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UAV Operations using Virtual Environments

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Summary

In virtual environments (VE), the limited field of view, the lack of information on viewing direction, and possible transmission delays may be considered as potential problems in developing and maintaining a good sense of situation awareness. Enabling unmanned air vehicle (UAV) operators to use high quality (proprioceptive) information on (changes in) viewing direction by introducing a head-slaved camera system with head-slaved display (HMD) may improve situation awareness, compared to using a joystick and a fixed monitor. However, HMDs may degrade comfort and the dynamics of head movements. Furthermore, time delays and zoomed-in images induce a non-steady presentation of the environment, and may impede adequate mapping of spatial information. This paper reports an exploratory study into the applicability of a head-slaved camera system in unmanned platform applications. To overcome the possible drawbacks of HMDs, we compared an HMD with a head-slaved dome projection in a simulator experiment. To overcome the possible drawbacks of transmission delay, we introduced a new method to compensate for the spatial distortions. This technique, called delay-handling, preserves the correct spatial relation between the viewing direction of the camera and operator by presenting incoming images in the camera viewing direction, and not in the actual viewing direction of the operator.

The experimental results showed that delay-handling is successful in supporting the perception of correct spatial relations, i.e., it improves situation awareness. No differences in task performance were found between the actual HMD and the dome projection.

Introduction

In operating a Maritime Unmanned Aerial Vehicle (MUAV) the flow of information is very poor as compared to real flying. If a human operator was physically present at the remote site and performs manipulations directly, he would receive a variety of information on the result of his manipulations, such as visual, auditory, tactile, and force feedback. However, when the human is physically separated from the task space, the feedback of the control actions has to be artificially transmitted back to him.

The man-machine interface determines the extent to which the operator can sense the remote environment and consequently control the platform. Thus, the display and controls in the operator environment should be

designed in such a way that the operator receives task specific information and sufficient feedback. The images provided by an on board camera is the main source of information on the outside world for MUAV operators. Because of the inherent characteristics of a camera-monitor system, and the restricted data link between the remote site and the operator, these images are of degraded quality, which may affect steering and control performance and the operator's situation awareness (SA).

Image degradation may come in different forms, e.g. a reduced field of view, a zoomed-in image, decreased information about the camera viewpoint and viewing direction, a time delay between the control input and the consequent feedback, and reduced spatial and temporal resolution. It is plausible that the degradation of some aspects of the feedback is more detrimental for operator performance or the sense of SA than others; some information may be redundant or of only secondary value. In order to identify the limitations that may become critical for the sense of SA when the operator manually controls MUAV and/or camera movements we first reflect on the concept of SA. Next, regarding MUAV operators, the main issues that affect SA will be discussed. Finally, we establish which principles of interface design may support the operator in developing a good sense of SA.

In teleoperation, situation awareness may be defined as the operator's ability to perceive, comprehend, and predict the spatial layout of the elements in the environment. SA is not a static phenomenon, but is composed of a variety of changing facts, interpretations and predictions in the context of task requirements. Although operator performance undoubtedly depends on SA, their exact relationship is not clear. Actually, there is still disagreement among researchers as to just what constitutes SA. However, the elements of SA are well known and include such familiar human functions as perception, information processing, decision-making, memory, learning, and action-taking, performed within a dynamic set of environmental circumstances and conditions.

SA is important in a wide variety of environments. Acquiring and maintaining SA becomes increasingly difficult as the complexity and dynamics of the environment increase. Under some circumstances, many decisions are required within a fairly narrow time span, and task performance requires an up-to-date analysis of the environment. Because the state of the environment is

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constantly changing (often in complex ways) a major portion of the operator's job becomes that of obtaining and maintaining good SA.

Barfield, Rosenberg and Furness (1995) describe the main components of situation awareness: spatial, status, and overall situation awareness. Spatial or navigational awareness deals with the three-dimensional geometry of the environment and refers to the operator's mental model of the vehicle's position. What is my position and how does this relate to the position of other objects? The state of the platform, e.g. the amount of remaining fuel, the position of the flaps, is represented in the status component of awareness. The combination of spatial and status awareness enables an overall awareness of the total flight environment.

Endsley (1995) gives a more elaborated model of SA with three components. Level one in this model refers to the perception of the elements in the environment and their relationship to other points of reference (i.e. internal model). At this level, relevant characteristics (colour, size, speed and location) and the dynamics of the objects in the environment are represented. This aspect is similar to what Barfield et al. (1995) termed spatial awareness. Level two of SA goes beyond simply being aware of the elements that are present, and includes an understanding of the significance of the elements. Based on level one knowledge, the operator forms a holistic picture of the environment, comprehending the significance of objects and events. Thus, the integration of various level one data elements at level two of SA is crucial for the comprehension of the situation. Level two of SA can be highly spatial in an operating context. The relevance of different objects for the operator's action planning will depend on their location and speed. Finally, the ability to project the future actions of the elements in the environment forms the third and highest level of SA. For example, in traffic, knowledge of the status and dynamics, and the comprehension of the situation, allows a driver to predict the future actions of other drivers in order to prevent collisions.

Another aspect of SA should be mentioned at this point. Although SA has been defined as a person's knowledge of the environment at a given point in time, it is highly temporal in nature. That is, some aspects, like the knowledge about the dynamics of the environment and path prediction, are acquirable only over time. Smolensky (1993) discusses the work of Stein, who showed that controller's eye fixation locations, which had varied widely in the initial 10 to 15 minutes of an air traffic simulation, decreased significantly beyond that point in time. Anecdotally, Stein's subjects reported that the initial 10 to 15 minutes of a controllers shift is the period of time during which he acquires the 'big picture', or, SA. Another temporal aspect of SA relates to the variations in relevance of elements across time. Some elements are not of equal importance at all times, although they should not fall out of consideration

completely. At least some SA on all elements is needed. SA, therefore, is based on far more than simply the information perceived about the environment. It is related to a model of human information processing in which attention and long-term memory enable comprehending the meaning of information in an integrated form. Memory does not only serve to direct attention effectively, but also serves to interpret the information that is perceived and to develop accurate projections of future events.

SA in teleoperation

In teleoperation, an intervening system senses, mediates, and presents information to the human operator. In this process, a loss of information can occur, which may be relevant to all three levels of SA.

At the lowest level, the system may fail to present certain information that is important for SA in the assigned task. First, systems may only present information of one modality (e.g. only visual information), based on technological limitations and the designer's understanding of what is required. Second, the information that is presented may lack important cues; e.g. no stereoscopic depth cues when a single camera is used.

Another major issue in teleoperation is the transmission speed and capacity. Intervening communication systems like satellites reduce transmission speed, resulting in delayed feedback to the operator about his manipulations.

For level two SA, the information displayed by the system must be integrated, and related to a mental model to obtain a holistic picture, and to determine which cues are actually relevant to the established goals. When no model exists at all, level two SA must be developed in memory. The absence of sufficient level one SA, the inability to develop a sufficient mental model or the inability to properly integrate or comprehend the meaning of presented data, can lead to inaccurate or incomplete level two SA. This may be caused by incomplete or inaccurate presentation of data to the human operator, or by a mismatch between information presentation and perceptual, attentional, and working memory characteristics of the operator.

Finally, level three SA may be lacking or incorrect. Even if the mental model is sufficient for level two SA, and the actual situation is clearly understood, it may be difficult to accurately project future dynamics. Lack of highly developed mental model and attention and memory limitations may account for this. Furthermore, some people are simply not good at mental simulation.

Regarding the control of unmanned platforms, loss of SA is already present at level one of SA, causing degraded sense of SA on level two and three as well. The inability to assess basic properties as position, direction and speed also hampers the operator in developing a correct mental model (level two), and in making adequate predictions about future states of the objects (level three). Part of the problems are probably related to

the poor information flow specific in MUAV applications, due to the following reasons:

A small field of view. A limited field of view suppresses the use of peripheral visual information. The peripheral area of the retina differs anatomically and functionally from the foveal area (Schneider, 1969; Trevarthen, 1968), and is used to generate our sense of spatial orientation (Ungerleider & Mishkin, 1982; Jeannerod, 1997). For example, a human operator's performance in a disturbance nulling task with only a central field of view display can be dramatically improved if the field of view is expanded to cover the peripheral retina (Kenyon & Kneller, 1992).

Furthermore, a small field of view requires a higher degree of integration of spatial information to build up a representation of the spatial environment. That is, rather than having a large field of spatial information in which several objects (and terrain features) are localised, a smaller field of view affords less spatial information at any instant, which forces operators to integrate these small 'pieces' of spatial information in time. The results of a search and replace experiment using an HMD (Venturino & Kunze, 1989) indicated that the field size affects one's ability to acquire spatial information. However, an important observation in this experiment was also that once the spatial information has been mapped into spatial memory, humans could use that information independently of the size of their 'window' to the world. This phenomenon is also found by Thompson (1983), who asked subjects to walk with closed eyes to previously viewed targets, and Tyrell et al. (1993) who asked visually occluded subjects to position a point of light at the location of a previously viewed target.

A zoomed-in image. Often, the small field of view is combined with a zoomed-in camera image. The zoom-factor of the camera disturbs the normal relation between rotational speed of the camera and translational flow in the camera image. For example, Van Erp, Korteling and Kappé (1995) found that operators largely overestimate camera rotations when viewing a zoomed-in camera image.

Few points of reference at sea. The lack of reference points at sea may hinder the operator in developing a good model of the position of objects in the remote environment and their relations.

Low update rate. Update rates lower than 4 Hz limit the perception of the direction and speed of objects, platform and camera.

Transmission delays. Transmission delays will mainly lead to degraded performance of the operator when manually controlling the camera. Eventually, the operator will develop a go-and-wait strategy, which will hamper developing a sense of SA.

Degraded information on (changes in) the viewing direction. Controlling the viewing direction of the camera by means of a joystick while the images are presented on a stationary monitor, withhold the operator of proprioceptive feedback on viewing direction. Normally this information is provided by muscle

spindles of neck and eyes, and therefore allows automatic mapping of visual information on a mental model. Since the viewing direction can not be directly deduced from the camera images, it is usually presented via additional indicators. However, this information requires the operator to perform some kind of cognitive processing in order to build a mental model, and it is not intuitive and therefore slow.

In previous research, it was shown that introducing high quality synthetic visual information can partly cancel out problems regarding the zoomed-in camera image, the lack of reference points, the low update rate and the transmission delay, which all have an important camera control component (Van Erp, Kappé & Korteling, 1996). Field size and information on viewing direction may be considered as the most important factors related to SA in unmanned platform applications. Moreover, both factors probably interact strongly. Although spatial information can be used effectively regardless of the size of the 'window' to the world once it is stored in spatial memory; the lack of information about the viewing direction of the camera hinders the building of a mental representation, and the integration of new information.

Head-slaved camera control

A possibility to convey high quality information about camera viewing direction is the use of a head-slaved camera system. When the viewing direction of the camera is coupled to the viewing direction of the operator, proprioceptive information is available, which can be interpreted automatically. Automatic processing tends to be fast, autonomous, effortless, and unavailable to conscious awareness in that it can occur without attention. It is hypothesised that system designs that support automatic processing of information directly benefit performance.

Applying a head-slaved camera system also requires a head coupled image presentation (i.e. a head mounted display, HMD) instead of a fixed monitor, see Kappé, Van Erp and Korteling (in press). However, the use of head-slaved camera control in combination with an HMD also has two potential drawbacks.

First, HMDs may influence comfort and control behaviour of the operator. Kotulak and Morse (1995) discuss a survey of 58 aviators by Behar, who found that 51% had visual discomfort, 35% had headache, and 21% had blurred vision. These symptoms could have a common origin: eye-head co-ordination could be affected by HMD characteristics, and smaller field sizes place heavy demands on head movements, since subjects must move their heads to sample the environment rather than using the more effortless joystick control. A study by Gauthier, Martin and Stark (1986) suggests that the greater head inertia associated with HMDs may induce a decrease in the amplitude-velocity relationship of head movements, i.e. slowing of head movement and small changes in head amplitude. Further, eye movements may change secondary to these changes in head velocity. Eye

movement maximum amplitude and velocity increase with increasing inertia. Gauthier et al. (1986) studied these effects of added head inertia and discuss that oscillopsia (continuous displacement or instability of the visual world) was prominent and consistent in perceptual reports of their subjects.

Second, transmission delays may distort the correct relation between the external environment and the perceived visual array. Because the images on an HMD are presented in the actual viewing direction of the operator, a transmission delay introduces a discrepancy between the viewing direction of the camera at the moment the images were recorded at the remote site, and the viewing direction of the operator at the moment the images are presented. This results in the operator perceiving the world as unstable when he moves his head. For example, when the operator has a steady image of an object, moving his head will 'drag' it across the environment during the transmission delay. Therefore, transmission delays will probably impede adequate spatial mapping of the visual information.

A possibility to reduce the first drawback (comfort) is to project the images in a moving window projected onto a dome, instead of on an HMD. A possibility to prevent the second drawback (delay) is to display the images in the viewing direction of the camera at the moment of recording, and not in the actual viewing direction of the operator (called *delay-handling* throughout the paper). This results in an image location which corresponds with the image content, and follows the actual viewing direction of the operator with a delay, instead of an image location which corresponds with the actual viewing direction, but not with the image content.

In case the field of view on the environment has the same size as the field of presentation (which is defined as the size of the display on which the view on the environment can be presented, e.g. the size of the dome), the principle of delay-handling will lead to image loss on the side contra-laterally to the direction of motion. Therefore, the field of presentation must preferably have spare space to overcome this loss. In this respect, domes are preferable. The size of this spare space and the transmission delay determine the maximum speed the camera can rotate without image loss.

Experiment

The present exploratory experiment was used to investigate the possibilities of head-slaved camera control for unmanned platforms. To elaborate on the possible drawbacks mentioned above, we used two *presentation modes*: a head-mounted display, and a moving window on a dome; and we introduced different transmission delays and tested the principle of delay-handling. To test the effect on the operator's sense of SA, we developed an experimental task, which included level one, two and three of SA as defined by Endsley (1995).

Subjects

Seven college-educated, right-handed male subjects (age: 20 to 27 years) participated in the experiments. All subjects had normal or corrected to normal vision, were paid for their participation, and had no experience with similar operator tasks.

Apparatus

All images were generated by a three-channel Evans and Sutherland ESIG 2000 image generator (30 Hz update rate). The images were presented via a head mounted display (N-Vision, $41.5^\circ \times 34.5^\circ$, 800×600 pixels H $\times$ V), or via a projection screen (a Seos PRODA S HiView S-600 projection system, consisting of a spherical dome and three video projectors; radius 2.9 m, $150^\circ \times 42^\circ$, 2400×600 pixels H $\times$ V). The subject's head was positioned in the centre of the dome. Head orientation (horizontal and vertical) was registered by a Polhemus Fastrack head-tracker (resolution 0.15° , 30 Hz), with the sensor coil either mounted on the HMD or on a lightweight plastic helmet (weight < 0.1 kg). Minimum delay between head-tracking and displaying was about 60 ms. Head tracker data was used as input for the mathematical model (ran with 30 Hz on a 486-based PC), which calculated the motions of the simulated (head-slaved) camera and the objects in the database. The mathematical model also simulated the transmission delay between the camera and the operator, by using a pipeline with a size of 30 times the transmission delay (s). A second 486-based PC was used for scenario generation and data storage (30 Hz sampling frequency). The presented view on the environment (window) had a size of $13.3^\circ \times 10.0^\circ$, and could be projected in the actual viewing direction, or in the viewing direction of the camera for which the images were generated. Note that with a transmission delay this resulted in a delayed image content and a delayed image location, respectively.

The subject was seated in a chair with a right armrest, on which a spring-loaded joystick was mounted. A response button was mounted on top of the joystick (Figure 1).

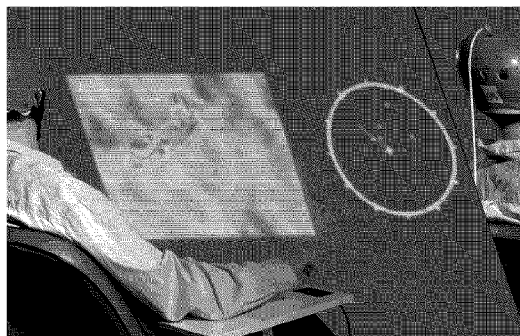


Figure 1: An overview of the TNO MUAV-simulator facility

Task

The camera-platform remained at a fixed position and orientation throughout the experiment, altitude of 500 feet. The virtual environment depicted by the camera

image consisted of a textured sea, twelve ships, and six square so called oil-rigs. The oil-rigs were arranged along imaginary gridlines, such that they enclosed an area defined by parallel and perpendicular lines between the rigs (Figure 2). This area was defined as forbidden for target ships. The distance between the platforms was 1000–2000 feet.

Six moving ships of equal type were defined as targets; the other six ships were distracters, were of a different, smaller type and had to be neglected. The targets moved at 45 feet/s along a winding route that was unknown to the subject, and had a maximum turn rate of $3^\circ/\text{s}$. The ships headed for an end position within the forbidden area.

Overall task instruction was to give a signal when a target ship entered the forbidden area, which actually consists of the following parts:

- determine the form and location of the forbidden area by detecting the position of the oil-rigs, and drawing imaginary borders,
- detect and monitor the position and track of the target ships,
- give a signal whenever a target ship enters the forbidden area.

This experimental task was designed to implement the different levels of SA as introduced by Endsley (1995). Level one refers to the position of the oil-rigs and the ships, their attributes, and their spatial relations in the environment. Level two refers to comprehending the significance of the different elements: which ships are targets, and which targets are heading for the forbidden area. Level three refers to the need to predict the future position of targets, e.g. assess which of the targets will reach the forbidden area first.

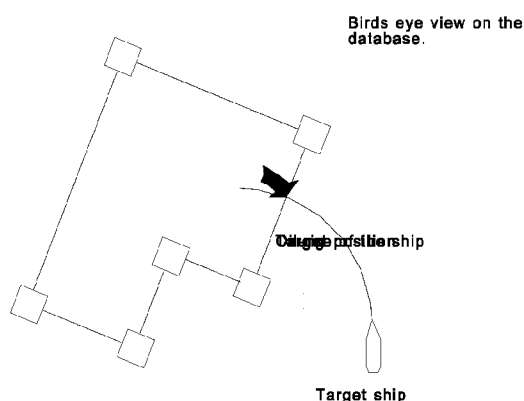


Figure 2: Illustration of a possible alignment of the six oil-rigs

At the time that one of the targets actually crossed a border (marked target position in Figure 2), subjects had to keep the ship's stern in the centre of the camera image and push the button on the joystick. The target ship disappeared when it was held within 2° of the centre of the image at the time of the response. When the subject did not give a response, the target ship automatically disappeared when it reached a predefined end position

within the forbidden area. Whenever a target ship disappeared, a new target ship was placed at a different position in the environment to keep the number of ships to be monitored constant during a run. A run was completed when six target ships had disappeared.

During the run, performance was recorded in order to calculate objective performance measures afterwards. Furthermore, after the completion of a session, subjects were given a post-test to ascertain that they had memorised the alignment of the oil-rigs, i.e. if they developed a mental model of the world during a run. A forced-choice procedure was used, in which the subjects had to choose the actual alignment of the oil-rigs out of the six drawings (bird's eye view) of possible alignments.

Independent variables

Three independent variables were manipulated in a full factorial within subjects design: *presentation mode* (HMD and dome projection), *delay-handling* (absent, present), and *transmission delay* (0, 0.5, 1.0, 2.0, and 4.0 s), resulting in twenty conditions.

Dependent variables

The following performance measures were used:

- *Time to locate the oil rigs (s)*. The measure was defined as the time it took a subject to locate all six oil-rigs, i.e. the time until the camera had been pointed at all of the six platforms at least once.
- *Time to border crossing (s)*. The measure "time to border crossing" for each target was calculated as the time that a target was away from the border to be crossed at the moment of the response of the participant. Time to border crossing was taken over all targets signalled by the participant (between 1 and 6). This measure reflects the accuracy of the subjects in estimating the position, course and speed of the target ship relative to the oil-rigs, i.e. their accuracy in the perception and prediction of spatial relations.
- *SD heading ($^\circ$)*. The measure "SD heading" is defined as the standard deviation of the heading of the viewing direction during a single run, and is a measure of viewing behaviour.
- *SD pitch ($^\circ$)*. The measure "SD pitch" is defined as the standard deviation of the pitch of the viewing direction during a single run, and is a measure of viewing behaviour.
- *Multiple choice on platform orientation*. This measure was calculated as the number of correct choices of the alignment of the six oil-rigs (summed over the levels of transmission delay).

Statistical design

The experiment was completed in sessions consisting of the five transmission delay levels for a combination of presentation mode and delay-handling. These blocks of five runs were, although not completely, order-balanced across the subjects. Within each block, the order of transmission delay was randomised. For each subject,

the twenty scenarios were randomly assigned to the conditions, with the restriction that each combination of condition and scenario occurred only once throughout the experiment.

Each dependent variable was checked for outliers (scores that deviated by more than 3 SD from the overall mean) and sphericity. Incidentally, a large score on the time to border crossing was found. Target ships could approach a border until they were at a short distance from it, but because of the winding route they moved along, not actually cross the border. Therefore, values greater than 20 s were removed from the analysis. No other outliers were found.

Results of the performance measures “time to locate the oil-rigs”, “time to border crossing”, “SD heading”, and “SD pitch” were analysed by a within-subjects design with three factors: presentation mode (2) $\times$ delay-handling (2) $\times$ transmission delay (5) with the statistical package STATISTICA 5.0. Significant results were further analysed by a post-hoc Tukey test. Results of the multiple choice question (only one observation per session of five runs) were analysed by a within-subjects design with two factors: presentation mode (2) $\times$ delay-handling (2).

Procedure

First, subjects received a brief written explanation about the general nature and procedures of the experiment. The instructor then showed the projection dome, chair, the plastic helmet and the HMD, and explained the purpose and task in more detail. The subjects came in pairs: one subject performed a session of five runs, preceded by a practice run, while the other subject rested. The practice run was with no transmission delay, was not registered, and performed with a scenario not used during the experiment. After a session the subject was instructed to perform the multiple-choice task in a room near the room in which the dome was situated.

Results

Presentation mode. On the basis of experimental observations (see Gauthier et al., 1986) and the smaller field of presentation, a disadvantage of the HMD was expected. However, none of the performance measures showed a significant effect of presentation mode.

Delay-handling. Two dependent variables showed a main positive effect of delay-handling. Time to border crossing showed a performance increase of 15% with the presence of delay-handling [means 5.8 s and 4.9 s, $F(1,6)=23.91$, $p<.01$]. The mean number of correct answers on the multiple choice task increases with 40% (means 2.4 and 3.4) with delay-handling present, $F(1,6)=21.00$, $p<.01$. Delay-handling showed no significant interactions.

Transmission delay. Three performance measures showed a main effect of transmission delay. The time needed to locate the oil-rigs [$F(4,24)=20.72$, $p<.01$], the time to border crossing [$F(4,24)=7.75$, $p<.01$], and SD

pitch [$F(4,24)=6.39$, $p<.01$]. All effects showed performance decline with increasing transmission delay. The post hoc tests indicated that performance on the former two variables was degraded for delays larger than 0.5 s, on the latter only for a delay of 4 s.

Discussion

The present study concentrates on the concept of situation awareness (SA) in relation to camera control of unmanned platforms using virtual environment (VE) techniques. In the introduction, it was hypothesised that inherent characteristics of the man-machine interface, like the limited field of view and the time delay between image recording at the remote site and image presentation, may hamper the operator in developing a good sense of SA. Providing the operator with high quality information on (changes in) viewing direction by introducing a head-slaved camera system with head-slaved display may support the operator and improve SA. However, literature also shows that such systems may degrade other aspects, e.g. comfort, control strategy, and the spatial relation between viewing direction of camera and operator as a result of transmission delays.

The present experiment focussed on the applicability of head-slaved camera systems in MUAV applications. To overcome possible drawbacks of HMDs, we compared a head mounted display with a head slaved dome projection and to overcome the possible drawbacks of transmission delay. We introduced a mechanism of delay-handling which preserves the correct spatial relation between viewing direction of the camera and the operator by presenting incoming images in the camera viewing direction, and not in the actual viewing direction of the operator. A new experimental task was introduced to include the different levels of SA as discerned by Endsley (1995).

The results show no significant effect of presentation mode. Although mean values on SD heading and SD pitch showed higher values with dome projection over the HMD, the effects did not reach significance ($p=.16$ and $p=.10$, respectively).

The results indicated a positive main effect of the principle of delay-handling (depicting the delayed images in the camera, not in the actual head direction). Both the results of the time to border crossing and the multiple choice task show performance improvement when delay-handling is applied. Time to locate all oil-rigs and control behaviour did not differ with delay-handling absent or present. This indicates that delay-handling is especially useful for developing higher levels of SA, i.e. in determining the exact spatial relation between the oil-rigs and the imaginary borders and the targets.

The main effect of transmission delay shows that this variable both degrades the development of the sense of SA at all levels, and the control behaviour of the operator.

Because delay-handling results in a window moving with a delay, the available field of presentation must be larger than the field of view. This may be a disadvantage for the HMD mode of presentation, because HMDs have a restricted field of presentation. However, the lack of an interaction presentation mode $\times$ delay-handling shows that the field of presentation of the presently used HMD was sufficient.

We also expected an interaction between delay-handling and transmission delay. Increasing transmission delays will disturb the spatial relations more for the same control signals, and was therefore expected to increase the positive effects of delay-handling. Even a third order interaction (presentation mode $\times$ delay-handling $\times$ transmission delay) might have been present. Transmission delays were supposed to be compensated by presenting the images in the spatially correct viewing direction. This method requires a field of presentation, which is larger than the size of the camera images, and must be increased with increasing time delays. Since the field of presentation of the HMD is restricted, an additional advantage of the dome projection was expected for larger transmission delays. However, none of the interactions was found.

Recommendations

It is recommended to perform human factors research aimed at further improving operator performance by optimising interface design. Areas of interest include the following:

- Directly compare the effects of joystick versus head-coupled camera control on the sense of SA and camera control performance.
- Investigate the effects of a zoomed-in camera image on head-coupled camera control. The zoomed-in camera image disturbs the relation between head rotations and translational flow in the image, which may be confusing and uncomfortable to the operator.
- Further explore the applicability of the method of delay-handling in, for example, situations in which the camera translates through the remote environment, or in which the camera image is zoomed-in.
- Investigate the relation between man-machine interface characteristics and the different levels of SA, and develop specific operator support. An example is adding high quality visual information to the camera image to provide the visual information that is lost in some situations, e.g. as a consequence of the low update rate of the image (by presenting visual motion information), a zoomed-in image (by presenting correct translational flow for camera rotations), and transmission delays (by introducing a predictive display).

References

- Barfield, W., Rosenberg, C. & Furness III, T.A. (1995). Situation awareness as a function of frame of reference, computer-graphics eyepoint elevation, and geometric field of view. *International Journal of Aviation Psychology*, 5 (3), 233-256.
- Endsley, M.R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, 37 (1), 32-64.
- Gauthier, G.M., Martin, B.J. & Stark, L.W. (1986). Adapted head- and eye-movement responses to added-head inertia. *Aviation, Space, and Environmental Medicine*, 57, 336-342.
- Jeannerod, M. (1997). *The cognitive neuroscience of action*. Cambridge, UK: Blackwell Publishers Inc.
- Kappé, B., Van Erp, J.B.F. & Korteling, J.E. (in press). Effects of head-slaved and peripheral displays on lane-keeping performance and spatial orientation. Accepted by *Human Factors*.
- Kenyon, R.V. & Kneller, E.W. (1992). Human performance and field of view. 1992 *SID International Symposium Digest of Technical Papers* (pp. 290-293), Playa del Rey, CA: Society for Information Display.
- Kotulak, J.C. & Morse, S.E. (1995). Oculomotor responses with aviator helmet-mounted displays and their relation to in-flight symptoms. *Human Factors*, 37 (4), 699-710.
- Schneider, G.E. (1969). Two visual systems. *Science*, 163, 895-902.
- Smolensky, M.W. (1993). Toward the physiological measurement of situation awareness: the case for eye movement measurements. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (pp. 41-42).
- Trevarthen, C.B. (1968). Two mechanisms of vision in primates. *Psychologische Forschung*, 31, 299-337.
- Thompson, J.A. (1983). Is continuous visual monitoring necessary in visually guided locomotion? *Journal of Experimental Psychology: Human Perception and Performance*, 9, 427-443.
- Tyrell, R.A., Rudolph, K.K., Eggers, B.G. & Leibowitz, H.W. (1993). Evidence for persistence of visual guidance information. *Perception and Psychophysics*, 54 (4), 431-438.
- Ungerleider, L. & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M.A. Goodale & R.J.W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549-586). Cambridge, MA: MIT Press.
- Van Erp, J.B.F., Kappé, B. & Korteling, J.E. (1996). *Visual support in target search from a moving unmanned aerial vehicle* (Report TM-96-A002). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- 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, The Netherlands: TNO Human Factors Research Institute.
- Venturino, M. & Kunze, R.J. (1989). Spatial awareness with a helmet-mounted display. *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 1388-1392).

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