ALLFlight- Fusing sensor information to increase helicopter pilot's situation awareness

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ABSTRACT

After years of experiences regarding enhanced and synthetic vision research projects in the fixed wing domain, the Institute of Flight Guidance is now addressing helicopter applications in the scope of the project ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites). The main objective of this project is to demonstrate and evaluate the characteristics of different sensors for helicopter operations within degraded visual environments. A visual guidance of the helicopter during take-off or landing on sand, dust or snow becomes impossible, if whirled particles from the ground produce a dense cloud around the helicopter. This effect is called brownout for landings on sand, or whiteout for landings on snow. In this situation, the pilot is no longer able to acquire visual cues from outside to evaluate the helicopter's lateral drift. Sensors, which are able to look through this nontransparent surrounding area could help the pilot in flying safely to the ground.

ALLFlight's sensor suite, which is mounted onto DLR's research helicopter EC135 consists of a standard color TV camera, an un-cooled thermal infrared camera (EVS-1000, Max-Viz, USA), an optical radar scanner (HELLAS-W, EADS, Germany) and a mmW radar system (AI-130, ICx Radar Systems, Canada). The data processing is designed and realized by a sophisticated, high performance sensor co-computer (SCC) cluster architecture, which is installed into the helicopter's experimental electronic cargo bay. The acquired raw data of each single sensor are the basis for the graphical 3D representation of the outside situation. The result of these image fusing processes can be used for planning online trajectories and for flying along these trajectories with a highly augmented flight control system. For simulating purpose, DLR has also realized tools to simulate sensors like mmW radar and Lidar. Details of simulated 2.5D terrain scanning radar are described in the paper "Real-time Simulation of a 2.5D Radar" (authors Peinecke and Groll) on this conference.

INTRODUCTION

Daily helicopter operations like search and rescue (SAR) or helicopter emergency medical service (HEMS) show that visual assistance for the helicopter pilot is essential. Compared to fixed-wing aircraft, flying a helicopter is still relatively unsafe. In 2007 the number of accidents per 100,000 flight hours was about 4.9 [1], which is by a factor 35 higher compared to the number of accidents of fixed-wing aircraft (1.39 accidents per 1 million flight hours [2]). Main reasons for this unacceptable amount of accidents are pilot errors due to high workload and adverse weather conditions. This is the motivation for developing new assistant systems [3].

While flying through a sandstorm, during take-off or landing on sand, dust or snow, whirled up particles from the ground can produce a dense cloud around the helicopter so that a visual guidance of the helicopter becomes impossible. This effect is called brownout for landings on sand, or whiteout for landings on snow.

During landing, the pilot has to ensure that the lateral drift of the helicopter does not exceed a certain magnitude directly before touching down. Otherwise a dangerous moment around the roll axis would occur after the first contact of the landing gear or skid with the ground. This turning moment could finally lead to a total roll over of the entire helicopter.

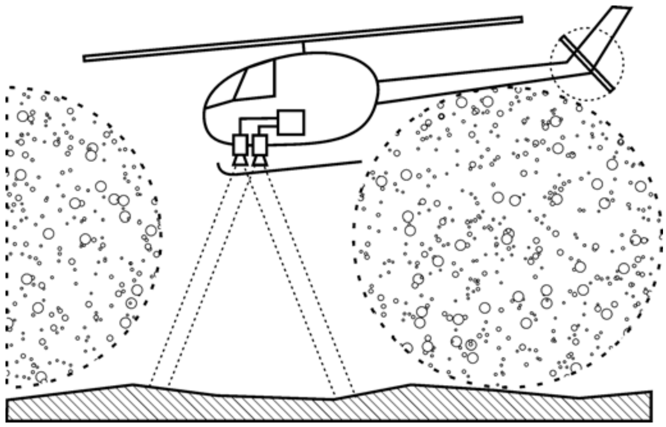

Figure 1: Landing on sand, dust or snow. Downward looking cameras are able to "see" through the remaining hole in the dust below the helicopter's fuselage.

The effect of whirling up dust is caused by the main rotor's downwash. Its strength increases with decreasing flight altitude. As long as the flight path of the helicopter has some forward movement, a horizontal cylinder of dust is formed behind the helicopter. This cylinder becomes a torus (like a "donut") as soon as the altitude and forward speed are falling below certain thresholds (Figure 1). After the dust torus has fully developed, the entire external horizontal field-of-view around the helicopter becomes in-transparent. Thus, the pilot is no longer able to acquire visual cues from outside to evaluate the helicopter's lateral drift. Nevertheless, a certain region directly below the helicopter remains free of dust during hovering - at least for a certain amount of time. Through this hole within the "donut" the ground remains recognizable.

State-of-the-art

Regarding the development of advanced technical solutions to reduce the risk of landing in brownout, the following research projects are currently in progress:

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 [4,5]. PhLASH is "a combination of an electro-optical sensor and infrared strobe lights which image and georegister (matches the image to a coordinate on the earth's surface) the ground prior to landing in brownout conditions."

LandSafeTM: Rockwell Collins and Optical Air Data Systems, 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 [6].

Sandblaster: The Sandblaster is an initiative lead by the US Defense Advanced Research Projects Agency [7]. "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.

Additionally, several patent applications are published regarding this field (e.g.,[8-10]). The different approaches can be grouped into three main categories:

- large solution - high sophisticated sensor-suite and complex data fusion setup
- see and remember - perspective display of real-time acquired 3D terrain data
- small solution - downward looking sensors are driving a simple drift and altitude display.

Large Solution: The large solution to solve the low visibility problem consists of a large and complex suite of different imaging sensors, such as millimeter wave Radar systems, optical Lidar systems, and infrared cameras. Besides, high accurate data bases and high precision navigation systems are an essential element of this concept. The biggest challenge of this approach is to design intelligent algorithms for data fusion and display generation. The expected advantage is that in every phase of the helicopter landing, at least one sensor is able to look through dust and snow. The main disadvantage is that such a large and complex system will be rather heavy and expensive and therefore is not easy to install [8,9]. Due to this, such systems will not be affordable for every helicopter. The DLR project ALLFlight can be regarded as a contribution to such a large solution.

See and remember: The second concept, called see and remember, means that during the approach phase some imaging sensors are acquiring data from the terrain below as long as possible. From these data a consistent 3D-model of the landing zone is permanently updated in real-time. In combination with precise positioning and attitude data, a perspective view onto this 3D-model is generated and shown to the pilot [8,9]. After the sensor looses its direct visual contact to the ground, pilots shall still make use of the continuously available perspective display of the 3D-model. Although the perspective presentation of the 3D data is steadily updated with respect to the changing position and attitude of the helicopter, the 3D data itself becomes outdated over time. Therefore many pilots are skeptic about this approach. They are familiar with flight training in simulated environments, but they cannot accept to fly a real aircraft based on a (probably) outdated 3D model (although the age of the model data might become rarely older than some 30 seconds until touch-town).

Small solution: The third approach applies downward looking cameras, which are mounted below the helicopter's fuselage. For example a German patent application describes a system which makes use of several so-called PMD sensors [10,11]. These are solid-state cameras which are able to measure ranging data for each pixel by using some special range gating technique. The basic principle is similar to an optical radar system (Lidar), where the whole scene is illuminated by a very short pulse of light. Pfenninger states that such an optical system, mounted below the helicopter's fuselage, would be able to help within the brownout situation. This is true, because during brownout there remains a dust-free zone within the inner part of the "donut-like" cloud. This inner zone allows a visual look-through onto the ground below. We will follow this argumentation. However, instead of PMD cameras, we will apply a pair of off-the-shelf standard CMOS-cameras, which are used to built-up a stereo-camera setup.

DLR'S PROJECT ALLFLIGHT

Objective

In 2008 the German Aerospace Center (DLR) started the project "Assisted Low Level Flight and Landing on Unprepared Landing Sites" (ALLFlight). This project deals with the development of an assistance system which allows the intuitive operation of a manned helicopter from start to landing in confined areas and intermediate low level flight in the presence of obstacles in a degraded visual environment. The objective of ALLFlight is to achieve a safe and effective 24 h all weather operation under above conditions by providing the pilot an optimal combination of assistance, consisting of advanced visual and tactile cueing and intelligent control augmentation, reducing his workload and increasing his situational and mission awareness.

During the forthcoming years until 2012 it is planned that ALLFlight will record a comprehensive archive of data from its complementary sensors in several flight trials under different mission scenarios. ALLFlight will provide curved and unsteady trajectories (in space and time) for all phases of operational helicopter flight (take-off, low level flight, landing) under all conditions (day, night, degraded vision). The trajectory generation incorporates the cognitive pilot's decision processes for trajectory planning [12] in the described scenarios and bases on the sensor-suite data. The generated trajectories can now be flown within ALLFlight developed flight control system based on a model based control (MBC) approach. They can be visualised with the helmed mounted display which is planned to be integrated into the helicopter. The development of different sophisticated real-time processing and data fusion concepts will pave the path for novel display formats. The project's goals also cover the development and evaluation of new concepts to overcome dangerous problems of brownout or whiteout situations, whenever raised dust or snow is blocking the direct visual ground perception by the pilot. This output will result in a broader mission potential of the helicopter compared to the present situation, where it is common that a mission cannot be performed or has to be cancelled due to bad visual conditions.

Figure 2: DLR's research helicopter EC135.

Figure 3: Sensor mounting between the landing skid.

Lidar, EADS, Germany	**IR-Camera, Max-Viz, USA**	**TV-Camera**	**2.5 D Radar, ICx Radar Systems, Canada**
			
1.5 micron pulse power 3.6…10 kW FOV [°] 31.5 × 32.0 scan frequency: 2 Hz 95 × 200 × 64 bit pixels range res.: 0.6 m range: 1000 m detect. range 600 m (10mm) min. range 20 m size [mm]: 320 × 318 × 500 weight approx.: 28 kg 140 W special software LAN-Interface	8-12 micron 320 × 240 px NETD 0.2 K FOV [°]: 53° × 40° hermetically sealed DO160 E qualified case [mm]: 70 × 172 weight 1.3 kg 10 W camera 40 W heating RS-170 Interface	visible (B/W or color) res. [pixels] 768 × 494 sensitivity 0.1 lux FOV [°]: 53 × 40 case [mm] 70 × 172 weight: 1.3 kg 5 W camera 40 W heating RS-170 Interface	35 GHz pulse radar H-FOV -90°..90° V-FOV -90°..20° beam width: 2.4° × 1.8° range 1 … 8 NM range res. 1.8 m scan time 1.8 sec for 30° × 21° terrain scanning mode size [mm]: 390 × 425 × 570 weight approx.: 25 kg 125 W special software LAN-Interface

Table 1: ALLFlight sensor-suite and the main parameters of each sensor.

Together with Eurocopter, DLR developed a special equipment carrier beam to install all sensors below the forward cross tube of the landing skid of the EC135 (Figure 2 and Figure 3). In addition, the helicopter was equipped with a higher landing skid to achieve the necessary ground clearance for the sensors in unprepared landing sites. The sensor-suite consists of standard color or b/w TV cameras, an un-cooled thermal infrared camera (EVS-1000, Max-Viz, USA), an optical radar scanner (HELLAS-W, EADS, Germany) and a mmW radar system (AI-130, ICx Radar Systems, Canada). Most important parameters are shown in Table 1.

Hard- and Software Architecture

For data acquisition, recording, real-time processing and data fusion, a high performance computer hardware was constructed, consisting of seven single-board computers which are interconnected via a high speed GB-LAN (Figure 6). Each of the boards is equipped with a 2.4 GHz Dual-core Intel CPU with 4 GB RAM and Windows XP operating system. Each sensor has its own main board (SCC-4 - SCC-7) for data acquisition, recording and pre-processing. The data flow from each sensor is reduced drastically by applying pre-processing and/or image processing algorithms. The results are sent via Gigabit Ethernet to the data fusion main board (SCC-2). This computer is responsible for gathering all the intermediate results to fuse them to one 3D model, representing the environment of the surrounding world. The 3D model serves as a basis for following guidance related processes, e.g., the trajectory planning module, and can be presented directly on the HMI displays of the experimental pilot (EP, Figure 4) and the flight test engineer (FTE, Figure 5). The SCC-cluster receives flight status data (position, attitude, etc.) from the helicopter's Data Management Computer (DMC). In addition, GPS time for sensor data synchronization, and keyboard commands from the control display unit are transferred.

Figure 4: FHS front display for experimental pilot (EP).

Figure 5: FHS rear display for flight test engineer (FTE).

For acquisition, recording, analysis and visualization of sensor data a specialized distributed software system was designed and implemented. This software system was developed in C/C++. Regarding the further development of new methods for data fusion on the basis of recorded data, a fast and selective access to recorded data was realized by using a control concept like a multimedia player, which is also used for validating the image/sensor processing algorithms.

Flight Control System

The explicit model based control (MBC) approach forms the basis of most of the control related DLR user programs, e.g. in-flight simulation, upper mode and auto pilot design, handling qualities investigations and pilot assistance technologies. These concepts enable to vary the pilot assistance from a direct mode, via upper assisted modes and finally to the full automated take off and landing mode, depending on flight mission and environmental conditions. Figure 7 shows the principal layout of the MBC design. A dynamic, "inverse plant" type of feed-forward controller is designed to cancel the actual helicopter dynamics and to impose the commanded response dynamics on the aircraft. The feed-forward controller makes use of identified quasi-linear models for hover and different forward speeds. In addition, a feed-back controller is designed to eliminate response errors due to occurring disturbances and eventual model deficiencies. The advantage of the explicit model based approach is the flexibility in the design of the command model. The command model can be adapted to investigate advanced controller systems, variations of basic handling qualities or to simulate other helicopters in flight. Also Figure 7 shows the placement of the air resonance controller within the control loop of the MBC [13].

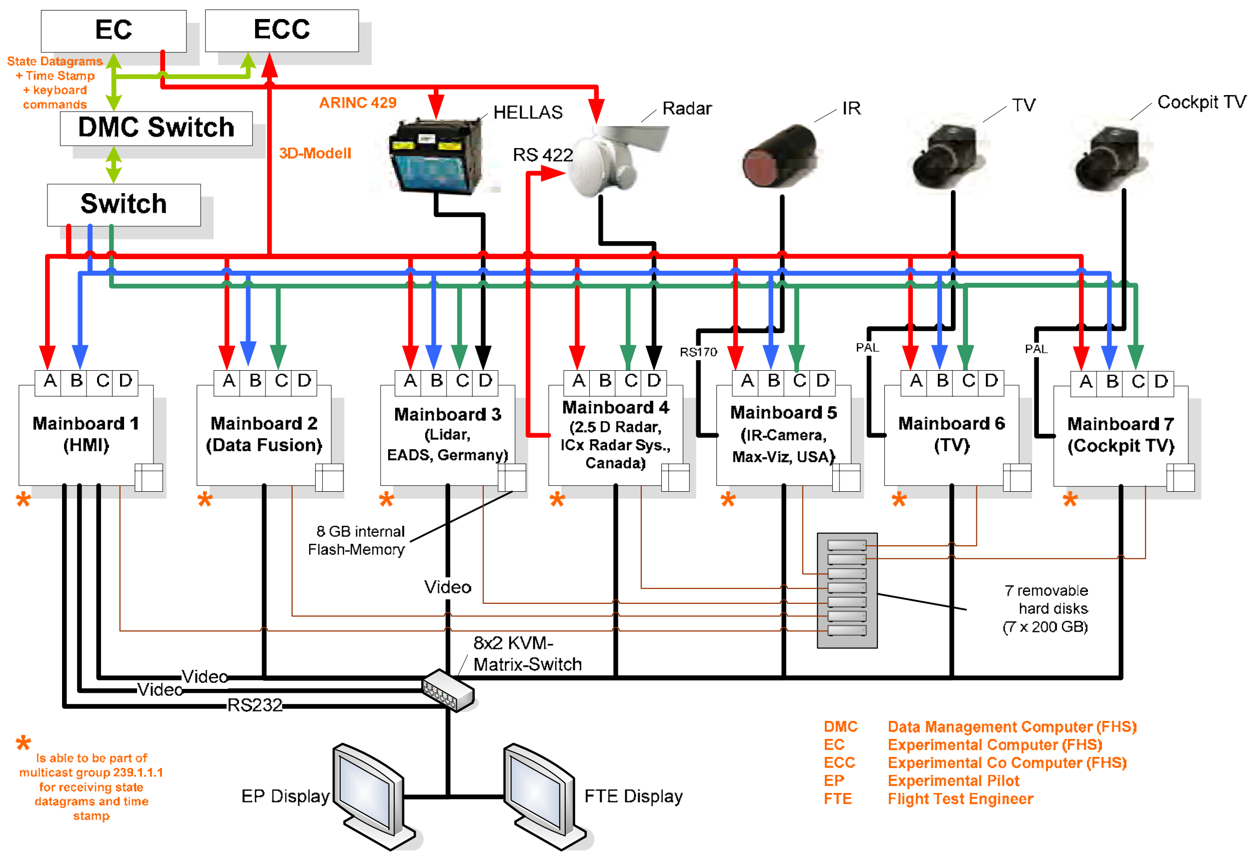

Figure 6: Computer architecture of the sensor-co-computer (SCC) applied for ALLFlight. It consists of seven single board computers which are interconnected via high-speed LAN (1GB – LAN).

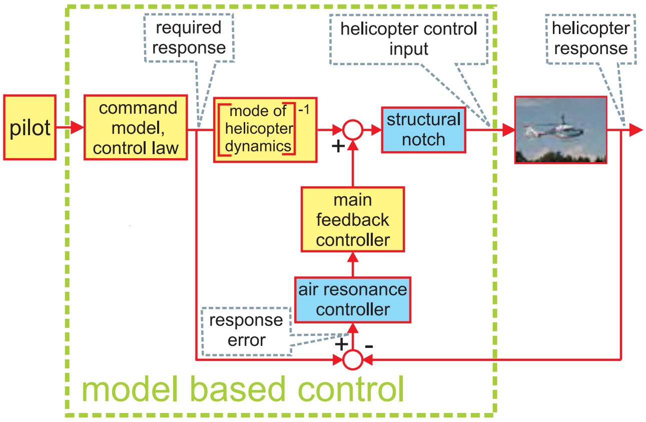

Figure 7: MBC environment

Up to now, the MBC command model features a decoupled RCAH (rate command attitude hold) with turn coordination, ACAH (attitude command attitude hold) and additional autopilot functions for departure and approach from confined areas, they are presently flight tested.

To avoid structural damages by triggering natural frequencies of structural modes e.g. fuselage heave, tail boom lateral and flap bending or fenestron drive train torque, structural filters were implemented in the feed forward command path, see Figure 7. They consist of multiple narrow notch filters with different stop band positions for the respective structural mode.

All necessary parts of the flight control system are designed with MATLAB/Simulink. The Real Time Workshop is used to generate C-Code which is running directly on the experimental flight control computer. After successful pilot-in-the-loop/Hardware-in-the-loop tests in the ground based system simulator the code is directly transferred to the FHS system for flight tests.

DATA FUSION TECHNIQUES

The acquired raw data of each single sensor are the basis for further processing for the graphical

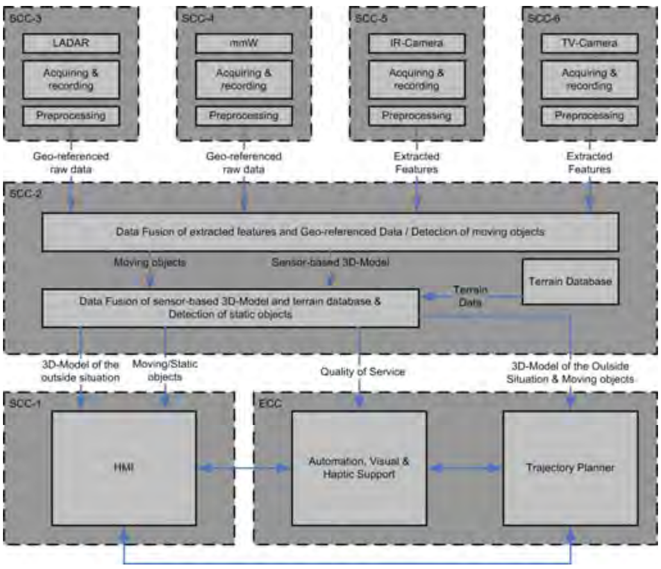

Figure 8: Data flows from sensor data acquisition, via data fusion, down to further processes, e.g., HMI, trajectory planning and automation.

3D representation of the outside situation, as well as for generating automatically an optimal trajectory for the final approach into the landing zone. Figure 8 depicts an overview of the data flows from sensor raw data acquisition down to the visualization of the fused data on the HMI, the trajectory planner process and the trajectory based automation with both visual and haptic support [14].

For imaging sensors (TV, IR, etc.), detection of static and moving objects is realized via feature extraction algorithms, which reduce also the incoming flood of data. The detection of moving objects requires the detection of the same object in a number of successive frames. The software architecture of the acquisition and recording processes allows a direct memory access of the last acquired number of frames instantaneously. Moving objects are not part of the produced data base and are handled separately as an independent data flow. In contrast to the imaging sensors, the Ladar- and the mmW-Radar data represent 3D geo-referenced measured points, but with a lower data rate.

Description of the outside world

The entire data from all sensors are transmitted over a UDP connection to the SCC-2 computer for the data fusion process which generates in a first step a sensor-based 3D-model. In the scope of a further data fusion process, elevation data of the sensor-based 3D model and a reliable 3D-terrain database are compared in order to generate a new 3D model representing the outside situation. Due to different resolutions of both models and with respect to the real time capabilities of the system, elevation data are matched on a discrete two-dimensional array with a configurable spacing. For safety reasons, higher elevation value for a specific grid coordinate of both 3D-models are written into the new elevation data base. In addition, entries for the difference value and a data acquisition time stamp can be provided at each grid coordinate. Time stamps are necessary for the realization of the "see and remember" philosophy especially in brownout conditions. Furthermore, obstacles which have been detected earlier could have changed in the real world, e.g., the orientation of a crane, the position of a vehicle, and so on.

Trajectory planning (on ECC, see Figure 6) and visualization of the outside situation on the HMI (on SCC-1) are driven by this discrete 3D model, and by the information on detected moving objects. The representation of the outside situation also includes helicopter drift measuring and estimation of the inclination angle of the landing zone and will be presented on the HMI as well. For the trajectory based automation processes (e.g., automatic flight guidance, automatic landing, haptic support in manual flight mode with a side stick), it is also important to have information about the sensor's reliability to have an idea about the quality of service, e.g., if the sensors did work in the full scope of operation.

Helicopter drift measuring and estimation of the inclination angle of the landing zone

As already mentioned, during the appearance of the dusty cloud in brownout, a small region below the helicopter's fuselage remains free of dust, at least for certain amount of time. If the pilot would be able to see a picture of the landing zone below the helicopter (e.g., on a camera display), it would still be difficult for him to interpret this image. This is due to the fact that the lateral shift of the entire image is not only effected by drift, but also by rotations of the helicopter around its roll and pitch axis. Therefore, we applied an automatic image analysis system to determine the cross- and along-drift of the helicopter. Our approach has to be supported by data of the turning rates around the along and transverse axis of the helicopter (pitch and roll axis). Together with a suitable display to show the computed drift rates to the pilot, this system will be able to assist the pilot in controlling the helicopter until touch down. Additionally, to estimate the height above the ground and the possible tilt angles of the landing surface, we apply a stereo camera system (Table 2).

Position and pose estimation by means of computer vision has a quite long tradition [16,17]. There are numerous examples from the field of autonomous robot navigation [18,19] and camera pose estimation [20]. The availability of cheap computer vision hardware integrated into mobile phones has already raised some interest [21,22].

We implemented a feature based image analysis technique. First of all, each input image is converted into a list of features representing the main image content. The implemented program allows adjustment of most predefined processing parameters during run-time. Thus, adaptation to different types of input images can be done easily. Processing time for feature extraction takes something between 20 and 40 ms for a single typical outdoor image (352 × 240 pixel, Intel Core2, 1.6 GHz).

Drift estimation is based on a shift analysis of the feature lists over time from image to image. Considering the time-stamp of each acquired image, we can compute the global 2D shift speed vector (denoted in pixels per second).

Characteristics	
camera type	uEye 1220SE-M
manufacturer	IDS, Obersulm, Germany
sensor type	CMOS – b/w
sensor chip	MTV0922 Micron, ID, USA
resolution	752 × 480 pixels
optical area	4.51 × 2.88 mm
pixel size	6 × 6 micron
frame rate	60 Hz @ full resolution
global shutter	0.04 … 5000 ms
lens	Fujinon 1.2/6.0 mm
interface	USB-2.0
software interface	WDM-driver
size (incl. lens)	32 × 34 × 75 mm
weight (incl. lens)	120 g

Table 2: Experimental stereo camera setup. A pair of cameras (uEye SE1220-M) and a small attitude sensor (InertiaCube) are mounted on a common mounting frame.

With regard to the known field of view (FOV) of the camera (in degrees), the 2D angular speed vector (denoted in degrees per second) is obtained. Finally, by adding distance data (computed from stereo reconstruction, or – if available – from the helicopter's radar altimeter) and the turn rates from the rate sensor, the lateral 2D drift vector (denoted in meters per second) results. The resulting drift vector can be displayed to the pilot.

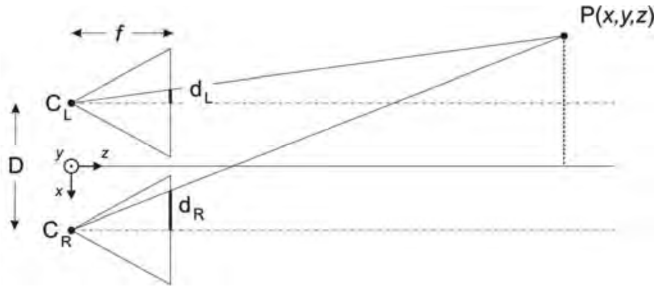

Figure 9: Geometry setup for stereo camera calibration

To estimate the helicopter's height above the ground, and the tilt angle of the landing area as well, a stereo matching process of the images from the left and the right camera has to be carried out. This is done with a similar method as applied for drift estimation. Before starting the actual estimation we need to calibrate the camera setup. The principal camera geometry can be seen in Figure 9.

We apply a parallel configuration of camera setup (Figure 9). For such a setup the distance z from a given 3D point *P(z)* results from the following equation:

$$z(d) = D\frac{f}{d} \qquad (1)$$

where $d = d_R - d_L$ denotes the disparity of the image of *P(z)* in both images, *f* denotes the focal length of the cameras and *D* is the lateral distance of both cameras. For calibration purposes and to adjust some deviation of the principle points between the cameras, as well as for correcting small disalignements between the cameras we apply an additional shift *d´*. To calibrate the setup some points with known distance z_0 have to be analyzed and the value of *d´* has to be adjusted so that the result is just the known distance z_0.

From the disparity list of feature pairs of the left and right image we compute a set of 3D points (denoted in relative sensor coordinates). In order to compute the best fitting plane through this set of points, we applied two different approaches:

- a least square plane fitting, which minimizes the z-distances to the plane, and
- a least square fitting method, which computes the plane normal from the eigenvector of the covariance matrix.

For our application, we found that both methods perform quite similar, with the first method being slightly faster.

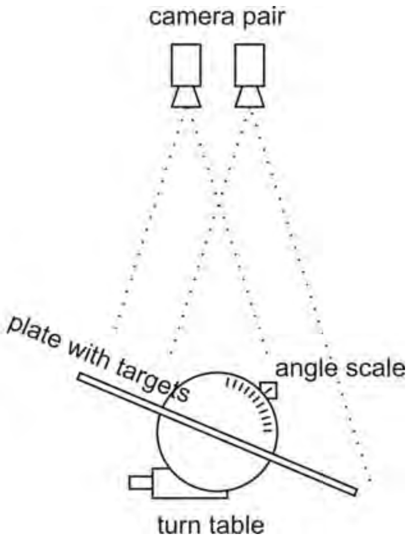

Figure 10: Experimental setup for measuring the tilt angle of an adjustable test plane.

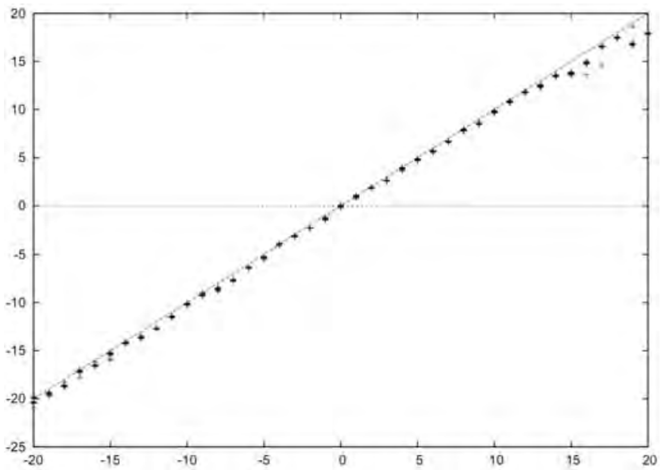

Figure 11: Measurement results with 19 randomly distributed targets on the plane. The x-axis denotes the reference tilt angle of the plane. The y-axis denotes the measured tilt angle of the resulting regression plane through all stereo-reconstructed 3D points. Accuracy is about 0.5 degree. This is even better than needed for helicopter landing.

To get a first impression about the achievable accuracy, we conducted an experiment with a white plate with dark markings on it mounted on a tilted platform with a highly adjustable angle and the cameras at a fixed distance. We recorded a set of measurements for predefined angles between −20° and +20° (Figure 10 and Figure 11). With an image resolution of 352 × 240 pixels and 19 randomly distributed dark targets on a white plane at a distance of 0.5 meter, our method provides an angular accuracy better than 0.5°. The maximal, mean and mean square error of the measurements against the exact angles are 2.36°, 0.5° and 0.48° respectively, the variance of the error is 0.24°. The accuracy of the measurements could be improved by using an appropriate camera calibration model. In the present state the method generates a small systematic error due to radial distortion. However, for most applications the method is already adequate ever since angles beyond 10° are of no practical importance for the intended helicopter application [23,24].

CONCEPT FOR HMI

The pilot's display for a graphic visualization of the outside 3D situation should be realized as simple as possible to avoid an increase of the pilot's workload. If objects would be presented with too much detail, the flood of information would become too high and the pilot would be distracted from his mission. As human factor studies for flight guidance have shown [25], displaying digital terrain grids as checkerboard pattern give the best results with respect to situational awareness. Following these studies, our first ideas for a 3D presentation could apply a concept of a "Lego brick scenery" (Figure 12). The elevation of each cell is represented as a tower. In case of a flat surface, this grid is colored like a checkerboard. The principle of alternating color changes is also applied in vertical direction and improves the height impression (3D-checkerboard). A standardized size of each cell with a fixed scale allows a simple visual interpretation. Of course, there are a lot of other options for visualization, such as contour lines, elevation coloring (Figure 13), or photo realistic. The best solution can be found by conducting part-task simulation trials, which are planned within our future research activities.

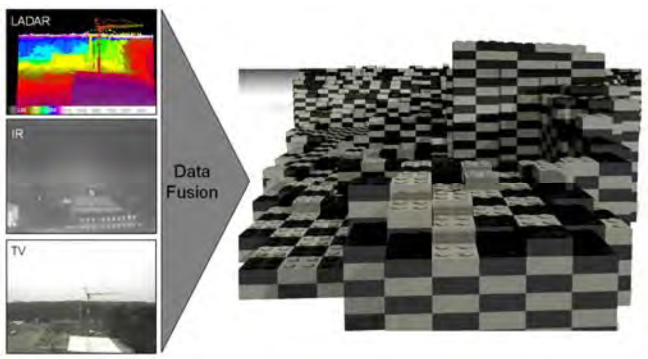

Figure 12: First approach of the representation of the data fusion result to present the outside situation to the pilot on the HMI.

Regarding the time aspect in order to realize the "see and remember" philosophy, the reliability (i.e., the age) of the sensed data can be visualized by changing the level of transparency of the Lego bricks. Another idea for visualization applies changing contrast values, which are depending on the brick's age. This kind of "fading out" effect can be interpreted by the pilot as follows: The older the sensor data the smaller the contrast.

Before starting the flight test campaign, the whole ALLFlight developing process is accompanied by intensive simulation trials in our ground based environment. This allows to detect any short comings in our software. The experimental setup regarding the system operation within the EC135 is emulated in the simulation environment on ground as well to help the flight test crew to learn about the operation details. Both, the flight test pilot and the flight test engineer are able to operate independently with the system by switching between the different graphic outputs of the SCC computer over a multi function display (Figure 4 and Figure 5).

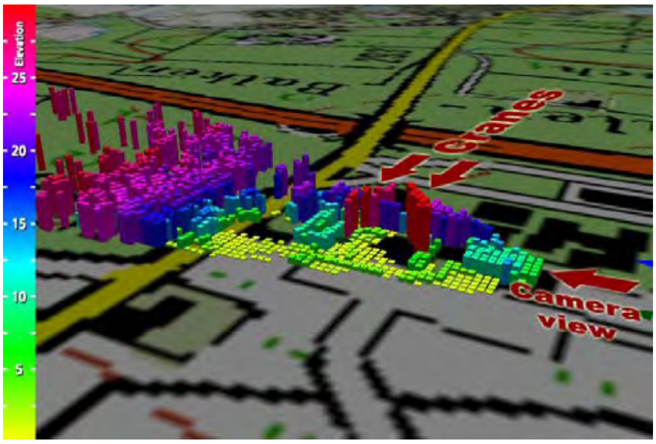

Figure 13: Elevation coded Hellas data

CONCLUSIONS

We described a general approach to support helicopter pilots during low level flight and landing under degraded visual environment. Although there are still requirements to develop new sensors with better performance, especially regarding weather and dust penetration, the sensor-suite of ALLFlight can be regarded as the best COTS technology which is currently available on the market. Following our own definition, the project delivers a contribution to the large solution to overcome the brownout problem. We described how to combine the sensor data with data from terrain models to generate a 3D description of the outside situation of the landing zone. We presented our ideas how to display this outside 3D situation to the pilot. Our concept integrates elements of the see and remember philosophy. This means that every observed single data element of the overall 3D data set is labeled with a certain quality value, i.e., a combination of the quality in the moment of acquisition and the time passed since that point of time. Due to that, every data element becomes devaluated over time, which can be visualized by a "fading out effect" within the pilots display.

Beside these more complex approaches, we also presented ideas how to aid the helicopter pilot during landing on sand or snow, by applying a simple and cheap stereo camera setup, which looks directly down to the ground through the hole in the "dusty donut". In principle, it works like a large-scale optical mouse system, which is able to measure the lateral drift of the helicopter. Additionally, the altitude above ground and the tilt angle of the landing zone is estimated. That type of system would allow to be installed in nearly every helicopter, because it does not require other cost intensive installations. With its own cheap attitude sensor it is not depending on a digital avionics interface of the helicopter. And with its own landing guidance display the system can help pilots directly while landing in brownout.

Presently we are still dealing with the test flight certification of some of the elements within our test equipment. Next steps in our project will be flight trials on our FHS (Eurocopter EC135), which are scheduled for end of 2010. We will then be able to record a quite large amount of data from all integrated sensors. This will allow further detailed sensor qualification and a stream-lining of data processing and data fusion algorithms, which will finally lead to advanced concepts for helicopter flight guidance displays.

ACKNOWLEDGMENTS

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- 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

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