ALLFlight - Helicopter Flight Trials under DVE conditions with an AI-130 mmW radar system

Thomas Lüken, Niklas Peinecke, Sven Schmerwitz, Hans-Ullrich Döhler
thomas.lueken@dlr.de, niklas.peinecke@dlr.de, sven.schmerwitz@dlr.de, ulli.doehler@dlr.de

Institute of Flight Guidance, German Aerospace Center, DLR
Lilienthalplatz 7, Germany, 38108 Braunschweig

Abstract

One of the biggest challenges for any kind of technology used for DVE landings and takeoffs is to provide an intuitive display in order to keep the workload low while providing all the necessary cues to perform the tasks safely and efficiently. The goal of displaying this information on a helmet mounted display is persued by the Institute of Flight Guidance within the scope of the project ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites). Mounting different complementary types of sensors like TV, Infrared (EVS-1000, Max-Viz, USA), Millimeter Wave (AI-130, ICx Radar Systems, Canada) and Ladar (HELLAS-W, EADS, Germany) with different characteristics onto DLR's research helicopter FHS (flying helicopter simulator) is the first step to gather information of the surrounding world. The data processing is designed and realized by a high performance sensor co-computer (SCC) cluster architecture, which is installed into the helicopter's experimental electronic cargo bay. The aim of generating a single comprehensive description of the current outside situation shall be achieved by a sophisticated data fusion concept. Data from the different sensors are collected in parallel and finally fed into that "scene description", which grows over time. The output of the project will result in a broader mission potential of the helicopter compared to the present situation, where commonly a mission cannot be performed or has to be canceled due to bad visual conditions.

In 2010 a DLR colleague spent a three month visiting period at the NRC in Canada. During that time our software could be adapted to an already existing hardware installation of the ICx AI-130 pencil-beam radar on the NRC's Bell 205 helicopter. Furthermore some additional special functions have been implemented on-site which allow a systematic evaluation of the ground/terrain scanning performance of the radar.

Accompanying the research activities in Canada, DLR has optimized the F3S simulation toolkit regarding the mmW radar simulation capability.

INTRODUCTION

In 2008 the German Aerospace Center (DLR) started the project "Assisted Low Level Flight and Landing on Unprepared Landing Sites" (ALLFlight) [1]. 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 unknown obstacles in a degraded visual environment. The objective of ALLFlight is to achieve a safe and effective 24h 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 to the pilot, reducing his workload and increasing his situational and mission awareness. Regarding the development of advanced

technical solutions to reduce the risk of landing in brownout, different research projects are currently in progress, e.g. PhLASH [2]-[3], LandSafeTM[4], Sandblaster[5].

During the forthcoming years it is planned that ALLFlight will record a comprehensive archive of data from its complementary sensors in several flight trials under different mission scenarios. Furthermore, it is planned to install a new full digital binocular head mounted display 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 brown-out or white-out situations, whenever raised dust or snow is blocking the direct visual ground perception by the pilot.

Due to delays concerning the certification of ALLFlight's hardware, DLR used the opportunity to work together with the National Research Council in Canada especially for adapting ALLFlight's software suite for acquiring and recording mmW radar data.

THE AI-130 RADAR SYSTEM

The mechanically gimbaled pencil beam AI-130 radar system operates at 35 GHz and should be able to penetrate dust in a brown-out situation [6]. The system itself covers a horizontal field of view of +/-90 degrees in azimuth, and +25/-85 degrees in elevation direction. The beam forming of the rather small aperture (280 mm) allows only a resolution of 2.4° x 1.8°. It picks up objects up to a range of 8 nautical miles but can be set to a range limitation of 1 nautical mile achieving 1.8 m range resolution. To reduce the scan-time, the antenna uses four vertically multiplexed beams with a vertical distance of 5.4°. The smallest scan pattern delivers a 30° by 21° field of view with 12 scan lines. The scan period is about

1.8 seconds for that smallest pattern, which delivers approximately 680 radar range measurements.

Figure 1: NRC's Bell 205 with the AI-130 radar

Figure 2: AI-130, HELLAS, FLIR and TV on DLR's research helicopter EC135

The physical installation of the radar is similar on both the NRC Bell 205 and the DLR EC 135 (Figure 1 and Figure 2). The interface software to the radar sensor contains special functions to control the radar and to acquire the data via a proprietary Ethernet protocol (by ICx), and is common to both installations. The control part of the interface, however, is unique to each aircraft. Functions for adjusting the field of view, the line of sight and the maximum range (from 1 to 8 nautical miles) are sent via Ethernet, while the state changes, status messages and an alive trigger are sent via a RS422 interface. On

the Bell 205 changing the operational state of the system between active, standby and off is set by a control box located in the center console. On the EC 135 this is also done by the software suite instead of the control box.

Each radar measurement consists of a byte array of 1024 range bins and its deflection direction denoted as azimuth and elevation angle. The entries of the range bins correspond to the number of received pulses within each range cell. The system delivers 375 measurements per second. This results in a data rate of approximately 400 kB/s.

SOFTWARE INTERFACE

For data acquisition, recording, real-time processing and data fusion, a specialized distributed software system was designed and implemented for the ALLFlight project, consisting of seven single-board computers which are interconnected via a high speed Gigabit-LAN. 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 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 GB Ethernet to a certain data fusion main board. 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 and the flight test engineer. The SCC-cluster (Sensor Co-Computer) receives flight status data (position, attitude, etc.) from helicopter's Data Management Computer (DMC). In addition, GPS time for sensor data synchronization, and keyboard commands from the control display unit are transferred.

This software suite was adapted for use on the Bell 205, allowing comparable flight tests on both helicopters. The same software can also be used for post flight evaluation at either DLR or NRC.

One of the central tasks of ALLFlight is to make the data from multiple sensors available to the pilot and sensor-fusion takes place at different stages of information processing. The processing pipe is realized as follows:

One requirement of the planned data fusion pipe is a given data base of elevation data, for example, from SRTM (Space-shuttle radar topography mission). Ground estimation is generated from sensor data using median filtering, if no ground data is available. Incoming data from radar and Ladar is time stamped, mapped to ground references and then compared to the existing ground information. Time stamping is essential to track whether the return is part of a moving obstacle, and also in cases where the data becomes outdated and is to be discarded later. Based on the classification algorithm, the measured points are either assigned to the ground, previously unrecognized buildings or other obstacles, or discarded as errors. Methods described in [7] can be used for the classification.

If returns are ground points the data is added to the ground information. For obstacle points it is decided based on history records if they belong to a moving (even flying) obstacle or if their position is fixed. Obstacle points are grouped into coherent objects described by their bounding boxes. In the case of a moving object a motion vector is estimated.

FLIGHT TEST OBSERVATION ON BELL 205

A portrait oriented display (with a 16x10 aspect ratio) is installed (see Figure 3) at the experimenter's seat on the right of the NRC Bell 205. The display is connected to the experimental computer system in the helicopter's cargo bay. Different information like a radar control display is

presented onto this display, e.g. present line of sight, previously scanned areas, general aircraft state information and the different operational modes of DLR's Sensor Co-Computer Software Suite (SCC suite). A perspective color-coded map view indicates covered areas. Below is a section with a top and side view of the radar's line of sight as well as general operation modes together with some basic aircraft state information. At the bottom the main screen of the SCC control suite is located (Figure 3).

Figure 3: Flight Test Display

For controlling purposes of the radar, some buttons, switches and dials are available (Figure 4). The operator can choose between different operational modes for steering the radar's line of sight, e.g., manual operation (LOS is oriented relatively to the longitudinal axis of the helicopter by azimuth and elevation offset via potentiometer), Auto-Heading (LOS is oriented relatively to the longitudinal axis also, but pitch and roll is compensated automatically), Auto-Track (similar to Auto-Heading but referenced to the present track) and Auto-Spot. If there is a designated target or landing spot this mode

Figure 4: Radar controls

is used to look at this spot whenever it is viewable by the radar.

FLIGHT TRIALS

Three flight tests with a total flight time of 3:40h have been conducted. Different scenarios have been selected: Terrain Mapping, Obstacle Acquisition and Dust Penetration in recirculating Sand.

Terrain Mapping

In the terrain mapping flight the general ability of the radar to collect consistent data without major gaps was tested. Two different experiments have been conducted: First to collect data with the highest possible resolution and second to study the loss of resolution and its impact on object discrimination.

Low Resolution: For the discrimination of objects the flights took place close to the Ottawa International Airport (CYOW) at an altitude of 1500ft above ground. The size of the mapped area was about 1 by 1 nautical mile.

High Resolution: Due to the required low flight path height above ground, it was not possible to record data close to built-up areas. Nonetheless the selected location had an overhead transmission line in the viewing field and varying topological plant cover. The field was mapped in narrow stripes by flying in opposing directions (Figure 5). The groundspeed was nearly constant at 30 knots and approximately 100 ft above ground. In the results this effect remains unnoticeable. The data is mostly without gaps and targets have been scanned multiple times. At some rare locations (mostly with man-made concrete surfaces) there were no returns received or false data recorded.

Figure 5: Terrain mapping layout for high resolution configuration

Obstacles Acquisition

The experiments for gathering data with known positions of moving objects were flown on the NRC Uplands research campus. Although there is a street with traffic present, low level flights are possible. In order to have an object with a known position a small pick-up truck was equipped with a DPGS system similar to the one installed onboard the NRC Bell 205. The layout of the trials (see Figure 6) was deliberately chosen to provide a challenging task of isolating the truck from the background. To the left of the picture there is a parking lot. The truck driver was briefed to start driving in certain situations or positions of the helicopter approaching the area. The surrounding has trees and buildings that obscure the truck from the radar scan. But there are also flat areas, where the truck should be detected easily. In order to be comparable to the mapping the truck was also viewed while standing aside of the street. The flight path was generated to be as well parallel as perpendicular to the movements of the truck.

Figure 6: Obstacle detection trials (red – trucks movement, white – helicopter trajectory)

Dust Penetration

The last flight was conducted inside a sandpit in close proximity to the airfield. The goal was to provoke realistic brown-out situations and obscure the radar's view with dust clouds. Four corner reflectors were placed across the surroundings. The truck with DGPS was placed close to a hollow as can be seen overlaid on the aerial photo in Figure 7. The helicopter circled around the target area to get a clear view of the pit. Thereafter the helicopter approached the pit in multiple low level flights from different headings. The helicopter hovered as long as possible at the end of each approach. The hollow held the dust cloud long enough to gather recordings with varying distances and obscuration levels.

Figure 7: Aerial view of sandpit with truck, camera and corner reflector locations marked

RESULTS OF FLIGHT TRIALS

Over all, it can be stated that terrain could be mapped but the radar was not optimized for usage at low altitudes for terrain mapping. As a result, the mapping is not reliable at all times. One should keep in mind that the radar was designed for detecting airborne targets and this was a novel application of this equipment.
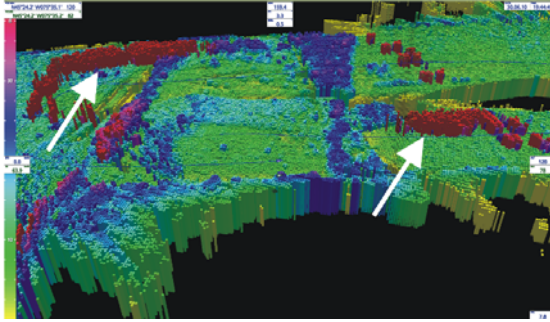

Figure 8: View of high resolution mapping results (long term fusion from collected data)

The complete data set collected from the flight over the deposit can be mapped into on sparse elevation mesh. The width of an elevation tile was set to 5x5 m. The result did not reflect the actual resolution of certain spots on the mesh, but in general showed the mean resolution gathered during the trial. Figure 8 shows the mesh-view in the sensor co-computer software and Figure 9 shows the Google Earth import with all tiles above the SRTM level. In both figures the poles from the power line show up clearly (Figure 8 – red, marked by a white arrow). There are data chunks that clearly arise from false measurements, as seen in the upper-left and lower right of the figures. The flight test team is unsure of the cause of the spurious radar returns. Nevertheless the figures show a comprehensible reproduction of the tree line in this area. The DEM reference shows the bare earth model. The color coded figure best shows the height of the trees above the bare earth model. The highest trees are located on the slopes of the deposit. On a closer look even the dirt roads become visible to some extent. Power cables are not picked up at all.

Figure 9: results imported into Google Earth

In order to illustrate the obstacle detection capability of the radar Figure 10 shows the appearance of the truck in the same kind of mesh as shown in the terrain mapping section. This figure does not provide as much precision or discrimination from the surface. The information provided gives coarse impression only. The circle around the four elevated mesh tiles represents the truck. In this data sequence the truck was parked next to Research Road at a designated position and fully exposed. The data with moving targets has not yet been processed with detection algorithms. The empirical examination of the data yields the assumption that objects of the size of a pick-up truck can be found in the data. Ongoing analysis is being performed to determine if the pick-up truck's motion may be detected.
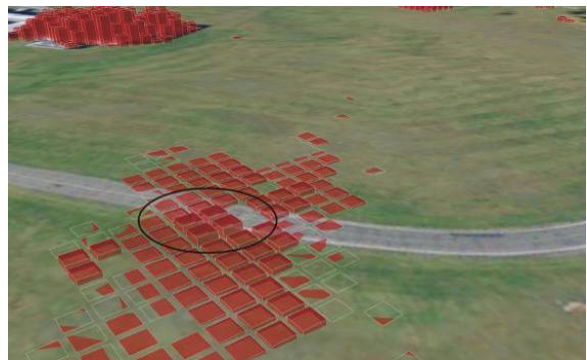

Figure 10: Obstacle detection trial: The elevated tiles (marked) next to the road represent the parked vehicle

Regarding the dust penetration, the onboard video data of this flight trial was damaged and could only be restored in parts. Still the video gives a good view of the recirculating clouds and the different levels of

obscuration. The video from the ground camera provides a good overview of each approach and provides additional cues for the analysis. The analysis is not yet completed but will be presented when completed.

MILLIMETER WAVE RADAR SIMULATION

Central to our approach of simulation in general are two aspects [8]-[10]:

1) We aim to provide real-time capabilities in the sense that the simulation can provide scanning data at the same rate as the original sensor.

2) The simulation delivers data in a scan pattern that is identical to the original device. The purpose is to have a simulation that can be used in place of real sensors in order to develop and test algorithms for post-processing and fusing sensor data.

2.5D radars, sometimes referred to as 3D radars, are a special case where the elevation angle is not lost but recorded with the data. This advantage is bought by a significant slower rate of operation and more moving mechanical parts compared to traditional 2D radar. 2.5D radar often has a very distinct scanning pattern generated by the complex mechanical movement of the antenna sweep. Therefore, the generated data is not delivered in image frames but rather as a sequence of packages representing measurements along a more or less deformed figure-eight or spiral path.

Simulating 2.5D radar becomes even more complex due to the figure-eight scan path of some systems. Instead of producing a fixed range-angle frame per period one needs to split the simulation in two processes. First, we generate a cube of 3D measurements inside computer memory making use of graphics hardware acceleration. In a second process the in-memory data is rescanned along a path that resembles the movement of the radar antenna. Both processes are executed in parallel making use of modern multi-core CPUs.

Radar geometry

The radar system mounted below the helicopter measures object distances by emitting radar pulses and evaluating the respective echoes. The typical radar imaging situation is depicted in Figure 11. Here φ is called azimuth angle and ψ is the elevation angle.
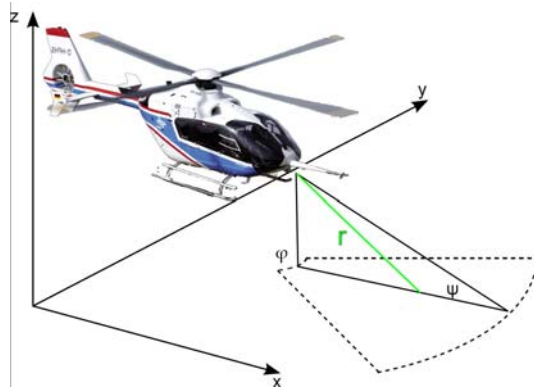

Figure 11: Typical Radar Imaging Situation

Note that on a traditional 2D radar screen the scene is projected to an (r, φ)-coordinate system, the range-angle view. Thus objects differing by angle ψ only are projected onto the same point and are indistinguishable in the range-angle view. In a 2.5D or 3D radar the elevation angle is not lost and can therefore be utilized for detection purposes. Thus, one "frame" of a 2.5D radar, that is, the results of a complete scan over all possible azimuth and elevation angles, is a three dimensional cube with dimensions azimuth angle, elevation angle and range.

The antenna scan window of the ICX radar-system has an elevation scan height of 21° and the azimuth width is adjustable between 30° and 180°. Its antenna gimbal scans with four beam positions aligned as shown in Figure 12.
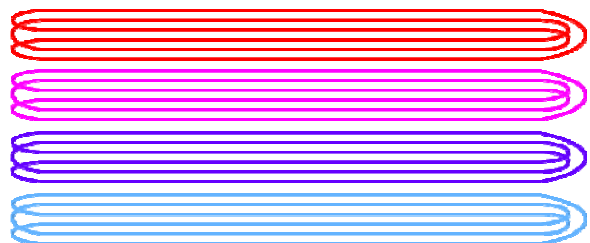

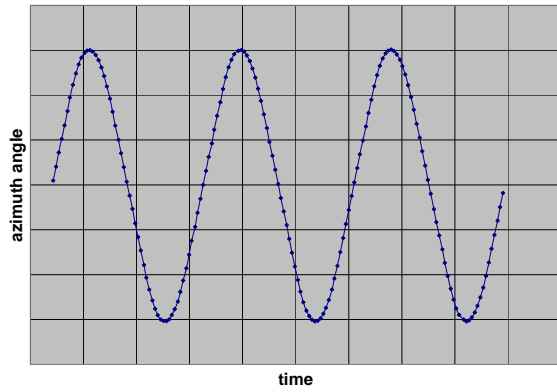**Figure 12: Scan Window of ICX Radar System with Four Beams**

Figure 13: **Real Horizontal Beam Deflection (AI-130)**

Figure 13 and Figure 14 show the measured horizontal and vertical beam deflection for beam 1.
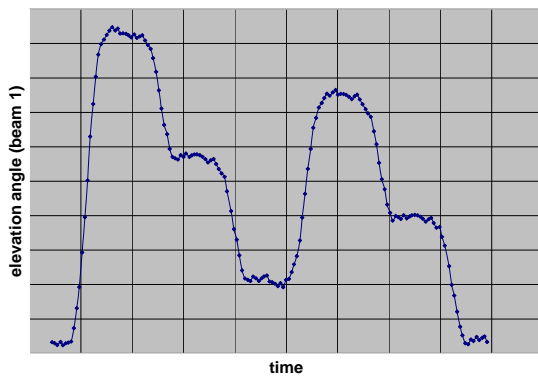

Figure 14: **Real Vertical Beam Deflection (AI-130)**

The change-over time between the particular elevation levels amounts to approximately 120 ms. A complete scan lasts about 1695 ms at an azimuth width of 30°. The distance between different elevation levels is at average 0.9°.
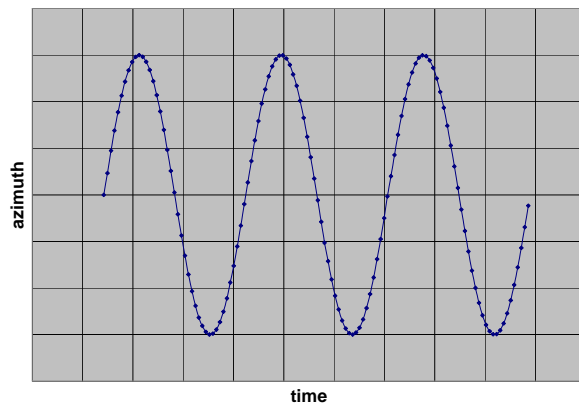

Figure 15: Simulated Horizontal Beam Deflection

In the simulation the deflection of azimuth angle is approximated with a sinus function. The elevation levels are simulated using constant values from the averaged measured real values (see Figure 15 and Figure 16).
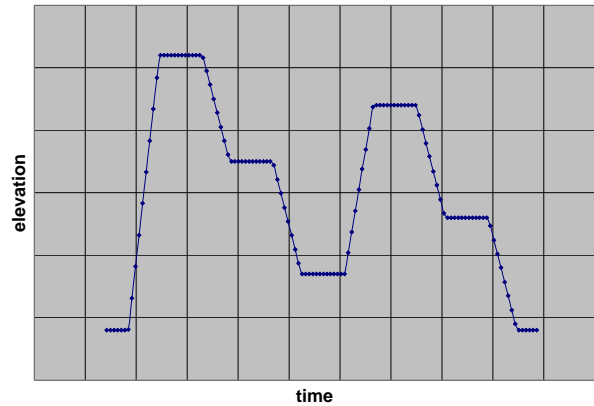

Figure 16: Simulated Vertical Beam Deflection

CONCLUSION AND OUTLOOK

The availability of flight test data is essential for both developing new data fusion algorithms and validating millimeter wave radar simulation data. This paper describes the bilateral benefits of a fruitful cooperation between DLR and NRC.

Regarding the AI-130 Millimeter Wave radar system characteristics, the gimbal mount offers the opportunity for enroute flight to observe the area with a wide field of view, as well as to follow all selected points of interest during the approach phase. Nevertheless at present, we are not able to make a conclusion concerning the usability of this kind of radar system under a degraded visual environment like brown-out. We need some more time to have a comprehensive review to the data, but the technique appears promising: A gimbal mounted millimeter wave pencil beam radar can supplement brown-out mitigation technologies for terrain mapping and static obstacle detection. Whether the technique is also useful to detect moving objects is still under investigation and part of the DLR project ALLFlight.

In addition, we will simulate the different scenarios in our F3S simulation environment to determine both a comparison between real and simulated mmW radar sensor data and to make a statement of the quality of the flight trial data.

REFERENCES

[1] Doehler, H.-U., Lueken, T., Lantzsch, R., "ALLFlight: a full scale enhanced and synthetic vision sensor suite for helicopter applications." in Enhanced and Synthetic Vision 2009, edited by Jeff J. Güell, Maarten Uijt de Haag, Proceedings of SPIE Vol. 7328 (2009).

[2] -, AFRL develops partial solution to helicopter brownout, www.eglin.af.mil/news/story.asp?id=123052402 (2007).

[3] -, Flying Blind in Iraq: U.S. Helicopters Navigate Real Desert Storms, www.popularmechanics.com/technology/military_law/4199189.html (2006).

[4] -, Rockwell Collins and OADS LandSafe™ system offers helicopter brownout solution, www.rockwellcollins.com/news/page10549.html (2008).

[5] Christina Martin, Aviation Aftermarket Defence Magazine, Mt. Kisco, New York (2007).

[6] Schmerwitz, S.; Doehler, H.-U.; Ellis, K. D. & Jennings, S., Millimeter-wave data acquisition for terrain mapping, obstacle detection and dust penetrating capability testing, Proceedings of SPIE, SPIE Defense, Security and Sensing, 2011, 8042B.

[7] Vandapel, N., Huber, D. F., Kapuria, A., Hebert, M., "Natural Terrain Classification using 3-D Ladar Data." ICRA 2004: 5117-5122 (2004).

[8] N. Peinecke, H.-U. Doehler, and B. R. Korn. Simulation of imaging radar using graphics hardware acceleration. In Enhanced and Synthetic Vision, volume 6957, page 695720, April 2008.

[9] N. Peinecke and E. Groll. Integration of a 2.5D radar simulation in a sensor simulation suite. Proceedings of 29th DASC, IEEE Press, Oct. 2010.

[10] Peinecke, Niklas und Groll, Ernst (2010) Real-time Simulation of a 2.5D Radar. Proceedings of ERF 2010. ONERA.