

MULTI SENSOR DATA ACQUISITION AND FUSION TO INCREASE SITUATION AWARENESS FOR A HELICOPTER PILOT

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Abstract

After a successful final demonstration of the pilot assistant system developed in the scope of the DLR project PAVE^[1] (Pilot Assistant in the Vicinity of Helipads) at the end of 2007, a new project called ALLFlight (Assisted Low Level Flight and Landing on Unprepared Landing Sites) has been started at the beginning of 2008. The main objective is to achieve a safe and effective 24h all weather operation capability of DLR's research helicopter EC-135 under difficult visual conditions, e.g. in brown-out or white-out situations. This will be realized by providing the pilot assistance with the help of advanced visual and tactile cueing and intelligent control augmentation. Reducing pilot's workload and increasing his situational and mission awareness are some more objectives within this project. ALLFlight deals with the integration of a full scale enhanced vision sensor suite onto DLR's research helicopter. This sensor suite consists of a wide set of imaging sensors, such as a colour TV camera, an un-cooled thermal infrared camera, an optical radar scanner and a mmW radar system. A compact high performance so-called sensor co-computer system (SCC) has been designed and realized to be able to process and display the huge incoming flood of data from these sensors. This computer system can easily be installed into the helicopter's experimental electronic cargo bay. A sophisticated, high performance, distributed data acquisition, recording, processing, and fusion software architecture has been developed and implemented during the first project year. This paper explains the architectural software concept and the implementation of the SCC. Some first data replays of gathered sensor data and some concepts of data fusion and display formats will be discussed. During the forthcoming years until 2012 the output will result into a broader mission potential of the helicopter compared to the present situation whenever a mission cannot be performed or has to be cancelled due to a degraded visual environment.

1. INTRODUCTION

For more than a decade, the DLR has conducted enhanced and synthetic vision research projects, mostly aiming for aviation application in the fixed wing field for flight phases near the ground, such as approach, landing and taxiing^{[2]-[4]}. The results of this research work, the built-up experimental equipment (simulators, flight-test equipment, sensor image processing, data fusion methods, display concepts, etc.), and the gathered expertise is now going to be transformed for helicopter application.

For fixed wing application enhanced vision (EV) systems - at least the infrared imaging systems - did already enter the phase of industrial line production. Together with the introduction of certified operational rules (e.g., the FAA enhanced flight vision system rule), EV for fixed wing aircraft landing under adverse weather on un-equipped airfields can be regarded technically as present state-of-the-art. Compared to this situation, EV systems for helicopter application are quite rare. Wherever EV concepts for helicopters have been proposed and experimentally realized, it has been mostly a simple adaptation of one single existing imaging or ranging sensor and its combination with

some direct visualization and display concept. As daily problems of helicopter operation, such as search and rescue (SAR) or helicopter emergency medical service (HEMS) and the need to operate under bad visual conditions show, visual assistance for the helicopter's pilot is even much more essential than for the fixed wing aircraft. This provides motivation enough to integrate the lessons learned into the ALLFlight project.

1.1. DLR Project ALLFlight

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 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, reducing his workload and increasing his situational and mission awareness.

During the forthcoming years until 2012 it is planned that the project 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 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 cover also the development and evaluation of new concepts to overcome the dangerous problems of the so-called brownout or whiteout situation, 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, whenever a mission cannot be performed or has to be cancelled due to bad visual conditions.

Over the last years, a wide experience of developing a helicopter pilot assistant system has been made within the project PAVE (Pilot Assistant in the Vicinity of Helipads, ^[1]). PAVE provided the system technology to support the pilot during approach and departure by improving situational awareness and offering human centered automation to one of the complex, work intensive and dangerous parts of helicopter missions. The motivation for this project was that helicopter landing sites differ widely and are often located near buildings or other obstacles. The helicopter pilot is reliant on visual cues during approach and landing to conduct the flight safely. Furthermore, helipads by their nature are situated close to populated noise sensitive areas. The development of noise abatement procedures to reduce the noise level on ground to a minimum was also an objective of this project^[10]. The developed prototype of a pilot assistant system addressed all of these problems and takes into account the full complexity of the pilot work during these flight phases. Therefore the system has integrated single solutions of dedicated problems and used all available information onboard, e.g., a terrain data base consisting of high resolution stereo camera images (HRSC). Nevertheless, it turned out that a combination of terrain database information and real-time sensor data is indispensable. This task will be one of the main challenges in ALLFlight.

1.2. Demonstrator platform

DLR's Flying Helicopter Simulator (FHS) - a modified Eurocopter EC135 - is the demonstrator platform on which all the sensors are installed (Fig. 1). Together with Eurocopter, a special equipment carrier beam has

been developed to install all sensors below the forward cross tube of the landing skid (Fig. 2).



Fig. 1. DLR's Flying Helicopter Simulator EC135



Fig. 2. Installation of the sensor-suite, first mounting onto EC135

Beside this, the helicopter was equipped with a higher landing skid to achieve the necessary ground clearance for the sensors in unprepared landing sites. All these sensors are connected to the experimental system of the FHS. The flight states (e.g. position, attitude, etc.) are provided from the DMC via ARINC-429. The sensors are supplied with 28V DC electrical power. The acquired data from the sensors are fed into the so-called sensor co-computer SCC. In cooperation with the German certification authorities a large flight test program was planned and will be conducted in summer/autumn 2009.

2. INTEGRATION OF SENSORS

The present ongoing development of enhanced vision systems in aviation is mainly triggered by the availability of imaging sensors, which are able to penetrate the atmosphere in darkness, as well as under bad weather situations. Up to now, IR camera technology (3-5 or 8-12 micron) seems to provide the most mature sensor for such applications. The high maturity of IR cameras is mainly a result of a long lasting development in numerous military applications, where IR technology was mainly used as a night vision sensor. The relatively low cost of IR cameras (especially for the modern un-cooled bolometer type) is their

second big advantage. But as shown in Fig. 3, millimeter waves (mmW) are able to penetrate the foggy atmosphere much better than IR radiation. Therefore, mmW radar systems (within three main windows at 35, 77, 94 GHz) are permanently under consideration to deliver the "better solution" for the "look through the fog" situation. Beside several ranging sensors for automotive applications, where distance measuring and automatic distance control

between following cars is the objective, there are only a few mmW radar systems for aviation on-board application on the market. Since 1995 the EADS (former DASA, Ulm, Germany) together with DLR developed and investigated a very promising prototype of a 35 GHz FMCW imaging radar system (HiVision, Fig. 4) [2]-[4]. Unfortunately, in 2005 the further development of this sensor was terminated by EADS.

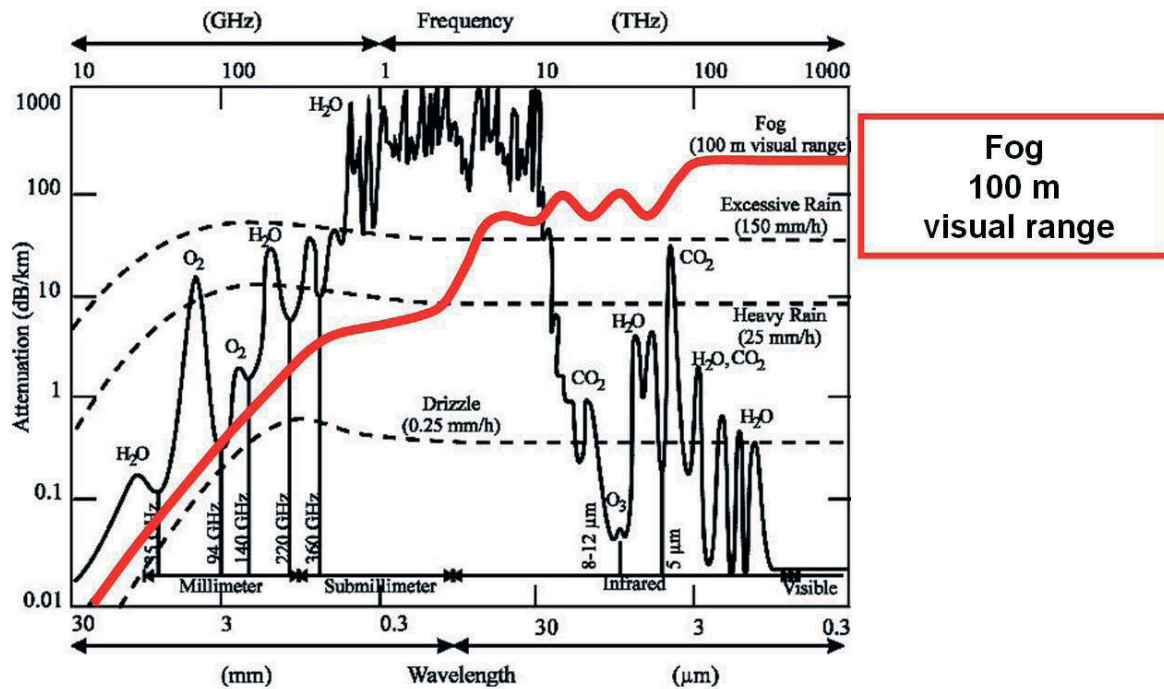


Fig. 3. Attenuation of the atmosphere (in dB/km) for different visual conditions is depending on wavelength (in mm or micron). Rule of thumb: the longer the wavelength – the lower the attenuation [5].

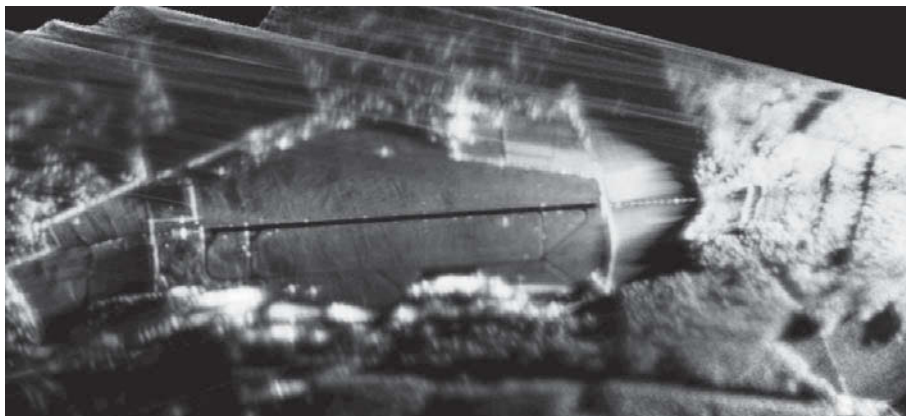


Fig. 4. Geo-referenced image of the HiVision radar (north up). The image is a fusion of more than hundred single images from an over-flight at airport Braunschweig (from east to west). The structure of the runway and taxiways, lamps, signs, and the fence around the airport are shown very crisp and clear. Within the large shadow area between the airport's east border and the contour of an easterly located forest, the single consecutive poles of the approach light system are clearly separated. The FMCW system applies not more than 1 Watt of transmission energy and delivers an image rate of 14 Hz [3].

The current challenge to help helicopter crews under very different degraded visual situations, like brownout, whiteout, darkness, fog and snow, will never be solved by installing one single sensor. For such a large bandwidth of different visual degradations, an “intelligent” combination of a set of different imaging sensors will be indispensable. The decision what sensor type and model should be integrated into the ALLFlight’s sensor suite was mainly based on availability, maturity, and price. We wanted to use commercial-of-the-shelf (COTS) products, which at most need some smaller special adaptations to be integrated into the project. The following chapter will describe the selected sensors in more detail.

2.1. Sensor selection

Two digital video cameras, one for looking outside, and another for looking “over the pilot’s shoulder” onto the helicopters cockpit displays are used as reference sensors. The recorded data of these cameras are used to document what the human eye can see. The third camera, the EVS-1000 from the US-company Max-Viz is a long wave infrared system as it is the present state-of-the art for aviation application. It is working in the thermal IR-range from 8 to 12 micron as an un-cooled bolometer system. This camera has a resolution of 320 x 240 pixels with an image rate of 30 Hz. It reaches a noise equivalent temperature difference (NETD) of about 0.2 K. The images from all three cameras are transmitted via RS-170 interface to the connected computers. A built-in window heating of the EVS-1000 casing can prevent condensing water on its window, whenever the surface temperature would fall below the air’s dew point.

Another state-of-the-art sensor is the HELLAS system from EADS, Friedrichshafen, Germany. It is an optical Lidar range scanner, which operates in the near range infrared region (1.5 micron). The German army and the German border control police apply this system as an obstacle warning system in parts of their helicopter fleet. The system is said to detect wires of 5 millimeters at a distance of more than 700 meters ^[6]. The maximum range of HELLAS is 1000 meter. The field of view is 31 x 32 degree. The system needs 500 ms for one scan. Flight status data are transferred via ARINC-429. Measured output data are transmitted via TCP/IP interface to the connected analysis computer.

Finally, the fourth sensor of ALLFlight is a radar system from ICx (former Amphitec, Canada) which works in the millimeter wave region. The system, formerly called OASYS, is now sold under the product name AI-130 as an obstacle warning system (OWS) for helicopter applications. It is a conventional pulse radar system with a frequency of 35 GHz and a beam width of about 1.8 degree. Its antenna (diameter 280 mm) is mounted onto a two-axis gimbal platform, which can produce a certain field of view by applying a certain type of scan pattern. For reducing the scan-time, the antenna uses four vertically multiplexed beams with a vertical distance of 5.4 degree. The smallest scan pattern delivers a FOV of 30 by 21 degree with 24 scan lines. The scan period is about 1.6 seconds for that smallest pattern, which delivers round about 400 radar range measurements. The maximum angular speed for each axis of the gimbal is about 150 degree per second. The system receives flight status data via ARINC-429. The system applies a special Ethernet-protocol for data output to the connected analysis computer.

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° x 32.0° scan frequency 2 Hz 95 x 200 x 64 bit pixels range res. 0.6 m max. range 1000 m detect. range 600 m (10mm) min. range 20 m size 320 x 318 x 500 mm weight approx. 28 kg 140 W special software LAN-Interface	8-12 micron 320 x 240 pixels NETD 0.2 K FOV 53° x 40° hermetically sealed DO160 E qualified case 70 x 172 mm weight 1.3 kg 10 W camera 40 W heating RS-170 Interface	visible (B/W or color) 768 x 494 pixels sensitivity 0.1 lux FOV 53° x 40° 41 x 41 x 56 mm. case 70 x 172 mm 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° x 1.8° range 1...8 NM range res. 1.8 m scan time 0.8 sec for 30° x 21° terrain scanning mode size 390 x 425 x 570 mm weight approx. 25 kg 125 W special software LAN-Interface

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

3. SENSOR CO-COMPUTER

A compact high performance so-called sensor co-computer system (SCC) has been designed and realized to be able to process and display the huge incoming flood of data from these sensors. This computer system can easily be installed into the helicopter's experimental electronic cargo bay.

3.1. Hardware Architecture

Real-time processing of both, acquisition of sensor data, as well as the data fusion process, makes high demands on computing power of the system to be used. For this reason, a cluster architecture is selected, consisting of 7 single board computers (Fig. 5). Each

board is equipped with a 2.4 GHz Dual-core Intel CPU with 4 Gbyte of RAM. The seven boards are interconnected via Gigabit Ethernet network. Each of the main boards is equipped with 4 independent network adapters and an 8 Gigabyte internal flash memory where the Windows XP operating system is installed. Each of the decoupled LAN connections is reserved for one special assigned task, e.g. transmitting the data of the pre-processing results. The sensor data itself are stored on an external vibration resistant hard disk with a capacity of 200 Gigabytes reserved for each main board which can easily be replaced by spare units directly after a flight campaign.

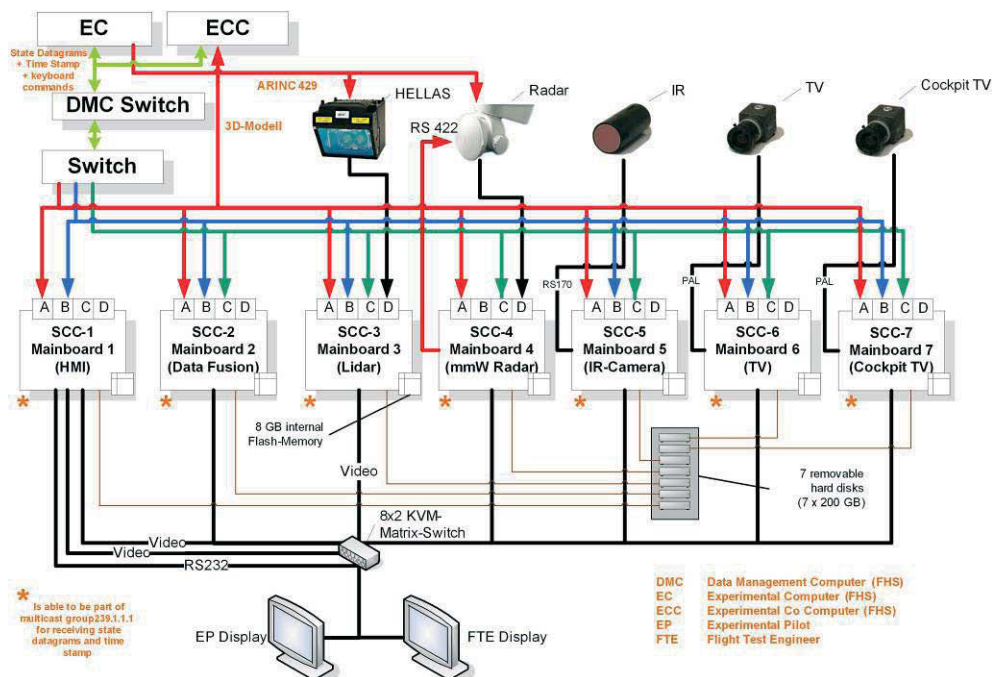


Fig. 5: The cluster architecture of the sensor co-computer (SCC) is constructed of seven main-boards (named SCC-1 to SCC-7).

The philosophy of this architecture is that for each sensor one main board is available for data acquisition, recording and pre-processing. The data volume of the result of the pre-processing is reduced after applying image processing algorithms and will be sent over a Gigabit connection to the data fusion main board (main board 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 will then serve as the basis for following guidance related processes, e.g., the trajectory planning module, or will be presented directly on the HMI displays of the experimental pilot (EP) and the flight test engineer (FTE).

The SCC also receives the state datagrams (position, attitude, etc.) of the helicopter from the Data Management Computer (DMC) with a frequency of 20 Hz. In addition, both a reference time-stamp derived from a GPS clock and keyboard commands from the control display unit are also transferred from the DMC to the SCC. The time stamp is used for time synchronization of sensor data acquired from different sensors (Chapter 3.2) and the keyboard command will be used for operating with the ALLflight system and for activating menu functions of the HMI.

3.2. Software Architecture

For acquisition, recording, analysis and visualization of sensor data a specialized distributed software system was designed and implemented. This software system, which runs under *Microsoft XP* operating system, was developed in *C/C++* applying *Microsoft Visual Studio 2005* development system. Co-ordination within the programmer community was assured by applying a subversion system (*SVN, Tortoise*).

Interface software to the sensors

All video input connections to “camera-like” sensors (TV-, IR-, B/W-, color-cameras, etc.) in the project are realized via applying a “hand full” of interface functions which are based on the *Microsoft DirectShow* concept ^[7]. Due to missing experience within our working group on the concept of *DirectShow*, there had been some criticism about this approach at the beginning. But in the end, the realized functionality offers the advantage that without any need of special software (e.g. camera-dependent SDK) nearly every standard video camera can easily be connected to the system. The only requirement is a *DirectShow* interface driver (*WDM* driver) for the applied camera. Presently all three cameras, the B/W-, IR-, and the color-video-camera of the ALLflight sensor-suite are connected via RS-170 interface. Because the IR-camera (EVS-1000, Max-Viz) comes with such an analog video interface, we decided to install the RS-170 interface for all three camera-connecting main-boards (SCC-5 – SCC-7, see Fig. 5). Again, future changes to cameras with other interfaces (e.g. USB, Firewire) would not need any further programming effort.

The interface software to the Lidar sensor (HELLAS, EADS) contains special functions to initialize the Ethernet connection (via TCP/IP), and to acquire data from the system. Each frame of Lidar data consists of max. 95 x 200 data points, with each of them being referred to its geographical location, denoted as latitude, longitude, altitude, and a timestamp. The frame cycle is 500 ms. Due to the fact that the system leaves out points with “no reflection”, the data rate depends on the image content. The maximum data rate of the system is about 590 kB/s.

The interface software to the Radar sensor (AI-130, ICx) contains special functions to control the radar and to acquire the data via a proprietary Ethernet protocol (from ICx). The control part of the interface comprises functions for adjusting the field of view (FOV), the line of sight (LOS), the maximum range (from 1 to 8 nautical miles) and for changing the operational state of the system between active and standby. Each acquired 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 275 measurements per second. This results in a data rate of approx. 280 kB/s.

Time stamping and flight status

A general requirement for the software design of a distributed data acquisition network concerns the availability of accurate time-stamping functions. From the beginning, we planned to apply some network time protocol (NTP) to synchronize the clocks on all seven computers within our cluster. But performance evaluations on that approach showed that the required time accuracy would not be reached on a WIN32 system. Instead we decided to realize the synchronization between all boards via transmitting time-stamp data from the experimental navigation system of the helicopter. Together with other flight status data, like attitude angles, position, speeds etc., the time-stamp is transferred as part of a UDP-datagram from the data management computer (DMC). Within the DMC this time-stamp is synchronized to the “pulse per second signal” (PPS) of the GPS signal. The datagrams are transferred to each main-board as a UDP multi-cast message with a rate of 20 Hz. Between two transmissions, local time-stamps on each main-board are extrapolated using the so-called WIN32 “multimedia timer” functions, which deliver a clock resolution of one millisecond. As evaluations showed, the applied method achieves an overall synchronization error below +/- 8 milliseconds between any two computers within our cluster. Regarding the fastest sensor rate of 30 Hz (33 ms) that amount of timing un-accuracy is regarded to be acceptable. The time-stamps are coded as double precision values (REAL64) representing seconds since 01. January 1970, 00.00 hours.

Data exchange and recording

Exchange of data between different processes which are running in parallel on the same main-board is realized via a shared memory concept. There is one acquisition process for each sensor data stream (“scc_acquire.exe”). This process enters the acquired sensor data into a certain part of a ring buffer, which is located within the shared memory. Other processes for recording (“scc_record.exe”) or pre-processing (“scc_prepro.exe”) are connected to that shared memory and get their input data out of the ring buffer (Fig. 6). The recording of data is done on each main-board onto a SATA-mounted shock-rugged hard-disk with a capacity of 200 GByte. Between adjacent flight trials this hard-disk can be replaced quickly. The frame based file format is decomposed into two files per recording track. Each recording track consists of a so-called sensor-look-up file (SLU-file) which contains

header information about the sensor data stream and an index table with time-stamps and a direct link (file-offset) into the second file. The second file, the sensor data (SDA-File), is a binary copy of input stream from the sensor. The file names are generated automatically from date and time at start of recording.

Data exchange between different computers of the network is realized via UDP connection from board to board ("scc_udp_write" and "scc_udp_read").

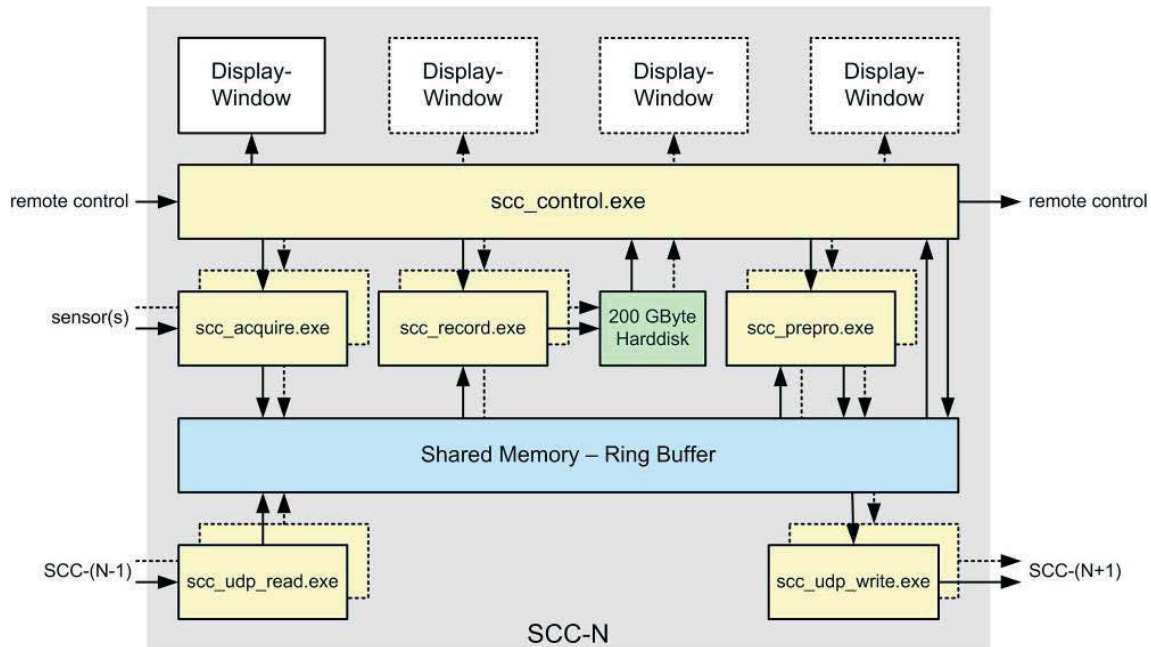


Fig. 6. Software architecture. The example shows the main-board SCC-N, on which two sensor signals are acquired and recorded on hard-disk (green). All parallel running programs (yellow) are controlled via scc_control.exe. Data exchange on the same board is realized via shared memory (blue). Data exchange with neighboring boards is done via UDP-transmissions.

Putting things together

As parent control process there is one process called "scc_control.exe" running on each main-board. This process, which is parameterized via a certain set-up file, is doing all the work for starting, monitoring and termination of all other processes on the same board. Another task of "scc_control.exe" is to generate display windows for viewing into the acquired sensed data or to show the helicopters position and attitude on a digital topographic and/or altitude map. All graphics programming is realized by applying the OpenGL graphics standard. Presently, "scc_control.exe" has a certain type of an "engineering GUI", including several buttons, sliders, and keyboard short-cuts. This GUI is mainly used for program development, sensor evaluation and data replay. On-board the helicopter, where the area of the two built-in 10 inch displays is unfortunately restricted to 800 x 600 pixels, the GUI will be minimized while its button-functions will be driven by built-in display function keys (F1 ... F12) which are located on both sides of the display frame. The function key commands are transferred to each main-

board as a part of the flight status vector (generated by DMC).

Furthermore there is a keyboard video mouse (KVM) matrix switch (2x8) between the SCC-N output and the two helicopter displays (see Fig. 5). This matrix switch is managed via RS-232 commands, which are generated with a program, running on SCC-1 ("scc_matrix_switch.exe"). Via a special UDP-protocol this program can receive requests for changing the matrix state from every computer within the SCC-cluster. Via UDP-multicast datagrams it also informs "scc_control.exe" on each board about the state of the matrix-switch.

Finally, there is one specialized instance of "scc_control.exe" running in the SCC-cluster (usually on SCC-2). This instance is engaged as a "master control process" (via a special flag within the set-up-file), which is able to co-ordinate the other "scc_control.exe" instances on the other boards. Data from all sensors are delivered to SCC-2, so that an overall fusion process can deal with all input data. Based on this modular software structure, the further development of fusion methods and algorithms will be

the most important topics within the forth-coming next project years.

4. FIRST EXPERIMENTAL RESULTS

For getting a first impression on what will be delivered from the different sensors, we installed the cameras (visual and IR) and the Lidar system on-top of a 24 meter high telemetry-tower of the DLR's site at the Braunschweig airport. The system was looking down onto a construction site of a new hangar. The scene consisted of several static objects, like fences, building parts, walls, floors, and ceilings. And there were also

several moving objects in the scene like motor trucks, heavy lorries, and two rotating cranes. The data of the Lidar system was visualized as overlay onto a topographic map-display. The altitude difference between the Lidar data and the map data is shown in special color-coded manner. (Fig. 7). This experiment showed that the software for time-stamped acquisition, recording and replay of data does perform as planned.



Fig. 7. View from a telemetry tower at Braunschweig airport onto a construction site of a new hangar. Left: color camera, center: IR camera, right: Lidar data (HELLAS). The Lidar data are overlaid onto a map display of the site's location. Certain height differences between Lidar measurements and terrain altitude are coded with different colors.

5. SUMMARY

The work during the first project year of ALLflight was mainly concentrating on the mechanical and electrical integration of the sensor hardware into the real helicopter's environment and its simulated counterparts (ground based simulation). The second important part of work was dealing with the development of a scaleable hardware (SCC) and software design for acquisition, preprocessing, and recording of data. As the first recordings of data did show, this design fulfills its requirements.

We designed and implemented a modular software architecture, which allows to draw-out as much of computing performance of a present state-of-the-art computer cluster. This architecture can be adapted quickly to different requirements and supports extensions with one or even several additional sensor(s). The implemented generic data structures for recording (and replay) will help to built-up a quite huge sensor data archive from numerous flight trials, which are planned for the remaining three project years.

The next important step in this project will be the "ALLflight maiden flight trials" with our EC135 helicopter which are scheduled for mid of 2009.

Further methodological development will mainly concern methods for sensor data analysis and for data fusion – fusion of data from complementary sensors and fusion between digital terrain data and sensor information^[8]. Finally, all work within this project is dedicated to the goal to generate as much knowledge about the helicopter's "outside situation", to be used for supporting the automated trajectory planning process. Our already build-up sensor simulation tools (Lidar and mmW radar^[9]), which are presently integrated into the ground-simulators, will also contribute a relevant part to reach that challenging goal.

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- "Leistungserweiterung FHS".

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