

The data show positive effects of the presence of a CGG in improving search efficiency of the MUAV operator; search time, total heading and total pitch movement were reduced considerably in presence of the CGG. In contrast, the more traditional method of operator support, by means of indicators, did not show any effect on the dependent variables.
This result clearly indicates the superiority of the CGG in improving the operators search performance. The CGG presents the visual information on MUAV and camera attitude as the operator would have seen if he was flying there himself. The optic flow of the CGG allows an effortless perception of MUAV and camera attitude. It is supposed that the CGG improves the operators 'situational awareness', resulting in improved search effectiveness, i.e., reduced search time, and search efficiency, i.e., less camera-heading and pitch movements required to find the target.

The effects of the CGG are most pronounced in controlling camera pitch. Controlling pitch was expected to be difficult, since, in contrast to heading, the desired pitch angle could not be clearly perceived from the radar image. Instead, subjects had to learn which pitch angles corresponded with the distances on the radar screen. This proved to be a difficult task, even when the altitude of the MUAV was kept constant. It is to be expected that the determination of pitch angle is even more difficult for non constant altitudes.

The more traditional method of operator support, by means of the linear quantitative indicators, did not show significant effects on any of the dependent variables. Using indicators requires the operator to perform mental calculations in order to determine the desired heading and pitch angles from the radar image.

The absence of an effect of quantitative indicators might have been due to the pictorial Combined Heading and Pitch Indicator (CHPI). The CHPI was introduced in order to prevent that the search task would be impossible in the conditions without CGG or quantitative indicators. However, the results suggest that the CHPI, which was always presented to the observer, may be a more powerful way of operator support than the quantitative indicators.

The success of the pictorial CHPI may be based upon the same principle as the success of the CGG. Subjects could compare the heading of the target relative to the MUAV on the radar screen with the camera heading indicated by the CHPI. Comparing two orientations is a more visual task than estimating desired camera heading and adjusting indicators accordingly.

Position and movement

It was expected that the linear quantitative indicators would provide optimal support when the MUAV is positioned in the *centre* of the radar screen. In that case, the desired camera heading can be read directly from the compass scale on the radar screen and be transferred to the heading scale. Contrary to this expectation, the interaction between the presence of the **indicators** and the **position** of the platform did not reach significance on any of the dependent measures. This finding may be explained by the, a priori unexpected, success of the pictorial CHPI. If the CHPI provides adequate operator support, the presence of quantitative indicators may not add much extra to its effective information.

As expected, the data showed that target detection from a *circling* MUAV was more difficult than from a MUAV with a *fixed* position: search time and total pitch movement increased when the MUAV *circled*. A circling MUAV generates two major drawbacks on searching targets. First, rotations of the muav will rotate its camera. In the current experiment this will be a minor problem, since the changes in camera orientation were clearly visible in all conditions. Second, MUAV translations change the relative position of the target. The latter effects are more detrimental to operator performance, since the relative position of the target has to be continuously monitored.

It was expected that the presence of a CGG would enable the operator to circumvent these problems. The CGG allows the use of a simple heuristic: estimate the target's position as a point on the grid and steer the camera towards it. This heuristic does not depend on MUAV motion, since the position of the target on the grid does not change, even when the position of the muav does. Unfortunately, the data only indicated a weak trend in the expected direction (interaction **CGG × movement**, $p=0.13$).

Note that the CHPI nor the indicators could provide information on the changing relative position of the target due to MUAV translations. Both these methods of operator support only provide information on camera heading, but not on its position.

In conclusion, the Computer Generated Grid (CGG) is a powerful method to improve the search performance of MUAV operators. Search times, and camera movements are significantly reduced in presence of the CGG. The success of the CGG may be explained by its provision of perspective and distance texture gradient information, which are supposed to improve the operators 'situational awareness'. These elementary natural invariants can easily be picked-up and interpreted by the visual system, without demanding substantial (visual) attentional effort. The more traditional method of operator support that was investigated (indicators depicting camera heading and pitch), showed no effect on any of the dependent variables. In contrast to the CGG, reading and interpreting quantitative indicators does demand attentional resources, since the target's heading had to be estimated and the scale values had to be adjusted accordingly. These estimations and adjustments, in turn, may have degraded the accuracy of the heading observations.

Surprisingly, there were indications that the Pictorial Combined Heading and Pitch Indicator (CHPI), which was used as a baseline condition, was a successful method of operator support. Since both heading indicator and radar image were north-up, subjects could match the orientation of the CHPI's heading indicator with the estimated heading of the target. Again, this indicates that visual information that is directly picked-up and interpreted by the visual system, without requiring higher cognitive information processing, may be preferred above more abstract information for vehicle control.

REFERENCES

Gibson, J.J. (1950). *The perception of the visual world.* Boston: Houghton Mifflin.

Korteling, J.E. & Van Breda, L. (1994). *RPV research simulator.* Report TNO-TM 1994 A-52, Soesterberg, NL: TNO Human Factors Research Institute.

Korteling, J.E. & Van der Borg, W. (1994). *Partial camera automation in a simulated unmanned air vehicle.* Report TNO-TM 1994 B-16, Soesterberg, NL: TNO Human Factors Research Institute.

NATO Naval Armaments Group (PG-35) (1990). *NATO staff target for a NATO maritime unmanned air vehicle (UAV) system.* Report AC/141(PG/35)D/8, Brussels.

Van Erp, J.B.F., Korteling, J.E. & Kappé, B (1995). *Visual support in camera control from a moving unmanned aerial vehicle.* Report TNO-TM 1995 A-26, Soesterberg, NL: TNO Human Factors Research Institute.

Soesterberg, 26 January 1996

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APPENDIX Detailed statistical results

Effect	measure	df	MSeffect	MSerror	F	p	means	
grid	search time	1 / 7	13295	1311	10.14	.015	absent	20.42 (s)
							present	15.15 (s)
grid	tot. heading	1 / 7	290	42.8	6.78	.035	absent	5.67 (rad)
							present	4.89 (rad)
grid	tot. pitch	1 / 7	32.4	2.24	14.46	.001	absent	.46 (rad)
							present	.20 (rad)
movement	search time	1 / 7	5939	208	28.58	.001	fixed	16.03 (s)
							moving	19.54 (s)
movement	tot. heading	1 / 7	8.3	19.1	.53	.53	fixed	5.21 (rad)
							moving	5.35 (rad)
movement	tot. pitch	1 / 7	4.81	.86	5.59	.050	fixed	.28 (rad)
							moving	.38 (rad)
session	search time	2 / 14	6283	547	11.50	.001	session 1	21.40 (s)
							session 2	16.00 (s)
							session 3	16.00 (s)
indicators × session	search time	2 / 14	1535	304	5.06	.022	absent / 1	19.16 (s)
							absent / 2	14.89 (s)
							absent / 3	16.80 (s)
							present / 1	13.64 (s)
							present / 2	17.01 (s)
							present / 3	15.15 (s)
movement × session	tot. pitch	2 / 14	2.12	.35	6.11	.012	fixed / 1	.40 (s)
							fixed / 2	.20 (s)
							fixed / 3	.24 (s)
							moving / 1	.36 (s)
							moving / 2	.37 (s)
							moving / 3	.40 (s)

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Camera control by operators of Maritime Unmanned Aerial Vehicles (MUAV's) is complicated by the poor quantity and quality of the available visual information, due to the limited bandwidth of its data-link. TNO Human Factors Research Institute has developed a new principle of visual support, involving an earth-fixed Computer Generated Grid (CGG), depicted with a high update frequency over the (slower updated) camera image. The CGG improves perception of camera and MUAV motion, resulting in improved tracking performance (Van Erp, Korteling & Kappé, 1995). The current experiment focused on the benefits of the CGG in improving target search performance, and compared its performance with other methods of operator support.
The results clearly substantiate the effectiveness of the CGG in improving the operators search performance: search time and total camera-heading and pitch movement were significantly reduced when the CGG was presented. Supporting the operator by means of linear scales depicting camera heading and pitch, did not reach significance on any of the dependent variables.

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