INCREASING HELICOPTER FLIGHT SAFETY IN MARITIME OPERATIONS WITH A HEAD MOUNTED DISPLAY

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Abstract

To increase flight safety and operational availability for helicopters, the potential benefits of helmet mounted displays (HMD) are investigated, with a focus on maritime operations. Helicopters have long downtimes, due to harsh weather conditions or other visual impairments, especially in maritime scenarios. Flying in these poor conditions can drastically reduce flight safety. It is often difficult to recognize the horizon due to sea fog, and the absence of reference objects can complicate the maritime flight. These conditions and especially the downtimes cost money or, at worst, life's. Therefore, DLR integrated the augmented reality glasses Microsoft HoloLens into DLR's simulator AVES to use it as HMD for pilots. Subsequently, displays and symbolism were developed and evaluated. To carry out a piloted simulator study, a maritime scenario was created to measure changes in the pilots' performance with the HMD, like workload or situational awareness. The paper focuses (a) on the integration of the HoloLens into the simulator with its challenges, solutions and findings, (b) on the symbolism and (c) on the piloted simulator study. Both the quality of the HoloLens as HMD and the study results are very positive. The pilots rated high usability, reduced workload, increased situational awareness and increased safety.

Keywords: Augmented Reality, Helmet Mounted Display, HoloLens, Conformal Display, Human-Machine-Interface, Pilot Assistance, Helicopter, Simulator

FIGURE 1: Photo taken through the HoloLens inside the AVES Simulator. Holograms are superimposed over the simulated world.

Presented at the 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

Abbreviations

AA	anti-aliasing
ACT	active control technology
AR	augmented reality
ASL	above sea level
AVES	air vehicle simulator
BIV	image intensifier
CS	coordinate system
DVE	degraded visual environment
FHS	flying helicopter simulator
FLI	first limit indicator
FPS	frames per second
GVE	good visual environment
HDD	head down display
HMD	helmed mounted display
IFR	instrument flight rules
LIDAR	light detection and ranging
SART	situational awareness rating technique
SUS	system usability scale
VFR	visual flight rules

1. INTRODUCTION

With the strong growth of shipping, offshore wind power and offshore drilling, the number of related helicopter operations is also growing. A high operational availability is desirable in almost all mission cases. Especially maritime helicopter operations are challenged with highly dynamic weather changes, rare opportunities for forced landing and often no reference objects to monitor the helicopter attitude. Maritime emergencies with lives in danger usually arise in bad weather conditions. Due to these bad weather conditions, the called rescue helicopter often cannot even start or has to abort the mission.
Helmet mounted displays (HMD) for helicopter pilots have a high potential to increase flight safety and operational availability for helicopter operations in general, but especially in maritime scenarios.

HMDs are well established in the military field, but mostly not used in non-military operations, because of its relative high costs. In the last years especially consumer grade HMDs made great progress, which will probably also influence commercial HMDs for helicopter operations in the future.

1.1. Related Work

At DLR HMD, or in other words augmented reality or conformal displays, have been under investigation at least since the 1990s [1]. Among the advantages of using HMD in cockpits is the reduction of scanning times between instrument information and outside world [2]. Attentional capture can be reduced and situational awareness increased [3]. Further advantages of HMDs for pilots, like improved situational awareness or reduced workload, are shown in numerous investigations like [1] and [4] and especially for degraded visual environments in [5].

Consumer grade AR glasses such as the Microsoft HoloLens are also under investigation in other aviation sectors, e.g. for single pilot aircraft operations [6].

1.2. DLR Project HELMA

The DLR Institutes of Flight Systems and of Flight Guidance are cooperating with the Flight Service of the German Federal Police (Flugdienst der Bundespolizei) for the project HELMA (Helicopter Flight Safety in Maritime Operations). The goal of the project is to increase flight safety and operational availability of helicopters, operated by the police in maritime environments, by making use of augmented reality (AR) displays. DLR's Air Vehicle Simulator (AVES [7], see FIGURE 2) is used to develop and investigate potential benefits of such visual aids.

The milestones of HELMA are (a) the development of a maritime scenario for the AVES, (b) the integration of an AR Display as HMD into the AVES, (c) the development of symbology for the HMD and finally (d) the experiments with pilots.

As maritime scenario the Alpha Ventus wind park, located in the North Sea, is used in the AVES. To simulate the different weather and visual conditions multiple effects were added to the scenario, like fog, sea fog, mist, clouds, local weather effects, precipitation and turbulence. The flight mission starts with an IFR flight to the wind park, followed by cloud breaking to VFR conditions. The task inside the wind park can vary, like approaching a wind turbine or a platform, or searching and winching a person in the water.

2. INTEGRATION OF THE HMD

The integration of augmented-reality-glasses [9] into the helicopter simulator with front projection was one of the main challenges (a result is shown in FIGURE 1). The Microsoft HoloLens [10] is used as a head mounted display for pilots (FIGURE 3). This section provides an overview of the general setup and focuses on the fundamental integration with the encountered problems and the related

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solutions.

2.1. Simulator

The flight simulator center AVES (Air Vehicle Simulator) has two high-fidelity simulators, one aircraft and one helicopter, for cutting edge flight research. The AVES is designed as a modular, flexible platform using the latest technologies for a comprehensive exploration of flight.

In core, there are two interfaces between the glasses and the simulator: First a LAN connection and second the projection of the outside world on a surface. The simulator sends the helicopter state data, like position and orientation, via UDP to the HoloLens.

FIGURE 2: Flight simulator center AVES, sphere on motion platform with cockpit inside.

FIGURE 3: Helicopter flying with the HoloLens in the AVES simulator (Picture: DLR)

The cockpit of the AVES simulator [7] is placed inside a sphere shaped dome. The outside world is projected using 15 projectors as an uncollimated front projection on the inside surface of the dome. The outside world representation is calculated for a fixed eye-point, and therefore exhibits inconsistencies for other eye-points.

The radius of the dome is 3.25 meters, hence the pilot's eye focuses at that distance while flying and looking at the (simulated) outside world.

The motion simulation was deactivated for the trials in HELMA. Using the HoloLens in moving environments will be addressed in the follow-up project HEDELA (Helicopter Deck Landing Assistance).

2.2. Development

For the development of holograms, the game engine Unity3D [11] and the script language C# is used. An example of the running application in Unity3D is shown in FIGURE 4. The developed application is compiled and deployed as a standalone application to the HoloLens.

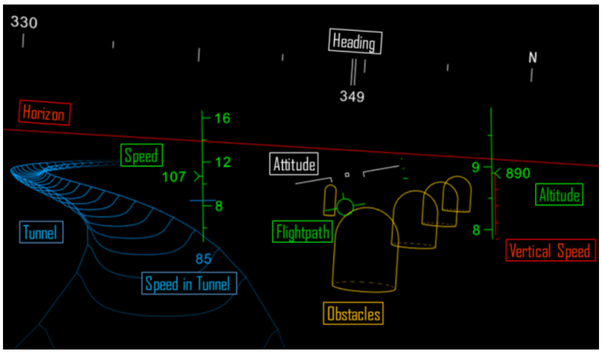

FIGURE 4: Screenshot from game engine Unity3D, showing holograms for helicopter pilots. Everything but black is rendered inside the HoloLens (after deploying) and shown as additional light to the viewers eye.

The holograms in FIGURE 4 mainly consist of Unity3D graphic primitives line (GL.LINES), meshes (with line topology) and text (3D-TextMesh), but almost all options by the game engine are available to develop holograms. This is mainly limited by the graphical performance of the glasses.

The "game world" in Unity3D is organized as a scene graph containing a hierarchy of nested coordinate systems (CS). In that world, it is possible to draw lines, create text or place other objects. The camera, as a game object in Unity3D, defines what is visible in the game and subsequently seen through the AR glasses. At start-up on the HoloLens, the camera parent will be positioned at the initial position (real-room-position) of the HoloLens. That is significant, because it positions the game world in the real world.

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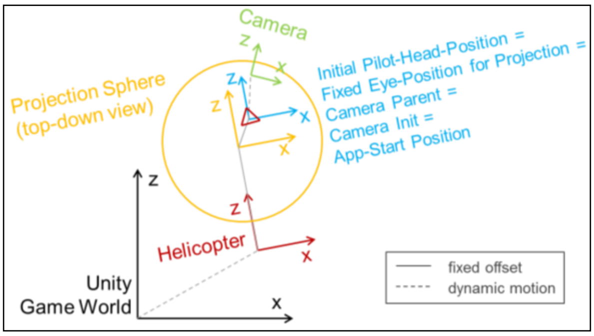

FIGURE 5: Coordinate systems used in the hologram application.

There are different possibilities to structure the coordinate systems. Head mounted displays often use the camera (or glasses) as the CS of reference. However, here the world is used as CS of reference, see FIGURE 5. In the world there is a helicopter-CS moving around, and in that CS the camera (or the glasses) is also moving. The position and orientation of the helicopter CS is based on the state data received from the simulator. One must be aware of large absolute numbers (about 10^5 m) that may occur here, because of floating point precision issues. This can be solved by converting the helicopter position into a Cartesian CS setting the reference geographical position close enough to the helicopter.

Holograms are usually attached to a world-fixed, head-fixed or helicopter-fixed CS. The projection sphere CS of the holograms needs to be positioned exactly at the projection sphere of the simulator to align the holograms with the projected outside world (see Section 2.6).

2.3. Projection Errors

In a simulator, when projecting the outside world uncollimated onto a surface, three relevant errors occur:

1. The outside world is calculated for a fixed eye point and projected onto a surface. The resulting error when the eye moves away from the fixed point is illustrated in FIGURE 6. This error occurs only with fixed-eye-point-projections.

2. The distances of objects are wrong, see FIGURE 6. The real object (blue cross) is further away than the projection of the object (red cross) from the fixed point perspective. The eye focuses on the objects distance (accommodation). With a front projection, the eye focuses at the distance of the projection surface.

3. The horizon has an offset, because it results through the Far Clipping Plane from which the rendering of the world ends. Note, that it is also possible to fix this error on the simulator side.

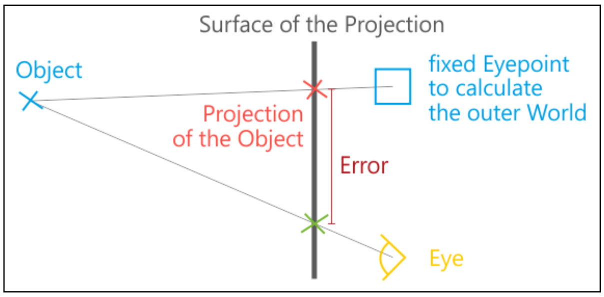

FIGURE 6: Projection error in consequence of a fixed eye-point. The object (blue cross) is projected onto the surface (red cross) for the fixed eyepoint. The correct projection for the actual eye (yellow) would be the green cross, but the object is displayed at the red cross, thus resulting in an error.

The first two errors result in incorrect object positions in the world. To fix these errors, the projection transformation is repeated at the glasses, thus doing the same errors to match the projected outside world. All points of the holograms are transformed to the sphere as shown in FIGURE 7. More precisely, for lines the start- and endpoint is transformed, and for text the anchor point is transformed. The transformation is calculated on the GPU with a vertex shader for the points. Mathematically, it is the intersection of a line and a sphere; the equations are given in [9].

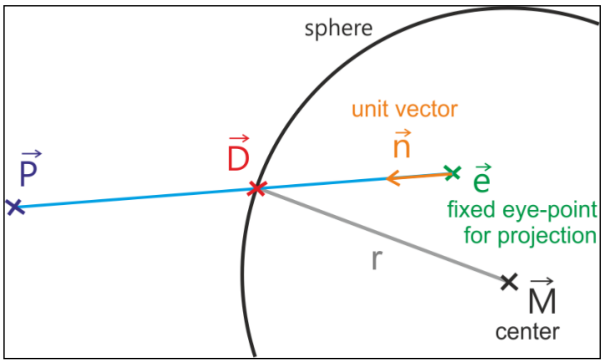

FIGURE 7: Transformation of a hologram point to the projection sphere (from P to D).

Analogous to the sphere transformation, the world points can be projected to any surface. Since a flat surface is frequently used for simulations, a cube transformation is additionally presented below, see FIGURE 8. This creates flat surfaces, thus ordinary projections at flat backgrounds (or TV / monitor) can be used with it.

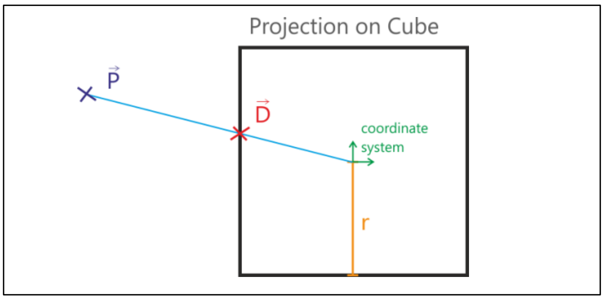

FIGURE 8: Cube transformation for flat projection surfaces, instead of spherical ones.

The third error is conspicuous for the user. Possible solutions are (a) hiding the wrong horizon with distance fog, (b) drawing the hologram horizon at the wrong simulator horizon or (c) fixing the horizon the on the simulator side.

2.4. Head-Fixed Holograms

For helicopter pilots there is a need for head-fixed holograms. The advantage of head-fixed holograms is that they can be perceived at any time, regardless of the head's position and orientation. They have however a poor quality on the HoloLens because of jittering and fan-outs of the head-fixed holograms (FIGURE 9).

The jitter is very uncomfortable for the user and it is hard to perceive the information provided by the display. It arises through the natural noise of the heads orientation together with pulse, breathing or vehicle vibrations. Especially the strong vibrations in a real helicopter make filtering mandatory.

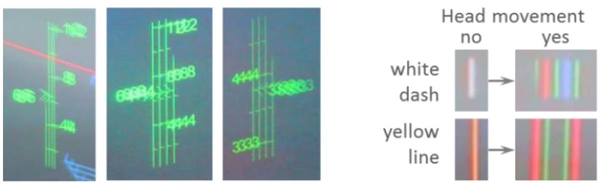

FIGURE 9: Examples of fan outs of head-fixed holograms, (left) fan outs of single color channels (monochrome), and (right) fan outs between the color channels (rainbow effect).

To design a filter against the jitter, a generic noise-step-noise signal was used to emulate the head movement, see FIGURE 10 - blue signal. It is desired to have no movement while there is only noise and a quick follow up for steps. First, a PT1-filter was tested. Despite significant improvement, the movement was still too much for moderate vibrations (Figure 16, green line at 4-6 sec). Therefore, the PT1-filter was used twice to get an initial response gradient of zero. That fixed the vibration problem, but the step-responses (e.g. FIGURE 10 between 3 and 4 sec) were too slow, for both PT1 and 2xPT1. The pilots had to wait multiple seconds for the appearance of the display after a 90 degree head rotation. Therefore, a dynamic time constant was added, resulting in a nonlinear digital filter, see FIGURE 11.

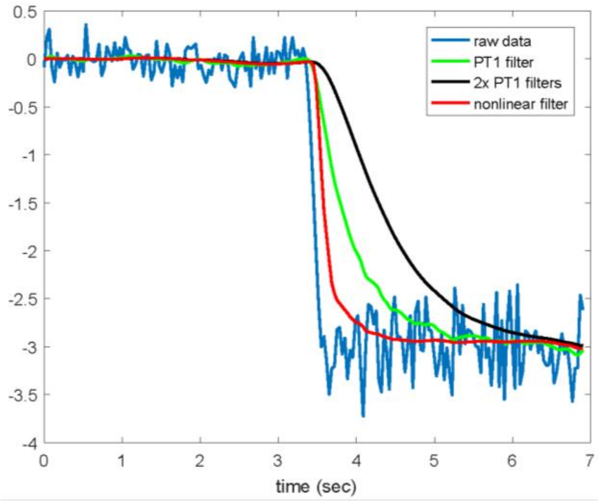

FIGURE 10: Filter design with generic noise-step-noise data and responses with different filters.

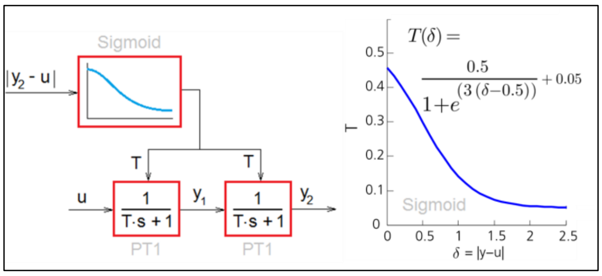

FIGURE 11: Nonlinear digital filter (top-left) using double PT1 and a dynamic sigmoid time 'constant' (top-right). The sigmoid parameters work for helicopter pilots and can be adjusted to the respective needs.

2.5. Quality of Lines

Lines are the core element of the holograms. The quality of the lines is crucial for the overall quality of the system. The jaggy, step-like appearance associated with simple raster line representations can decrease the perceptual quality. For improved quality anti-aliasing (AA) is mandatory, although AA decreases rendering performance. Low FPS are a draw-back for the system. Furthermore, without AA the lines may flicker, which probably also increases the users' workload.

The holograms for the pilots usually show about 1000-4000 lines. Lines are drawn using Unity's Mesh with line topology or GL.LINES. The AA-Setting is 8xMSAA, resulting in 30 FPS (as contrary

Presented at the 45th European Rotorcraft Forum, Warsaw, Poland, 17-20 September, 2019

to 60 FPS without AA).

To examine the quality on the HoloLens when drawing lines, a test application was developed. It basically draws lines into a cube (1m³) with various different settings to analyse the FPS and the visual quality. Test cases are methods to draw lines (GL.LINES, Vectrosity [12], Line Renderer, Mesh, etc.), the characteristics of the lines (number, anti-aliasing, length, etc.) or FPS related functions (like the sphere-transformation see FIGURE 7) and its influence on the FPS.

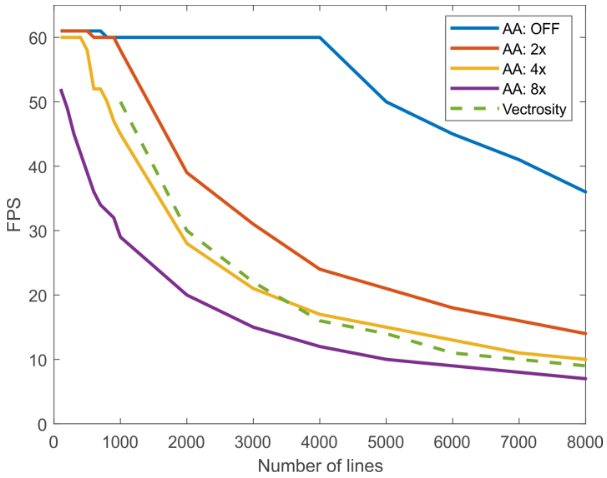

FIGURE 12: FPS on HoloLens over the number of lines and Anti-Aliasing (MSAA). The lines are drawn with GL.LINES, except the dashed green.

One result of that examination is shown in FIGURE 12. The FPS drop from 60 to 20 because of 8xAA for 2000 lines and there is a limit for the number of lines (~3000) for which the FPS are unacceptable. Without AA the FPS will leave the cap of 60 at 4000 lines. Vectrosity has about the same visual quality as 8xMSAA but uses a different method for anti-aliasing. A texture that is transparent at the edges and bilinear filtered results in fast AA; therefore Vectrosity achieves better FPS. Nevertheless, Vectrosity is not used here to minimize external dependencies.

The sphere-transformation (FIGURE 7) has a minor influence on the FPS with active AA, but a large influence without AA (40% FPS drop).

Low FPS causes hologram jitter, stutter, flicker and a fanning out of lines, especially noticeable with fast movement of the glasses or vehicle. This degrades the visual quality but is not critical for 20-30 FPS.

2.6. Calibration

Calibration is the matching of the hologram world and the real world. More specifically, it is the positioning of the hologram sphere CS on the AVES sphere CS, as shown in FIGURE 13. This positioning can be done loosely with head movement or more precisely with a controller, e.g. the Bluetooth keyboard. Afterwards, it is possible to save and load the calibration result with a "World Anchor", as explained in detail in [9].

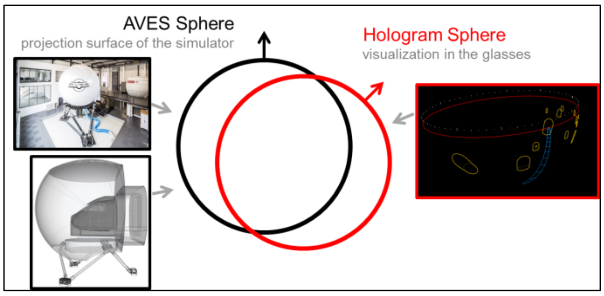

FIGURE 13: Spheres to align at the calibration. The red virtual sphere of holograms needs to be positioned at the physical black sphere. With the top-down perspective, the three position axes and the heading need to match.

2.7. HoloLens in a Simulator Cockpit

The simulator cockpit (on a fixed-base) is no big difference to a "normal" space for the HoloLens. The shape of the room and the low brightness are no problem. The moving pictures in the background didn't cause any problems in the maritime scenario. However, in other scenarios with strong image features, like the edge of a runway, occasionally loss of the head tracking happened. The Holograms are very stable with head movement, and they have an excellent visual quality. Integrated as described here, the HoloLens is flexible with the head and eye positions of the user. It can be handed over to the other pilot or to persons sitting in the rear. Drawbacks of the HoloLens used as a HMD in a simulator are the small field of view, the low computational power and the inability to influence the head tracking. The inside out head tracking requires no additional system but occasionally head tracking loss happen, mostly as result of blocked sensor vision. Summarized, the HoloLens is great for research and development, but unreliable for more critical tasks without improving the head tracking.

In real vehicles there are multiple unsolved problems we are working on. The main problem is that the head tracking of the HoloLens gets confused in a moving environment.

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3. SYMBOLOGY

The symbology is illustrated in FIGURE 14. The world-fixed holograms are horizon, heading, obstacles, tunnel and marker (e.g. for navigation). The horizon and the heading are drawn on a full circle. The circles are moving with the helicopter position. The obstacles are highlighted based on a databank and they are always rotated towards the pilot. The tunnel can be loaded from a databank or it can be calculated live for the actual helicopter position and speed with a given target. The tunnel fades in and out to reduce clutter and avoid unwanted attention and workload due to high frequency hologram changes. So that the pilot knows where the tunnel leads him, there is an animation added in the non-visible part, making a tunnel piece visible and moving it forward with time. A marker for navigation is illustrated in FIGURE 14-bottom. It shows additional information (like distance in NM) when the HoloLens looks at it.

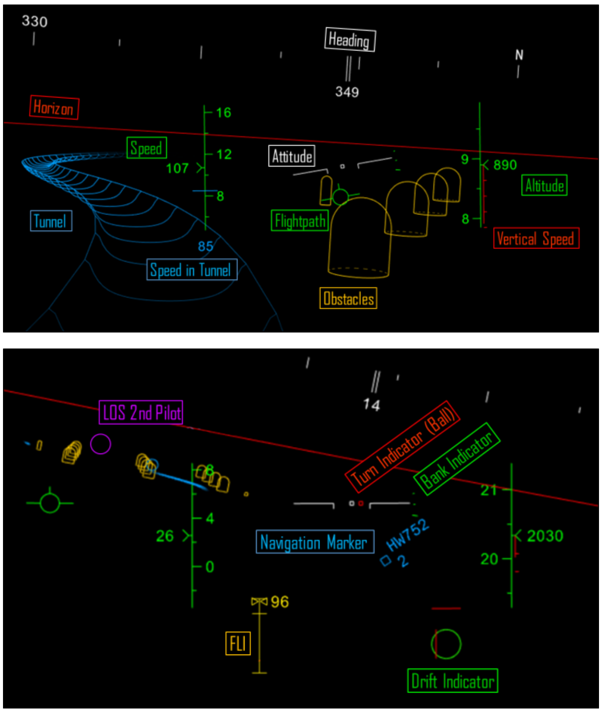

FIGURE 14: Symbology.

All head-fixed holograms are located on a filtered plane, as explained in Section 2.4. The head-fixed holograms are speed, altitude with vertical speed, FLI, drift indicator and head-fixed attitude. The FLI and the drift indicator are only visible if needed. The 2D drift indicator represents a top-down view on the helicopter, with the red lines showing forward and sideward drift. The speed and the FLI change their colour as a warning when approaching or exceeding limits. The head-fixed attitude (FIGURE 15) is only visible when the helicopter attitude is not in the field of view of the HoloLens. The other attitude (FIGURE 14 in white) sticks on the extended forward axis of the helicopter and is therefore helicopter-fixed. The ball of the turn indicator is integrated into the attitude displays as red square and the bank indicator as small green lines at the side of the attitude (see FIGURE 14-bottom). Also illustrated in FIGURE 14 in violet is the line of sight (LOS) representation of the other pilot. Note that all displays are parametric with a variety of possible settings and layouts, which can be switched on the fly by the pilots.

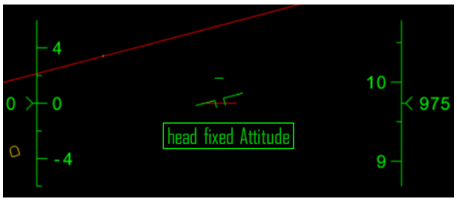

FIGURE 15: Symbology, head-fixed attitude

Additionally, a Lidar sensor simulation was developed using shaders. FIGURE 16 and FIGURE 17 show the resulting Lidar representations of a wind turbine and a platform. The raw sensor data is drawn as point cloud for multiple sensor frames. Since the water doesn't generate sensor points, the obstacles are automatically highlighted, contrary to data at land. This property creates potential for search operations. The point cloud is visible through the helicopter frame, which can be very useful to keep track of obstacles or of the platform while landing for example. Another natural property of the point cloud is that it looks solid from a distance while being transparent when being close.

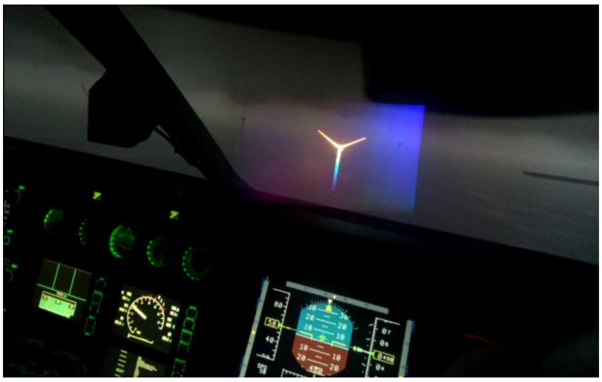

FIGURE 16: LiDAR in HMD of wind turbine.

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FIGURE 17: LiDAR in HMD of platform.

4. PILOTED SIMULATOR STUDY

Several helicopter pilots, among them experienced test pilots as well as police pilots with maritime experience, participated in the development of the HMD symbology. The final evaluation was conducted in the AVES helicopter simulator [7] with five police pilots. The goal was to evaluate the general usability and the potential benefit for maritime helicopter operations of the German federal police. Two maritime scenarios were flown, both with and without the HoloLens. After each task with HMD or HDD (head down display) conditions, the pilots were asked to rate their workload and their situational awareness. A final questionnaire was answered by the pilots during debriefing.

4.1. Experimental Setup

The AVES helicopter cockpit, resembling the research helicopter EC135 ACT/FHS [13], was used on the fixed-based simulation platform. The AR glasses Microsoft HoloLens were configured as described above.

Two different scenarios were selected to investigate the potential benefit of the AR glasses for maritime police operations:

1. **Rescue mission**: Approach to Alpha Ventus wind park [14] through dense clouds
2. **Navigation task**: Navigation within the wind park under constantly decreasing visual conditions due to fog.

The first scenario "rescue mission" had been developed in cooperation with police pilots for representing a typical maritime helicopter operation. It started approximately 40 km south of the wind park Alpha Ventus at 6,500 ft ASL (above sea level). The pilots were guided along predefined waypoints (similar to HW751, AV S). The position of the waypoints was either orally communicated by the experimenter or visually displayed in the AR glasses. The approach was conducted under IFR (instrument flight rules) conditions through dense clouds with 20 kt wind from north (345°). After reaching the cloud base (approx. 1,000 ft), the flight was continued under VFR (visual flight rules) conditions until the wind park was reached. The actual rescue mission was not part of the scenario and therefore not simulated.

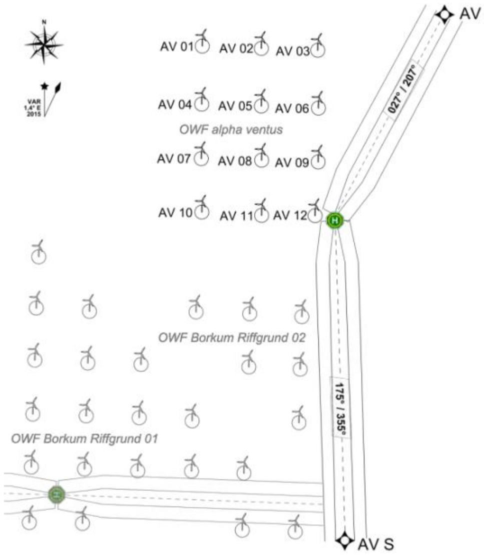

FIGURE 18: Alpha Ventus wind park [14].

The second scenario "navigation task" was conducted within the wind park that contains 12 wind energy plants in a rectangular 3 x 4 pattern, see FIGURE 18. The pilot started in hover close to one of the plants. His task was to approach the next plant by flying between the plants in form of an "L". (Example: hover at no. 7, fly to no. 2, hover, fly to no. 9, hover, …). The allowed altitude was limited between 350 and 450 ft ASL, around the height of the top of the wind energy plants. The task was started with no wind and good visual conditions (range of sight 3,000 m). The simulated visual conditions were gradually degraded by increasing the fog's density with each plant reached. The pilot's task was to navigate through the wind park or abort the procedure at his own discretion.

Five police helicopter pilots participated in the final evaluation. Their age was between 36 and 60 years (45.5 y mean and 9.4 y standard deviation). Their flying experience ranged from 2,250 to 6,400 flight hours (3,789 h mean and 1,704 h standard deviation). Two of the pilots had an IFR rating and

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all of them were experienced in the used of image intensifier goggles (BIV).

After 30 minutes of theoretical introduction each pilot had 50 minutes of practical familiarization in the simulator. The rescue mission was flown first and took approximately 60 minutes per pilot. Following to that the navigation task was completed in approximately 120 minutes. All tasks were flown with and without AR glasses. In order to minimize training effects, the pilots started the tasks alternately with or without AR glasses.

Right after completing a task in a certain configuration, the pilot rated the experienced workload with the aid of the NASA task load index (NASA TLX [15]) and the subjective situational awareness with a SART questionnaire (Situational Awareness Rating Technique [16]).

NASA's TLX measures workload in the categories mental, physical and temporal demand, performance, effort and frustration level. The summed averaged score lies between 0 (lowest workload) and 100 (highest workload). The second, optional part of weighing the individual subscores was not conducted in order to save simulator time as suggested in [17].

A variety of methods exist for measuring situational awareness in complex situations as summarised in [18]. The widely used self-rating technique SART was applied in this study. The pilot answers a questionnaire on his subjectively experienced situational awareness. The advantage is that the rating can be done post-trial, so the actual flying task does not need to be interrupted. Furthermore, neither an additional observer nor additional equipment is necessary. The disadvantage is that the rating is subjective instead of objective. Certain aspects of situational awareness might be lost especially in situations with overall low awareness [18]. The SART questionnaire consists of ten questions, divided into the categories attentional demand, attentional supply and understanding. The answers are given on a seven point scale and the overall SART score calculated as "situational awareness = understanding – (demand – supply)." Higher scores indicated higher subjective situational awareness.

Before the first and after the last flight with AR glasses each pilot was asked on experienced somatic issues, e.g. fatigue, nausea, headache or eye strain.

The debriefing contained additional questionnaires on usability (System Usability Scale, SUS [19]), general system ratings and a free part for final remarks. The used System Usability Scale was originally developed for rating office software. Due to its general nature it can easily be applied to other systems. It consists of ten statements on effectivity, efficiency and usability that the pilot has to agree to or decline on a five-point scale. The weighed overall sum can reach values between 0 and 100. Higher values are associated with better usability. Verbal expressions of the numerical SUS values were not provided by the inventor of the scale but are discussed in literature. It is suggested to associate a SUS score of 50 with "ok", "fair" or "so-so".

4.2. Results

The following diagrams show the main results of the pilot questionnaires. FIGURE 19 shows the workload rated by the five police pilots for both tasks. For the rescue mission four of the pilots rated their workload to be lower when flying with the AR glasses (blue circles) in comparison to the configuration without glasses (black crosses). Only pilot 2 experienced higher workload due to the AR glasses. His feedback suggests that additional training time would have lowered his workload rating.

Overall, the navigation task was associated with higher workload, compared to the first task. Here, three of the pilots rated their workload to be lower when flying with AR glasses compared to the flights without glasses. Pilot 2 and pilot 3 experienced higher workload with the additional visual system.

Ratings of the subjective situational awareness are plotted in FIGURE 20. Four of the five pilots rated their situational awareness to be higher when flying with the AR glasses in the rescue mission. Pilot 2 saw now differences regarding situational awareness for both configurations. For the navigation task all of the five pilots stated to have a higher situational awareness when flying with the AR glasses in degraded visual environments.

During the navigation task the visual conditions were gradually degraded and the pilots had to decide on the abortion of the task on their own discretion. When flying with head-down display information only, flights under foggy conditions with a visual range of 500 m were usually flyable and the pilots decided to abort when a visual range of 400 or 300 m was reached. With the aid of the head-up AR glasses, flights under conditions of 300 m visual range or even less were still possible.

The results of the usability analysis are plotted in FIGURE 21. They reach from 65 to 98 points on the SUS scale, clearly in the upper half of the diagram and above the middle of 50 points that would be associated with “ok”. Potential improvements on the AR display were mentioned by the pilots and will be discussed in the following subsection.

FIGURE 22 shows answers to selected questions on the general display design that were asked after the trials in the debriefing. The bars represent the number of answers to the statement in the title of each diagram. All of the pilots agreed (three) or rather agreed (two) that the AR glasses would lower the workload. The pilots fully agreed that situational awareness and safety could be increased by the AR glasses. Operational availability can also be increased according to the answers (three rather agree, two agree). All five pilots would want to use the AR glasses in degraded visual environments (DVE). In contrast to that, only two of them rather agree to use the glasses in good visual environments (GVE), two pilots rather disagree and one disagrees.

The ratings of the necessity of certain symbology elements is summarised in FIGURE 23. Again, the bars show the number of answers; light blue for displaying the element named in the title on a head mounted display like the AR glasses; and black for elements displayed on a conventional head down display (HDD).

Bounding boxes for marking obstacles like the wind turbines are a major strength of the AR glasses. Four pilots rated them to be essential in HDD and one rating was given for desirable. For the HDD case only two pilots rated them as essential and three ratings were given for desirable.

The display of point clouds derived from sensor data like LIDAR was rated controversially. For HMD two rating were unnecessary, one desirable and two essential. For HDD no essential rating was given but two desirable and three unnecessary.

The display of torque or FLI (first limit indicator) was seen as essential in both configurations by the majority of the pilots (HMD: three essential, two desirable, HDD: four essential, two desirable).

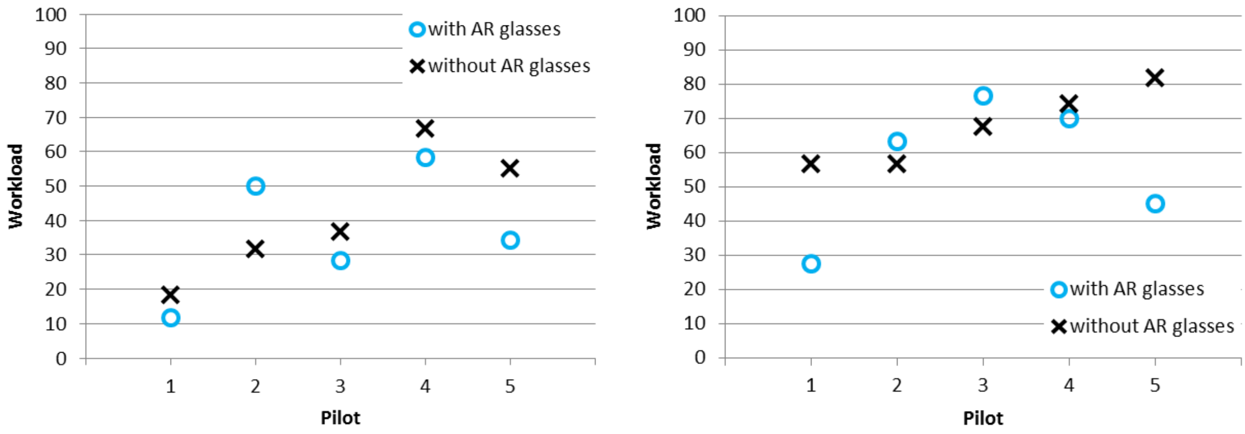
The target marker was also rated to be a useful element (HMD: two essential, three desirable, HDD: four essential, one desirable).

The ratings for the tunnel-in-the-sky display shown for automatic trajectory planning are widely spread from unnecessary to essential in both configurations.

Finally, the display of the line of sight of the second pilot or another crew member is seen to be rather unnecessary here (HMD: four unnecessary, one desirable, HDD: three unnecessary, two desirable). However, this element was shown only in a short demonstration and was not part of the actual tasks.

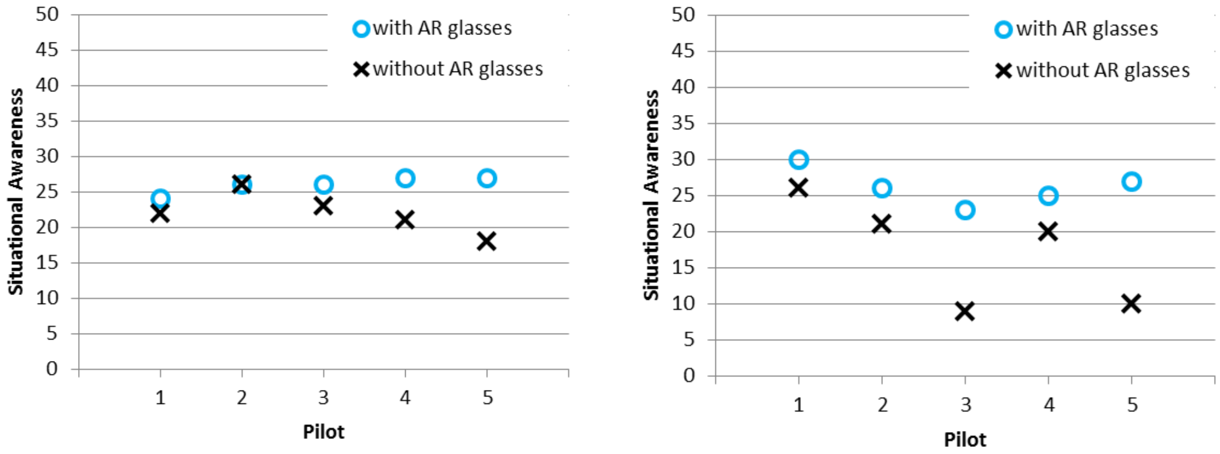
Further findings from the questionnaires, not shown in the diagrams above, are shortly summarised here. While the visual comfort was rated to be good to very good, the wearing comfort received mixed ratings ranging from poor to very good. The field of view could be bigger, though. Several pilots rated it to be only satisfactory. Significant somatic issues were not reported during or after the use of the AR glasses. Selected pilot comments were:

- Very intuitive display.
- The AR glasses have a calming effect in situations close to limits.
- The AR glasses are unnecessary in cruise flight for IFR pilots.
- Perfect for maritime operations. Controlled VFR flight into DVE becomes possible.
- Perceived safety increases, flight at limits becomes possible, risk of overestimating capabilities increases.
- Benefit of comfort in good visual conditions, benefit of safety in degraded visual conditions.
- I can’t imagine a pilot who doesn’t want to wear these glasses.



a) *Rescue mission* b) *Navigation task*

FIGURE 19: Workload ratings (NASA TLX).



a) *Rescue mission* b) *Navigation task*

FIGURE 20: Situational awareness ratings (SART).

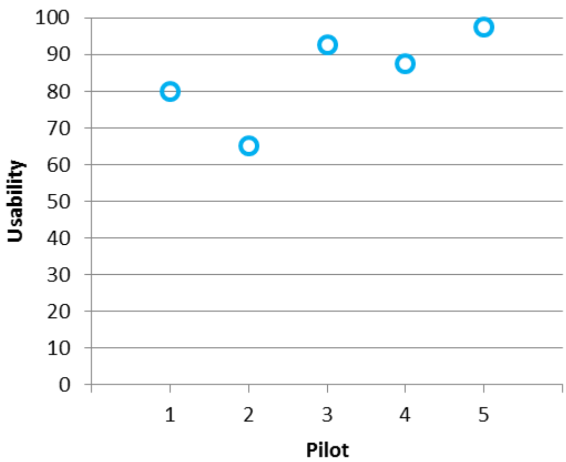


FIGURE 21: Usability rating (SUS).

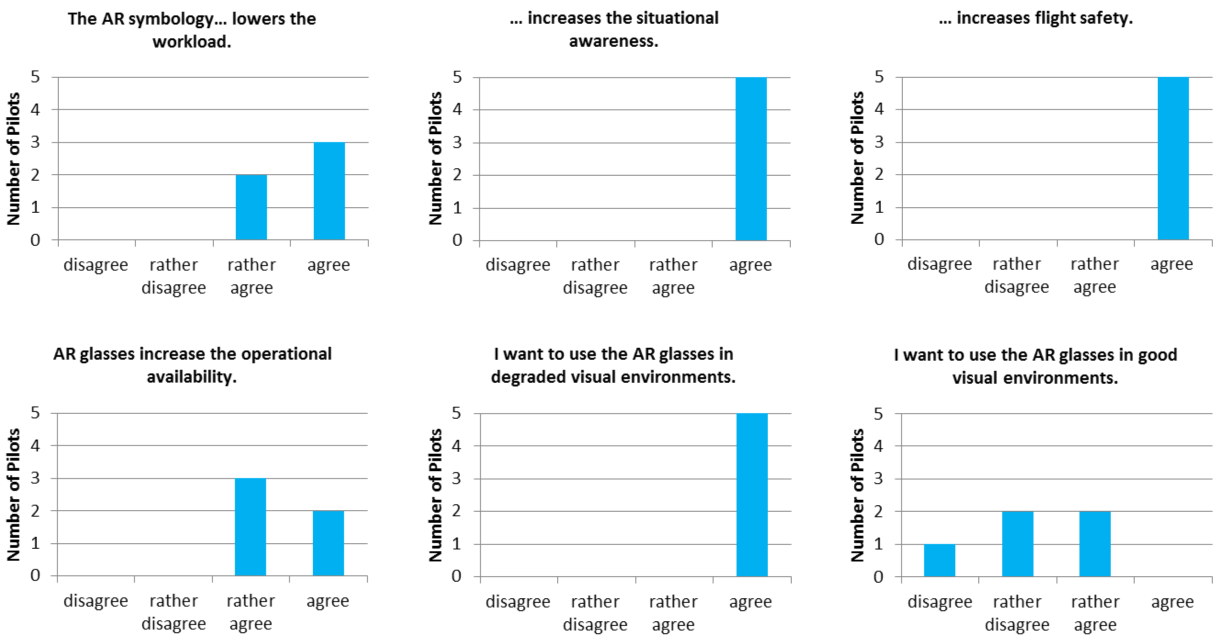


FIGURE 22: Selected answers from the display design questionnaire.

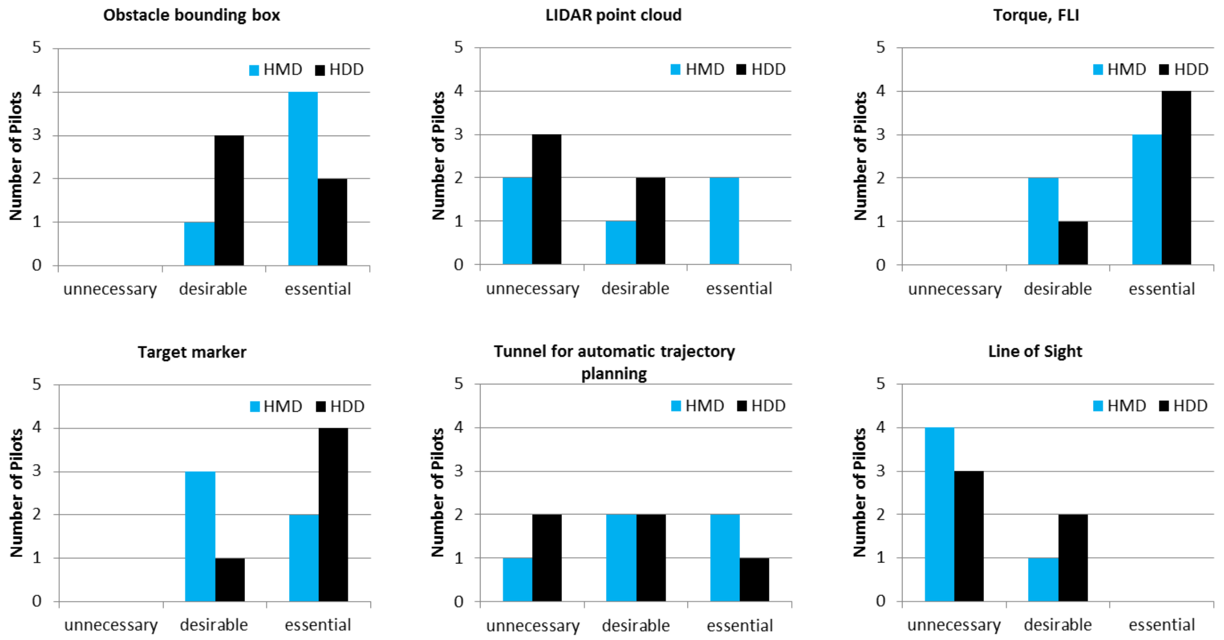


FIGURE 23: Selected answers regarding symbology elements.

4.3. Discussion

The results of the simulator study with pilots from the German federal police are generally very positive. The AR glasses were accepted by the pilots and their benefit for maritime operations could be proofed.

The majority of the pilots perceived lower workload (TLX) when flying with the AR glasses, except for pilot 2 (both tasks) and pilot 3 (navigation task). Pilot 2 was especially critically regarding the flight simulation in general. As the AVES represents the research helicopter ACT/FHS, its simulated behaviour differs from a baseline EC135. This can negatively affect the workload. Furthermore, the available training time was very limited (50 minute for familiarization with simulator and AR glasses). Pilot 2 commented that only sufficient training time (like for BIV or IFR ratings) would establish the necessary confidence into the new technology. Only well trained pilots can tap the full potential of the AR glasses. Despite the deviant TLX ratings of pilot 2 and 3, all five pilots stated in the final questionnaire that the AR glasses would lower their workload. Presumably, the pilots assume an adequate level of training at this point.

The situational awareness ratings are generally higher when flying with AR glasses compared to flights with standard cockpit displays only. Although pilot 2 found no difference in the SART ratings in the first scenario, all five pilots stated clearly in the final questionnaire that they expect the AR glasses to increase their situational awareness.

The system usability analysis turned out positively with the ratings lying mainly in the upper third of the SUS diagram. Nevertheless, potential improvements could be identified:

- Increased field of view desirable.
- Wearing comfort should be increased; field of view was displayed too high for certain test persons.
- Sink rate should be displayed in numbers.
- "Time to go" is a desirable symbology element.
- Free configuration of symbol sets is desirable.

5. CONCLUSION

Integrating a Microsoft HoloLens as augmented reality glasses into a simulator is inexpensive and results in a head mounted display of high quality. The potential for further development and research is enormous. The integration is worth recommending because literally all visual HMIs could be reconsidered in an augmented reality version with renewed cues implemented as artificial objects integrated in the real world vision.

The HoloLens was tested by five police helicopter pilots in a maritime scenario simulated in the AVES helicopter simulator. The core benefits of the augmented reality display compared to conventional head-down displays are:

- reduced workload,
- increased subjective situational awareness,
- increased perceived safety, and
- increased operational availability especially for maritime operations in degraded visual environments.

For future work, it is planned to develop symbology for different mission tasks. Two examples are ship deck landing and more generally obstacle avoidance. Lidar data could be processed more to improve quality and applicability of the display. Other sensors including different variants of Lidar and radar are planned to be simulated and visualized inside the AR glasses. The integration of the successor, HoloLens 2 is on the plan. Further, there is a project to integrate the HoloLens into a real helicopter cockpit (ACT/FHS).

6. ACHNOWLEDGEMENTS

This work was mainly sponsored by the Program Coordination Defence & Security Research (PK-S) of the German Aerospace Center (DLR) with the Project HELMA. We would like to thank the German Federal Police Aviation Service for their support as an associated partner in the project.

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