ALLFLIGHT - A SENSOR BASED CONFORMAL 3D SITUATIONAL AWARENESS DISPLAY FOR A WIDE FIELD OF VIEW HELMET MOUNTED DISPLAY

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Abstract

In the present situation, helicopter missions can be hindered by adverse visual conditions. Supporting a helicopter pilot during landings and take-offs in a degraded visual environment (DVE) is one of the challenges within DLR's project ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites). Complementary types of sensors (TV, Infrared, radar and Ladar) are mounted onto DLR’s research helicopter for gathering different sensor data of the surrounding world. A high performance computer cluster architecture acquires and fuses all the information to get one single comprehensive description of the outside situation. Especially under whiteout or brownout conditions, a visualization of relevant information on a helmet mounted system can yield a broader mission potential of the helicopter.

Recently, DLR has integrated a wide field of view binocular helmet mounted display system (JedEye) produced by Elbit (Israel) into both the research helicopter ACT/FHS and the Generic Cockpit Simulator GECO. The system can increase the situational awareness especially under degraded visual conditions by displaying an adequate symbology. A variety of different video input formats can be used to present the current situation around the helicopter. In order to provide a synthetic vision display on the helmet mounted system, it requires a very precise measurement of the line of sight (LOS) in conformance with the head movements of the pilot with minimal latency between LOS measurement and image presentation. Otherwise Level 1 handling qualities cannot be guaranteed and if conformal symbology does not correspond to the real world, an increasing irritation and possible sickness of the pilot after a few minutes can occur.

1. OVERVIEW

This paper summarizes the main stages of developing new display formats especially for landing in a degraded visual environment (DVE) beginning with a close look to the installation processes of the helmet inside both the research helicopter ACT/FHS and the generic cockpit simulator (GECO). After highlighting feature extraction algorithms on the basis of fused sensor data, this paper will describe first investigations regarding novel 3D conformal symbologies on the helmet mounted display. Main purpose of these symbologies will be to make maximum use of the possibilities given by the highly precise head tracking and wide field of view of the Helmet Mounted Display (HMD). Therefore, a variety of display alternatives will be investigated.

2. INTRODUCTION

Landing in brownout conditions is still a dangerous phenomenon experienced by many helicopter pilots during landing approaches in dusty environments. The absence of visual cues of the surroundings makes it extremely difficult to make a safe landing. US Army cites that three out of four helicopter accidents [1][2] in Iraq and Afghanistan resulted from a loss of vision due to brownout.

Brownout at night shows additional phenomena. Especially during the landing phase, aircraft lighting can enhance the visual illusions by illuminating the brownout cloud. Another effect observed at night is the Kopp-Etchells Effect [3] caused by small particles hitting the leading edge of the rotor blades and making tiny sparks, creating a visible corona or halo around the rotor blades. This effect can also produce spatial disorientation in the uninitiated pilot [4] [5].

Assistance by using Night Vision Devices (NVD) mounted on conventional helmets can help the pilot during his missions, but there are several problems that can occur. For example, while wearing a NVD and looking at two objects of different sizes that are side-by-side, the larger object appears to be nearer. While viewing overlapping objects through a NVD, the one that is in front "appears" to be nearer - maybe much more than is true. The reason for that is that the human brain tends to associate the loss of detail sharpness with distance. Furthermore, when taking of NVD in the dark, the eyes have to readjust to the lack of light, just like when entering a dark room from a lit one.

With respect to these deficits, using complementary sensors for acquiring data about the outside world at night and day combined with an adequate presentation of the surroundings on a helmet mounted display might be a better solution than using NVDs. Especially at night, night vision inside the helmet will reduce the effects of g-forces on the pilot's head and neck and will eliminate hardware configuration changes. Pilots can benefit from new display technologies in order to reduce pilot’s workload while increasing his situational awareness.

Figure 1 Helmet Mounted Display (left) and DLR’s research helicopter ACT/FHS (EC135, right)

Within DLR’s project ALLFlight [6][7], sensors with different characteristics concerning resolution, image frequency, etc. have been mounted onto DLR’s research helicopter ACT/FHS (Figure 1, right). After sensor data acquisition of infrared, TV, Ladar, and mmW radar data [8], a high performance computer cluster applies data fusion algorithms in order to generate one single representation of the outside situation. One big challenge of current research work at DLR is to generate 3D conformal and/or 3D virtual conformal symbology on a wide-field-of-view helmet mounted display system in order to increase situational and mission awareness. First investigations of possible representations of the outside situation will be presented in this paper.

3. RELATED WORK

Since several years, research projects are carried out all over the world to develop concepts and prototype systems assisting helicopter pilots to conduct brownout landings with a higher level of automation, situational awareness, and safety:

PhLASH: The USAF Laboratory Rapid Reaction Team has successfully integrated and tested a science and technology solution called the Photographic Landing Augmentation System (PhLASH). This “see and remember” system shall reduce aircraft accidents resulting from the loss of visual cues during take-off and landings in dusty conditions [9]. PhLASH is “a combination of an electro-optical sensor and infrared strobe lights which image and geo-register (matches the image to a coordinate on the earth’s surface) the ground prior to landing in brownout conditions.”

LandSafeTM: Optical Air Data Systems and LLC (OADS) have teamed to introduce a new solution to help helicopters in navigating and landing safely in degraded visual environments, especially brownout conditions. The LandSafe solution was developed through an exclusive licensing agreement between the two companies and incorporates commercial-off-the-shelf fiber-optic laser technology to “sense through” particulate matter such as dust, snow, rain, smoke or fog while providing altitude, groundspeed and airspeed information to the flight crew [10].

Sandblaster: The Sandblaster is an initiative lead by the US Defense Advanced Research Projects Agency [11]. “It involves the participation of the US Army, Air Force and Marines to varying degrees. It integrates four distinct interrelated advanced concepts as follows:

- A radar sensor sending radio frequency pulses and receiving the returns from objects in the field of view for three-dimensional scanning. The scans are processed as three-dimensional images through the use of algorithms.
- A database that captures and integrates the images produced by the scans with a stored image of the surrounding terrain.
- An advanced three-dimensional synthetic vision system with predictive state-of-the-art aircraft information to restore the pilot’s lost visual cues.
- An agile flight control system tailored for low-speed helicopter operations during landing, giving the pilot the option to let the helicopter land itself.”

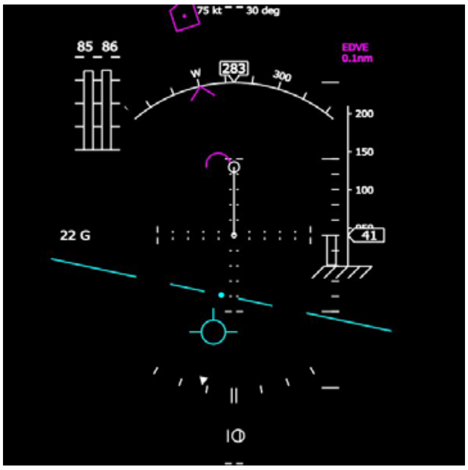

Figure 2 BOSS brownout landing display

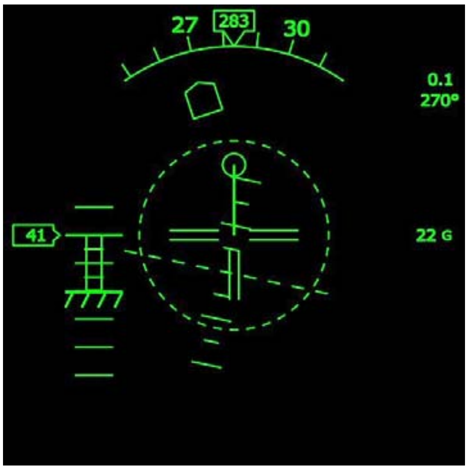

Figure 3 DEVILA brownout landing display

Figure 4 Jedeye brownout landing display

Furthermore, without using high expenses of additional on-board sensors, some more simple approaches have been proposed and developed with the aim of implementing a brownout landing display only. Such systems can be easily installed into existing helicopter fleets. A study [12] was realized to compare different proposed symbol sets, e.g. BOSS [13] (Figure 2), DEVILA (Figure 3) and JEDEYE (Figure 4). During approach and landing trials in our helicopter simulator these different formats were presented to the pilots on head-down and helmet-mounted displays. The evaluation of this study is based on objective (flight guidance performance) and subjective (questionnaires) measurements. One result of this study shows, that static 2-D formats do simply not provide enough guidance quality to provide the anticipated assistance. The option to show guidance data (e.g. approach trajectory, highway in the sky, etc.) together with some obstacle visualization (based on terrain data and/or even on extracted data from imaging sensors) should follow the idea of generating 3D-referenced conformal images [14]. Overlaid onto the real world vision such perspective presentations are intuitively understandable. DLR is working on this topic for the next years by using Elbit's high performance wide-field-of-view helmet mounted display system.

4. JEDEYE HELMET MOUNTED DISPLAY

The main electronics of the JEDEYE system is built-up with three boxes, the aircraft fixed magnetic head tracker unit (MTU), the JEDEYE display unit (JDU) for transfering the image into the helmet display, and the JEDEYE system display unit (JSDU) for producing the images and for realizing the interfaces to the out-side world (Figure 5). The front-end of the JEDEYE system consists of a transparent helmet mounted display (HMD). Its monochrome (green) binocular projection system consists of two image projectors, each with a resolution of 1920 × 1200 pixels. The optics consisting of the projection lenses and a transparent holographic spherical mirror (visor) for each eye offers a field of view (FOV) with approximately 80° × 40°. Together with a magnetic high precision tracker the system yields an unlimited field of regard, i.e. -180°…180° for azimuth and -90°…90° for elevation. To align the system's optical axis with the aircraft axis, a so-called "boresight reference unit" (BRU) is applied which produces an aircraft aligned optical reference beam. Before flight, pilots have to align a special marking on the HMD with this reference beam. Controlling of the alignment process and adjusting contrast and brightness of the display can be carried out via a control unit. The system offers a built-in symbol generator software which produces a stroke display format similar to the BOSS display (Figure 6).

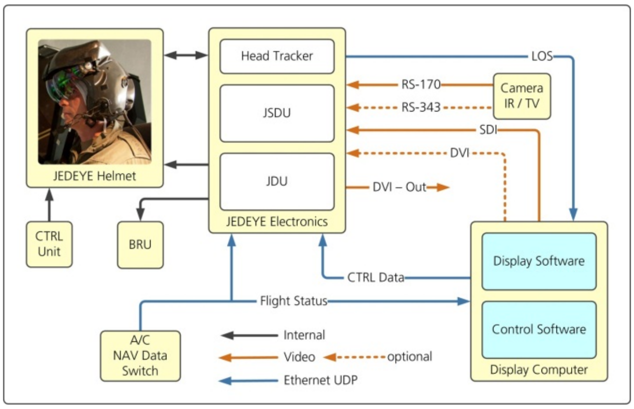

Figure 5 Functional integration of JEDEYE system into A/C and/or simulation environment

Data exchange between JEDEYE, aircraft, and the control and display computer is realized via Ethernet connections. All data are transmitted via UDP protocol. The system offers various image input formats and interfaces. Cameras can be connected via RS-170 or RS-343. Computer generated graphics, which are computed on a rugged PC, are fed in via SDI (serial digital interface) coax cable which offers a reliable data connection even in the electromagnetic noisy environment of a helicopter. The image format offers a maximum bandwidth for a HDTV image with 1920 × 1080 pixels, interlaced with 30 Hz. For the lab-configuration of the JEDEYE system it is also possible to apply images via DVI with a resolution of 1920 × 1200 pixels at 60 Hz. The system can show different images on the right and left eye, thus it is possible to visualize stereo imagery, as well. The fed in images can be overlayed onto the built-in stroke display as background , foreground or picture in picture . The system configuration and control is realized via a control software which runs on the external display generator. This computer receives the orientation of the pilots head and the aircraft euler angles as well. Therefore it is possible to easily produce imagery which is perfectly aligned to the outside world. This is the most important feature of the JEDEYE system for our future work, developing conformal perspective displays, which can be easily interpreted even by untrained pilots. This topic is often referred to as 3-D display format but we feel that this wording is a bit misleading. Therefore we prefer the term conformal perspective display format (CPDF), which we will use in the forthcoming parts of our contribution.

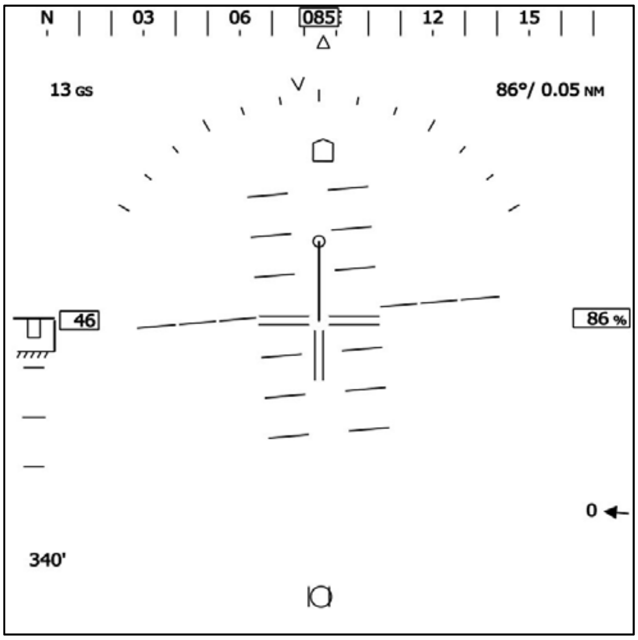

Figure 6 Built-in stroke display format of JEDEYE

5. SYSTEM INTEGRATION

In order to find the best location of the magnetic tracker with a minimum of electromagnetic influences, the motion box of the pilot's head has to be measured by a 3D scanning robot. The requirement of the robot is a perfect zero degree leveling of the platform that has to be constructed for both the ACT/FHS (Figure 7) and the GECO (Figure 8). The magnetic head tracker was temporarily attached to different possible mounting positions in order to find the best. The final position has been established as a permanent installation of the MTU.

Figure 7 Magnetic Survey of the ACT/FHS

Figure 8 Magnetic Survey of the GECO

In contrast to the GECO-integration, a so-called boresight reference unit (BRU) is needed for system alignment. By targeting this unit through the helmet, two symbols (one symbol in the helmet, another symbol is shown inside the BRU) have to be aligned by the pilot. This method allows pilots to align the system with different body sizes in terms of the 0° LOS, which means an alignment of the helmet with the extension of the longitudinal axis of the helicopter. An installation of a BRU in the GECO was not necessary, since the alignment process can be started by focussing the 0° coordinate of a high-precision coordinate grid.

As part of the magnetic surveys, Elbit has determined that the head rest of the pilot's seat may disrupt the communication between the MTU and the helmet. Due to the closed O-shaped design of the headrest, electric fields can be caused by induction, which may have a negative influence on the overall system. Consequently, DLR has exchanged the seat with a compatible pilot seat.

Figure 9 ACT/FHS Ground Acceptance Test with rotating rotor

Due to technical problems of the ACT/FHS, a flight acceptance test (FLAT) was not able to be conducted, but a functional test based on a ground test (Figure 9) with a rotating rotor was performed. Both the interface between the data management computer (DMC) and the helmet and the verification of the accuracy with respect to angle measurements between previously selected real objects could be successfully tested and validated. For the validation of the angular measurements, the properties were previously measured using a theodolite.

The FLAT will be conducted after the maintenance phase of the helicopter at the end of 2012. As part of these flight tests, the raster mode of the helmet, which can be used for the presentation of both symbols and synthetic visions will also be tested.

6. SENSOR DATA

There are four types of sensors used in ALLFlight: An electro-optical, forward looking camera mounted on the outside of the helicopter, a similarly mounted infrared camera, a forward looking, high resolution Ladar scanner, and a 3D imaging radar system. Each of these sensors has its own advantages and disadvantages. Consequently, each sensor produces its very own type of data that is typically not ad-hoc compatible with any of the other’s.

Both cameras show a perspective image of the outside world. Such an image is easily interpretable by a human observer. However, the scenery cannot be viewed, for example, from a different point of view. The electro-optical camera image is probably the most familiar kind of sensor data. Typically, such a camera can operate at frame rates above 25 Hz. The main disadvantage of this camera is, that it is nearly useless in degraded visual environments such as low-light conditions, brownout, and overexposure. Infrared performs slightly better under these conditions but still has problems with, for example, whiteout or brownout.

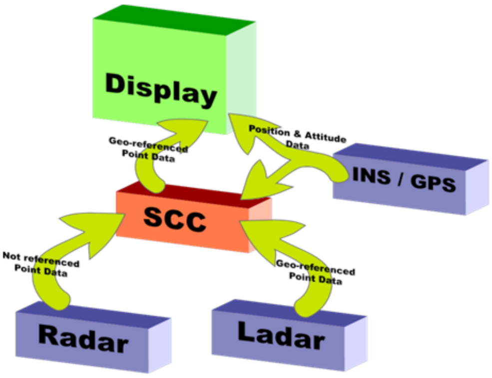

Figure 10 Data-flow within the current ALLFlight processing chain.

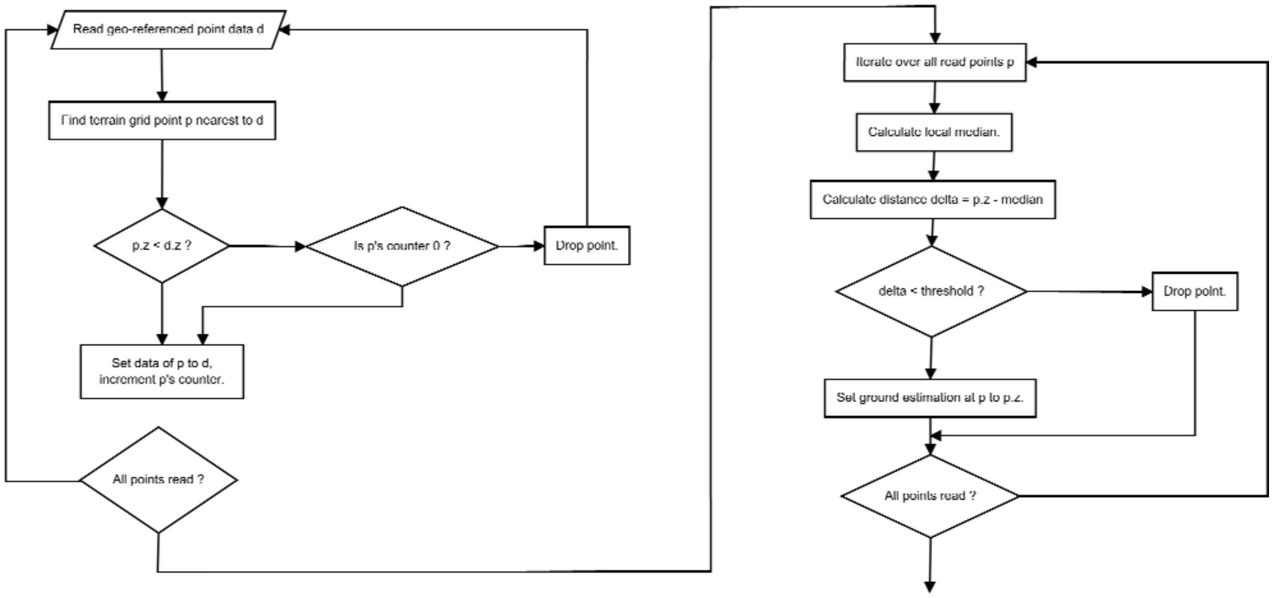

Figure 11 Implementation of the filter chain to separate terrain from obstacles.

The high-resolution Ladar scanner yields a stream of geo-referenced 3D points. The advantage is that due to its active nature it can operate under low-light or overexposed conditions. Before the pilot can make use of the resulting data it needs to be pre-processed since point cloud data cannot be easily interpreted by a human observer. Furthermore, the sensor operates at a relatively low frame rate of 2 Hz. Finally, the 3D radar can look through all of the mentioned degraded visual environments. Radar will typically not be affected by dust, snow or light conditions of any kind. Nevertheless, due to its mechanical tilting the overall frame rate is relatively low, as well as the resolution. The data is delivered in form of a stream of local coordinate 3D point data, therefore extensive pre-processing is necessary.

Figure 10 shows the data-flow within the current ALLFlight processing chain. Sensor data acquired by radar or Ladar sensors are sent to the central SCC (Sensor Co-Computer) processing cluster. Here, the raw data is filtered and, in case of the radar data, geo-referenced with respect to position and attitude information of the aircraft. The geo-referenced data is then compared to a ground database, analysed if it belongs to the ground or if it represents some kind of obstacle, and finally either added to the ground database or possibly entered into a list of non-terrain obstacles. See Figure 11 for the implemented filter chain.

7. CONFORMAL SYMBOLOGY – FIRST INVESTIGATIONS

The result of filtering is a terrain database with fused information from the sensors and a separate list of 3D obstacle points. In order to display these data to the pilot we have implemented three basic methods:

1. Show the terrain in a continuous, color coded display and integrate obstacle points ground referenced into the terrain. Obstacles will appear as part of the terrain, i.e., a house may appear as some kind of hill (Fig. 12 b). We will refer to this display alternative as “Terrain”.

2. Show the terrain as before but display obstacles separately as ground referenced columns aligned in a regular grid (Fig. 12 c). In this display variant obstacles appear as artificial objects. Since they are displayed ground based the pilot cannot make use of form cues,

since structures that are not attached to the ground appear grounded. E.g., a bridge is shown closed and can no more be recognized as a bridge. This display is called “Manhattan”.

3. Show the terrain as in “Terrain” but display obstacles separately as free placed cubes of varying sizes (Fig. 12 d). This display requires more computational power from the display system. It enables the pilot to make use of simple form cues. E.g. bridges, cranes and poles can be recognized as such. This display variant is called “Octree”.

A first evaluation with these three display variants was conducted in order to determine preferences of pilots in an early stage of development. After an extensive briefing test pilots were asked to perform a simple reaction experiment. For each display 20 pairs of scenery photos were presented alongside with a 3D reconstruction of the scenery in the respective display. The pilots were asked to identify which of the presented photos corresponded to the 3D reconstruction shown. As a result most of the pilots showed best performance concerning reaction time and accuracy of the identification in the Manhattan-display. However, debriefing showed that most of the pilots preferred the more detailed Octree-display. See [15] for full details of the study.

8. SUMMARY AND CONCLUSION

We have invested a lot of effort for enhancing our simulation environment and for equipping our research helicopter with several additional sensors and a lot of computing equipment. As first results from simulations and flight trails have shown, the combination of such a complementary sensor suite and the high resolution helmet mounted display from Elbit, is the right way to built-up a generic research environment for developing new concepts of pilot assistance. This will play an important role for further evaluation of combinations between sensed data, terrain data bases and the art of presentation of the result to the pilot.

Beside this positive summary, we have to state that up to now, there is no single sensor available which fulfills all needs

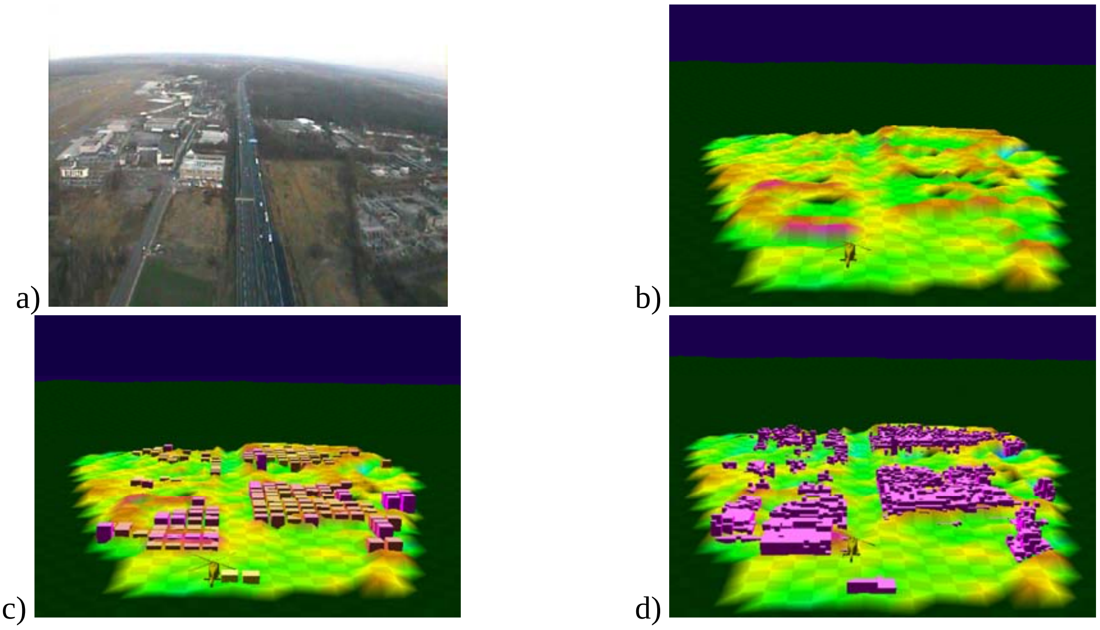

Figure 12 Highway scene from over flight: a) TV-image, b) display mode “Terrain”, c) display mode “Manhattan, d) display mode “Octree”.

within reduced visual situations. There seems to exist some type of nature principle that penetration of darkness, weather and dust becomes better with growing applied wavelength. But on the other hand it is clear, that the rising wavelength is reducing the spatial resolution, at least as long the sensor's aperture cannot grow without limits.

Nevertheless head-tracked helmet mounted displays are a key technology towards helicopter operation under DVE. The option to show guidance data (e.g. approach trajectory, highway in the sky, etc.) together with some obstacle visualization should follow the idea of generating 3D-referenced conformal images. Overlaid onto the real world vision such perspective presentations are intuitively understandable. The evolving maturity of these systems should one day overcome the hurdle from VFR assistance to reliable IFR control systems, so that finally the high purchasing cost will be justified. Beside all efforts towards more and more automation of helicopter control [7], enhancing pilot's situational awareness will stay one of the most important topics regarding flight safety.

9. ACKNOWLEDGMENT

The ALLFlight activities are sponsored by the German Federal Office of Defense Technology and Procurement (BWB) within the following projects:

- Increase of all-weather capability by developing a flight management system in connection with the use of a helmet mounted display (HMD)
- ALLFlight - Assisted Low Level Flight and Landing on Unprepared Landing Sites.

Thanks to Eurocopter Germany (ECD) which has actively supported our work regarding the integration and certification processes of both the MTU and the BRU, as well as for supporting the approval of the modified pilot seat.

10. ABBREVIATIONS

ACT/FHS	Active Control Technology / Flying Helicopter Simulator
ALLFlight	Assisted Low Level Flight and Landing on Unprepared Landing Sites
BRU	Boresight Reference Unit
CPDF	Conformal Perspective Display Format
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DVE	Degraded Visual Environment
FLAT	Flight Acceptance Test
GAT	Ground Acceptance Test
GECO	Generic Cockpit Simulator
HMD	Helmet Mounted Display
JDU	JedEye Display Unit
JSDU	JedEye System Display Unit
LOS	Line of sight
MTU	Magnetic Tracker Unit
NVD	Night Vision Device
SCC	Sensor Co-Computer

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