HELICOPTER ROTORSTRIKE ALERTING SYSTEM

Tim Waanders, Airbus Helicopters Germany, Donauwörth, Germany
Richard Scheiblhofer, Airbus Helicopters Germany, Donauwörth, Germany
Qi Qian, Airbus Helicopters Germany, Donauwörth, Germany
Benno van Noort, Airbus Helicopters Germany, Donauwörth, Germany
Volker Ziegler, Airbus Group Innovations, Munich, Germany
Falk Schubert, Airbus Group Innovations, Munich, Germany
Richard Koerber, Astyx GmbH, Munich, Germany

Abstract

This paper reports on the development of a miniaturized and low-cost, near-field obstacle warning system for helicopters based on mass-market automotive radar technology. This so-called Rotorstrike Alerting System (RSAS) supports the flight crew in detecting obstacles in the direct vicinity of the helicopter (H/C) to avoid main and tail rotor strike accidents. The system is designed as a flight aid to enhance situational awareness and flight safety when manoeuvring in ground or obstacle vicinity possibly under reduced visibility conditions. The activities described herein were performed in the frame of a research project partially funded by the German Federal Ministry for Economic Affairs and Energy (BMWi). Between December 2012 and June 2014 the system concept was elaborated and a prototype system was developed and successfully tested both in ground and flight tests. This paper describes the system concept, its design considerations and it presents first test results.

1. INTRODUCTION

The helicopter's unique hover and vertical take-off/landing capabilities make it well suited for transport in difficult access areas, winching operations and take-off and landing at unprepared sites. However, the technical complexity of the helicopter and the nature of helicopter operations make it generally more demanding than fixed wing operations. In spite of the high safety standards and pro-active safety culture, helicopter accident rates have remained high and trends have not shown significant reduction over the last decades.

Especially, when operating in ground vicinity, in high crew workload situations and potentially under degraded visual conditions, there is an imminent danger of collision with all kinds of obstacles, which continues to be among the top causes of civil helicopter accidents. Although the higher number of fatalities can be attributed to Controlled Flight Into Terrain (CFIT) accidents, collisions with obstacles during landing and take-off are the number one cause for commercial air transport accidents in general [1].

For operators performing their job under these conditions, such as Helicopter Emergency Medical Services (HEMS), Search And Rescue (SAR) operators and law enforcement services, these challenges are part of their daily routine. With additional stress related to the urgency of the situation or deteriorating weather conditions, safety is compromised even further.

These statistics support the belief that new ways to assist the flight crews in these conditions should be developed. In today's avionic systems various passive solutions are readily available to support the flight crews in the obstacle and terrain detection task. Passive, database-based systems have become widely accepted such as Helicopter Terrain Awareness and Warning Systems (HTAWS) and Synthetic Vision Systems (SVS). With approved terrain and obstacle database information these systems increase terrain awareness and have proven to be valuable in preventing CFIT accidents. The availability and quality of data (e.g. completeness, resolution) are however not such that these systems can provide adequate support during low level operations.

To also warn for smaller and uncharted obstacles an on-board sensing system is required. Only a few sensor systems are deployed today using different sensing technologies. The majority of systems, however, come at a high cost often combined with a large physical size and power consumption. These systems are therefore mainly deployed on para-public or military platforms. The near-field obstacle detection system described herein aims at reducing the sensor Size, Weight, and Power (SWAP) and system cost by adopting mass-market automotive radar technology.

2. SITA RESEARCH PROJECT

In 2010, the former Eurocopter Germany GmbH initiated a research project under the name of “SITA” - SITuational Awareness [2]. The objective of this research project was to develop a near-field obstacle warning system affordable for civil operators. The novel aspect in this project is the re-use of automotive radar technology being developed for different automotive safety and driver assistance functions. The dual-use of this technology presents itself by having similar stringent requirements on size, weight, power and cost. The SITA project was supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) in the frame of the Aeronautical Research Programme IV (LuFo IV). In the SITA consortium various partners from the German aerospace and automotive industry contributed with their specific knowledge and expertise.

The initial objective in the SITA project was to develop a sensor system that would cover the complete lower hemisphere and detect obstacles up to distances of 250m. In the first phase of the project (2010-2012), the aim was set to develop a system concept, elaborate on system architecture and to validate detection performance of the automotive radar technology. For this purpose, a first prototype sensor was realized by the adaptation of an automotive radar sensor and tested extensively in both ground and flight tests [3,4]. In these tests, basic detection performance was found to be very promising and on this basis the project was granted a prolongation for a second phase.

In this second phase of the SITA project (2012-2014), the focus was placed on the further development of the sensor technology, miniaturization of the sensor system and realization of a complete sensor array. By redesigning the antenna layout the radar frontend could be significantly reduced in size. Furthermore, optimization of signal processing and corresponding hardware components resulted in an optimized packaging of the sensor hardware. The end result was a sensor array composed of 3x3 matrix-arrangement of identical radar sensors providing a large Field-of-View (FoV) sensor system (Figure 1). This sensor array was eventually tested in various laboratory and ground tests.

During the course of this prolongation it became evident that despite all proposed optimizations the size, weight and complexity of a system covering the complete lower hemisphere would be substantial. In this phase of the project it was decided to focus efforts on a similar but technically and commercially more viable concept in which fewer but less complex sensors cover a smaller FoV.

Fig. 1. SITA Radar sensor-array prototype

Instead of having the ambitious target to cover the complete lower hemisphere, in this new concept the sensor coverage and thereby the alerting envelope is reduced to a volume covering H/C main and tail rotor. Obviously the operational benefit of this solution is less than originally anticipated in the SITA project but it is deemed to have better chances of realization. In the final year of the SITA project the efforts were therefore focused on developing and evaluation of this new, so called Rotorstrike Alerting System (RSAS) concept.

3. RSAS SYSTEM DESIGN

3.1. Intended Function

The RSAS system intends to enhance flight safety by supporting the flight crew in detecting all kinds of obstacles in the direct vicinity and flight path of the main and tail rotor during low speed manoeuvring in ground or obstacle vicinity. The system is defined to be a flight aid supporting the flight crew in the obstacle detection task meaning the indications of the system are to be interpreted as advisories. This implies that a pilot action is only to be initiated after visual confirmation of the indication provided by the RSAS system. In consequence, the system is to be certified as a flight aid for operations under Visual Flight Rules (VFR).

The added value of the RSAS system is that it increases situational awareness and the probability of detection of all kinds of obstacles that are a potential hazard for main or tail rotor strike. The intended function of the RSAS system is analogue to the parking aid systems in a car whereas for H/C operations there is a third dimension to be taken into account. Figure 2 illustrates the intended function of the RSAS concept.

Fig. 2. Illustration of RSAS intended function

The following operational use cases are identified for the RSAS system:

- Approach, landing, take-off at off-airfield locations; e.g. HEMS landing on a highway to provide assistance during a car accident
- Hover operations; e.g. sling load or hoisting operations close to obstacles
- Manoeuvring in ground vicinity; e.g. air or ground taxiing
- Operations in degraded visual environments; e.g. brownout or whiteout conditions during landing

These use cases are typically characterized by flying at low speeds in ground and obstacle proximity. Crew workload is typically high when trying to control and navigate the H/C while at the same time scanning for obstacles to maintain sufficient clearance. The flight crew is head-up, eyes-out and pilot attentiveness is high. Even for smaller, civil aircraft, modern flight control systems and autopilots can provide support by alleviating the pilot workload by automating specific control tasks (e.g. hover hold).

From these use cases and characteristics a RSAS concept of operation was defined from which key design requirements were derived. The typical low airspeed together with a prescribed warning time, effectively determines the required detection range of the sensor system. To accommodate for the various degrees of freedom and procedures in these flight phases, the sensor system shall detect obstacles approaching the helicopter from every direction in azimuth. The coverage in elevation shall be adapted to match the typical vertical speeds in this regime. The Human Machine Interface (HMI) shall be intuitive not to increase pilot workload and shall maximize head-up, eyes-out time during these critical phases of flight.

3.2. System Requirements

From the intended function and the different use cases described above the following top level system requirements have been derived:

- Affordability: the system shall be affordable for civil operators.
- Coverage: 360° sensor coverage in azimuth, >10° sensor coverage in elevation.
- Detection range: detection range of at least 50m from rotor blade tip to allow for minimum 5 seconds pre-warning time for groundspeeds up to 20kts.
- Obstacle types: detection of all obstacles that are a threat to H/C operations including most notably suspended wires.
- Detection performance: high probability of detection to minimize nuisance warnings. For an advisory system this is decisive for the acceptance by the flight crew.
- Installation constraints; low SWAP to enable installation on small to medium sized H/C.
- All weather obstacle detection capability.

3.3. System Architecture

The intended function of the RSAS system can be broken down into three main sub-functions (Figure 3).

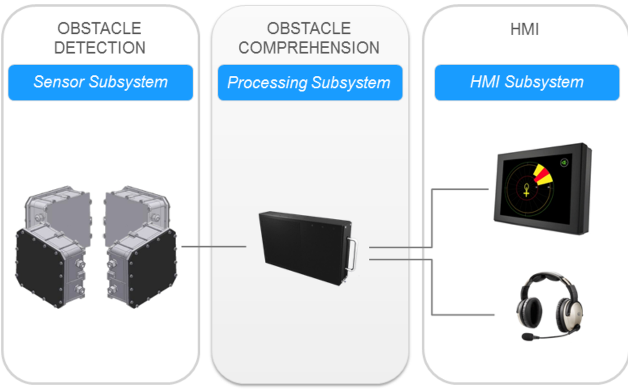

Fig. 3. RSAS functional breakdown and system design

- **Obstacle Detection:** perception of the environment around the H/C by using a distributed sensor system
- **Obstacle Comprehension:** merging and

processing of multi-sensor data and evaluation of threat potential of detected obstacles.

- **HMI:** interface to the flight crew for providing both aural and visual indications and system command and control

The allocation of functions to system components as illustrated in Figure 3 is merely an example for a typical stand-alone or retrofit solution where the RSAS system is hosted on dedicated equipment (processing unit, display etc.). If on-board avionics permit, it has obvious advantages to host these RSAS (sub-) functions on existing equipment thereby reducing the number of components to be installed and simplifying the physical integration of the system. In the current research project the stand-alone configuration was realized for convenience.

3.3.1. Obstacle Detection Function

The obstacle detection sub-function of the RSAS system performs the actual perception of the environment by using radar technology. The system uses a distributed arrangement of small radar sensors to illuminate the scenery around the H/C and to extract information from the electromagnetic energy backscattered from the scene. The RSAS sensors use a Frequency Modulated Continuous Wave (FMCW) principle of operation in W-Band (76GHz) for a concurrent measurement of obstacle distance and relative velocity.

The RSAS sensors used in this research project are off-the-shelf electronically steerable sensors developed for automotive applications. These sensors are already highly optimized in terms of cost and SWAP and have a favourable detection performance under adverse weather conditions.

The radar sensor is transmitting a fast ramp FMCW signal with a single microstrip patch-antenna. It is receiving the signal with an array of patch-antenna columns, each equipped with an individual receiver. This allows for digital beamforming by the sensor's signal processing unit by which 11 beams (plus two auxiliary) are synthesized within the sensor FoV. Each beam is represented by a range-doppler-matrix, which contains information about amplitude, range and velocity for each pixel. Using monopulse techniques between neighbouring beams, the angular measurement accuracy is significantly improved. Figure 4 shows the prototype RSAS sensor and its main characteristics.

The RSAS sensor is capable to output the range-doppler matrices of all beams at a moderate update rate or alternatively an already pre-processed list of object hypotheses, the co-called pre-target list. The pre-targets are pre-processed objects detected by an ordered statistic constant false alarm rate (CFAR) receiver. These pre-targets also include information on amplitude, relative velocity, radial distance and azimuth angle.

Operating Freq	76 GHz
Tx Power	20mW
FoV Elevation	10°
FoV Azimuth	100°
Resolution Az.	<10°
Nr. of beams	11
Range	80 m
Range resolution	10 cm
Size (WxHxD)	114x102x38mm
Weight	900gr

Fig. 4. RSAS sensor characteristics

Although the output of range-doppler matrices was used for testing and evaluation purposes, only the output of the pre-target list was considered for the sensor system in order to meet update rate and latency requirements. Finally, the RSAS sensor outputs the information over an Ethernet interface to the obstacle comprehension sub-function for further processing.

3.3.2. Obstacle Comprehension Function

The comprehension function is a data processing function, in which digital radar output is processed to synthesize the obstacle environment. The processing can be subdivided in the following tasks:

- Combination of multi-sensor data
- Filtering of artefacts
- Tracking of pre-targets

In the first step, the data from all sensors are combined into a single presentation of the obstacle environment. Based on the known sensor positions and orientations a detection map is constructed in which all pre-targets are plotted.

In the subsequent step, the detections are filtered for known artefacts. These artefacts include detections of H/C structural components such as the tail boom, tail rotor and rotor blades. For the sake of simplicity, these artefacts were filtered out based on their known location.

For the resulting list of filtered pre-targets a tracking function is then initiated. The aim of this tracking function is to increase the probability of detection and to reduce the false alarm rate. Inherently to the physical properties of radar, the characteristics of a radar reflection can vary significantly due to changes in local geometry between transmitter and receiver or artefacts such side lobe detections or multi-path effects. All this makes the radar image from a moving platform in a complex obstacle environment relatively unstable over time.

Tracking algorithms can mitigate these effects by checking for the plausibility of radar characteristics of pre-targets over consecutive scans. Either an obstacle is not detected for a short period of time (false-negative) and can be 'extrapolated' from the detection history or an artefact is erroneously detected as an obstacle (false positive) and can be discarded by a tracking its properties over time.

For this purpose a tracking is set up based on the pre-target position. For every pre-target a track is initiated and updated over consecutive scans. Different temporal statistics and filters are used to check for consistency and plausibility. A linear model is used to extrapolate the target positions taking into account the ego-motion of the platform. Data on the H/C's ego-motion are provided by a separate Attitude and Heading Reference System (AHRS).

The outcome of the tracking function is a list of targets with a higher level of confidence of being a real obstacle. This list of targets is used in the consecutive step for the evaluation of the threat level and generation of the associated alerts.

3.3.3. Human Machine Interface (HMI)

The function of the RSAS HMI is to communicate to the flight crew information on the presence of obstacles. The challenge for this is to bring across this information under conditions in which both, crew workload and the amount of information to be cognitively processed by the crew, are already high. The objective therefore is to provide the right information at the right time without overloading the sensory channels of the flight crew.

The HMI sub-function can be subdivided in the following tasks:

- Evaluation of threat level
- Generation of visual alerts
- Generation of aural alerts

Contrary to other obstacle warning systems such as the HTAWS system in which the alerting is based on a time-to-collision (i.e. speed dependent), the RSAS alerting concept is based on the distance to an obstacle. The concept is very similar to the concept commonly used in automotive parking aid systems. When flying at low speeds in an obstacle environment, the crew tends to think more in distances than in time to reconstruct the obstacle environment in the near-field.

Based on the distance to an obstacle the following threat levels have been defined:

- **Advisory:** for information and situational awareness (green)
- **Caution:** immediate attention required (amber)
- **Warning:** immediate action required (red)

Although the flight crews do not want to take their eyes in the cockpit in these phases of flight, the graphical presentation of the obstacle environment was well appreciated. It provides directional information at a glance and greatly enhances situational awareness. Figure 5 shows one of the earlier display concepts. In this polar plot the detected obstacles are indicated by highlighting the corresponding sector starting at the radial distance of detection. As the RSAS system is not an imaging system only a coarse indication of direction to the closest obstacle suffices. The radial distance to an obstacle is detected with higher accuracy and is displayed accordingly. The different alerting levels are indicated by concentric circles at defined distances from the H/C and are marked accordingly.

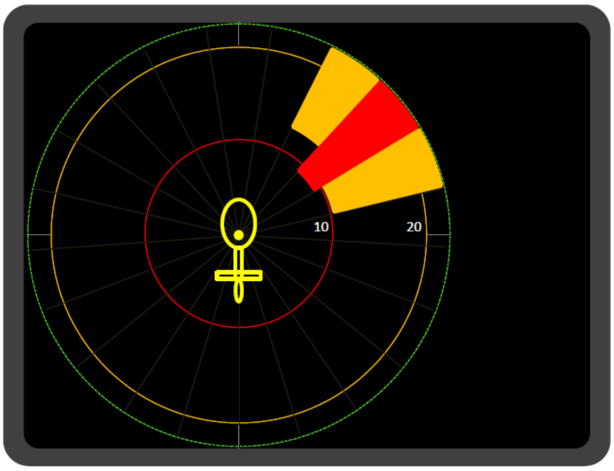

Fig. 5. RSAS display concept

In addition to this graphical presentation the primary means of informing the crew about the presence of obstacles is through the audio alerts. Discrete tones are sounded through the intercom system at a repetition rate that depends on the distance to the H/C. The closer an obstacle is to the H/C, the higher the repetition rate. Various combinations of tones and repetition rates were tested with pilots in the research simulator before a selected set was used for the flight tests.

Command and control of the system should be kept to a minimum. The system shall be care-free in handling not to distract the flight crew in the critical phases of flight. Obvious functions such as ON/OFF/MUTE can be easily incorporated on a small control panel or integrated on a separate display.

3.4. System Integration

System integration refers to the integration of RSAS system components (e.g. display, sensors, wiring) into the H/C platform. As stated before, the system is of particular benefit to users operating small to medium sized H/C. This imposes obvious challenges on the integration of the multi-sensor system. Firstly, the complete system weight is an issue as these operators are often operating at their weight limits. Adding weight will be at the expense of useful load, range and performance. Secondly, there is often limited free space for installing all the system components. This is especially true for the sensors which also need to be placed in a specific arrangement with an unobstructed FoV to secure system coverage and performance. What matters in the end is the installed performance of the RSAS system on the H/C.

For the purpose of this project a serial H135 was chosen as a test bed, because it possesses a main rotor mast cowling which provides ample space for mounting the sensors. For the sake of simplicity, the sensors were mounted on the outside of the cowling using specially designed brackets (Figure 6).

Fig. 6. H135 Mast cowling with RSAS sensors

For a future serialization it is obviously preferred to integrate the sensors behind the cowling provided that a radar transparent inset can be constructed. For such an installation also the clearance of sensor mounting and wiring with the rotor mast and control rods needs to be carefully assessed in a more detailed installation study.

4. TEST AND EVALUATION

During the course of the research project the RSAS system and its components were tested in consecutive steps on several levels. In the early stages of the project a simulation of the complete system already enabled prototyping and validation of the HMI concept. As first sensor hardware became available, initial ground and flight tests with a single sensor were performed to verify interfaces, the first stages of processing and sensor detection performance. Subsequently the complete system was built together and tested intensively on ground before installation on the H135 test aircraft. The RSAS system was finally evaluated by test pilots in June 2014 in a flight test campaign accumulating several flight hours of valuable test data.

4.1. Test Architecture

The following figure shows the RSAS test architecture with which all RSAS functions were demonstrated in real-time and relevant data were recorded. This test system was used in the various ground and flight tests.

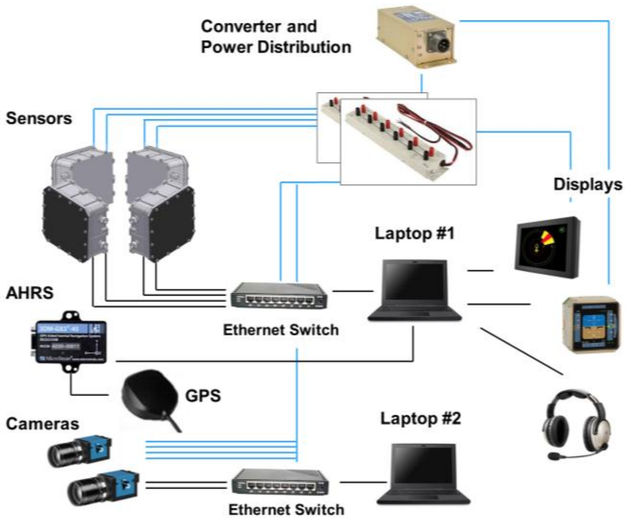

Fig. 7. RSAS test architecture

The test system consisted of:

- 4x RSAS sensors
- 4x Ethernet cameras for instrumentation
- AHRS and GPS sensor
- 2 Laptops for RSAS and camera processing and recording
- Large and small displays
- 2x Ethernet switches
- 28VDC-12VDC converter and distributor panels

The actual processing of radar data (see *Obstacle Comprehension Function*) was performed in real-time on Laptop #1. For the test flights, the HMI was displayed on a large industrial display on the centre-console and on a small, avionics display mounted on the side of the instrument panel (Figure 8). The RSAS laptop generated audio alerts that were sounded to the pilot/co-pilot through an interface with the intercom system. All camera and radar data were recorded on a dedicated laptop for post-processing and evaluation.

Fig. 8. RSAS displays in H135 cockpit

4.2. Dynamic Ground Tests

In order to test the *Obstacle Comprehension Function* (see section 3.3.2), the complete test system was initially installed on the roof of a car to enable testing under dynamic conditions with a system that is representative for the installation on the H/C (Figure 9). This installation provided the capability for verification and optimization of filtering and tracking algorithms for the multi-sensor system covering 360° in azimuth. In addition, the system was used to approach obstacles at realistic speeds in manoeuvers that resemble typical H/C use cases.


Fig. 9. RSAS dynamic test vehicle

4.3. Flight Tests

After having verified a proper functioning of the complete system it was installed on the Airbus Helicopters H135 test aircraft. The installed system was judged safe for flight after having undergone different tests prior to the actual flights. Electromagnetic compatibility tests were performed to investigate possible interference with the on-board avionics. Modal testing in the form of a 'bang test' was performed to evaluate the modal characteristics (e.g. frequency response, damping) of the mast cowling with sensors attached to ensure structural integrity.

In several hours of flight testing the RSAS system was evaluated in different flight phases and for a variety of man-made objects and natural features including high and low voltage power lines, poles, buildings, trees, forest edges, wind turbines and terrain contours. The different test scenarios were designed to represent closely the use cases for which the RSAS system is intended (see Figure 10 and 11)


Fig. 10. RSAS helicopter approach to weather station


Fig. 11. RSAS helicopter approach to low voltage power line

During the flights, the performance of the system as well as different HMI concepts were evaluated by the pilots and discussed in post-flight debriefings. Between the flights, time was available for optimizing the processing function and the HMI based on the findings of the previous flights. Surround radar and camera data were recorded in flight for post-processing.

The following figure shows the RSAS user interface for the RSAS operator seated in the cabin. In addition to sensor and processing settings it shows a detection map with sensor pre-targets marked by a red asterisk and tracked objects by a green square. In accordance with the logic described in section 3.3.2 only information of tracked objects was provided to the flight crew through the HMI.

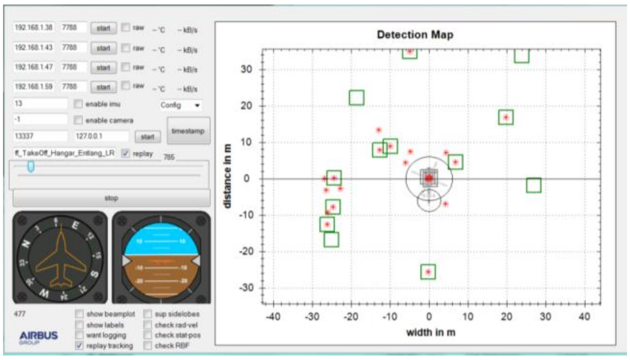

Fig. 12. RSAS operator interface

With all available recordings (GPS, radar data, and camera data) the exact behaviour of the RSAS system including HMI could be replayed for evaluation purposes. In addition, the recorded radar data could be re-played with modified processing parameters (e.g. tracking settings) or different HMI concepts. The composition of data and displays as shown in Figure 13 proved to be a valuable tool chain for evaluation of the system's performance.

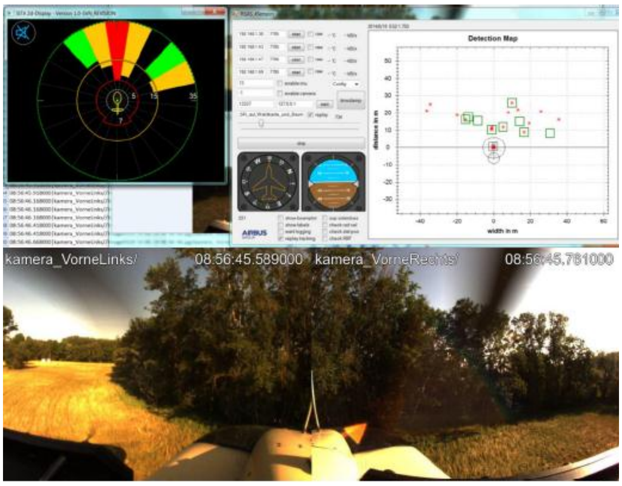

Fig. 13. RSAS evaluation tool using recorded radar and camera data

RSAS flight test results and crew assessments have confirmed the intended function of the system. Following results of the flight tests campaign are worth to be mentioned explicitly:

- The pilots approved the general usability of the alerting concept and HMI with potential identified for further fine-tuning.
- The flight tests have shown a reliable detection of all obstacles in flight including suspended cables. Although radar returns are received from only a small part of the wire perpendicular to the sensor line of sight, the 360° azimuthal coverage guarantees that there is always energy directed perpendicular to and reflected from part of the cable which is closest to the H/C.
- The surround coverage in azimuth was accomplished without any gaps in the coverage. The tracking function provided an uninterrupted tracking of objects across the boundaries of the sensor FoVs.
- Radar processing based on pre-targets and HMI generation was performed in real-time on a consumer laptop without any noticeable latency.
- Pilots often underestimated the distance of blade tip to the obstacle. This was even more pronounced for larger obstacles. At least the perception of the crew is on the safe side. Also the flight crew had a slightly different spatial perception of the obstacle environment because of their offset from the rotor mast or centre of sensor system.
- The system itself performed as expected without any major flaws and interruption already thereby making the demonstration a success.

In addition, several points were identified that can be improved:

- It was noted that the vertical FoV of the sensors (10°) is too small to support during manoeuvers with higher pitch angles (e.g. flare during landing). Obstacles in the flight path are detected too late or not at all.
- Strong reflectors on the ground can cause ghost-targets when being detected through the radar side-lobes while flying in direct ground vicinity. They appear as a target although they are outside the alerting envelope and not to be warned for (false positive).
- The location of the display on the side of the instrument panel is suboptimal as it is neither in the primary FoV of the pilot nor part of or close to the instruments that are systematic scanned. The consequence was that the pilots did not look at the display at all when flying in direct obstacle vicinity.

All in all, the results of the test campaign were very promising and satisfying. It has been confirmed that the system successfully performs its intended function with a serial-like installation on an H/C typically used by operators in need for such as system.

5. FREQUENCY ALLOCATION

Today, frequency regulations do not allow the operation of 76-77 GHz radar systems for any airborne application. Already in the beginning of the SITA project negotiations were therefore initiated with authorities at national and international level to investigate the extension of the current regulations to heliborne applications.

The frequency allocation efforts started in 2012 with the publishing of a system reference document describing the intended use of the RSAS system and its technical characteristics [5]. This document was published by the European Telecommunications Standards Institute (ETSI) committee for electromagnetic compatibility and radio spectrum matters. Based on this document, sharing and compatibility studies were performed in the spectrum engineering working group of the European Conference of Postal and Telecommunications Administrations (CEPT) [6]. The report considers the effect of the airborne use of this technology on the following services that are already active in this frequency band:

- Radio Astronomy Service (RAS)
- Radio Amateur and Amateur Satellite Services
- Automotive radar application
- Fixed transport infrastructure radar

Taking into account the current allocations and the protective status of RAS in this band, a solution is sought that is acceptable for all users. Interference studies have shown that only the RAS stations require protective measures to prevent any interference with their highly sensitive receivers used for celestial observations. The current solution proposal is to define exclusion zones around these stations in which the use of the RSAS system is prohibited automatically. The following figure shows the results of the interference investigation with the RSAS system at the position of the RAS station Effelsberg (Germany). It shows the resulting field strength of the RSAS system taking into account atmospheric attenuation and terrain topography. Drawn in white are the proposed exclusion zones in which the use of the RSAS system shall be prohibited.

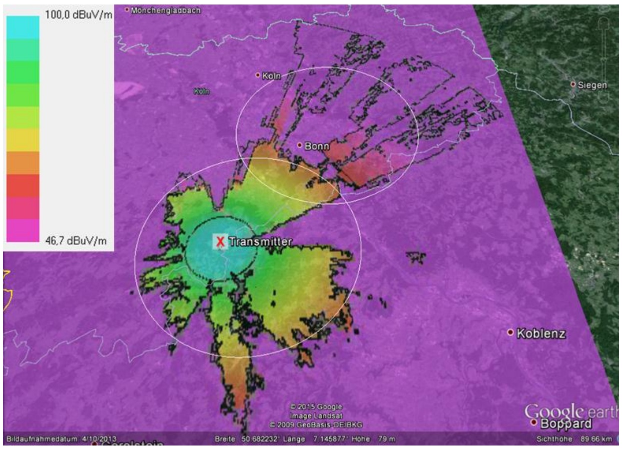

Fig. 14. RSAS field strength (colour coded) and proposed exclusion zones (white circles with radius 21km and 20km) for RAS station Effelsberg, Germany and RSAS system in 300m height above ground.

As of today, different proposals are under harmonization with the national authorities and the CEPT. A proposal for a European decision has been drafted which prepares the basis for a frequency regulation for the RSAS application within the CEPT countries.

6. CONCLUSION

This paper presents the results of the development and test of a novel Rotorstrike Alerting System (RSAS). The system is intended to support the flight crew in detecting obstacles in the direct vicinity of the main and tail rotor during low speed manoeuvring in the vicinity of ground or obstacles. To support a future realization which is commercially viable for civil operators, the system uses a distributed arrangement of small, affordable mass-market automotive radar sensors. In the research project, a first system architecture was elaborated and the system and its components were prototypically developed, integrated and tested in various ground and flight tests.

In these tests, basic sensor performance and detection performance were evaluated for a variety of obstacles typically compromising safe helicopter operations. The results have shown a confident detection of all relevant obstacles including suspended cables and power lines. The feedback provided by different flight test crews has been very positive and constructive which supports the next steps of the RSAS system development.

Although the results so far have been very promising, several opportunities have been identified that can further increase system performance or reduce system size, weight, and cost and therefore deserve further investigation. For instance, the enlargement of the vertical FoV of the sensors to also provide obstacle detection at larger pitch attitudes of the H/C during final approach or the integration of the RSAS display in existing flight or mission display formats to avoid having a dedicated RSAS display. These and other opportunities should be addressed in follow-on studies. In parallel, the frequency allocation activities shall be continued at European level to secure an extension of the current regulations to enable a heliborne application of these sensors.

As a conclusion, considering the complete SITA research project (2010 – 2014), it can be stated that the successful demonstration of the RSAS system is the evidence that this technology is suitable for the obstacle detection function with a sensor size and weight that enables the integration of the system also on smaller H/C types. Furthermore, the re-use of this mature technology makes it interesting from a cost perspective.

7. ABBREVIATIONS

AHRS	Attitude and Heading Reference System
BMWi	Bundesministerium für Wirtschaft und Energie
CEPT	European Conference of Postal and Telecommunications Administrations
CFAR	Constant False Alarm Rate
CFIT	Controlled Flight Into Terrain
ETSI	European Telecommunications Standards Institute
FMCW	Frequency Modulated Continuous Wave
FoV	Field of View
HEMS	Helicopter Emergency Medical Services
H/C	Helicopter
HTAWS	Helicopter Terrain Awareness and Warning System
LuFo	Luftfahrtforschungsprogramm
RAS	Radio Astronomy Service
RSAS	Rotorstrike Alerting System
SAR	Search And Rescue
SITA	Situational Awareness (LuFo project)
SVS	Synthetic Vision System
SWAP	Size, Weight and Power
Tx	Transmit
VFR	Visual Flight Rules

8. ACKNOWLEDGEMENT

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9. REFERENCES

[1] EASA, “Annual Safety Review 2010”, 2011

[2] SITA Project number #20H0912A, German Federal Ministry of Economics and Technology (BMWi)

[3] T. Waanders, Q. Qian, R. Scheiblhofer, B. van Noort, V. Ziegler, F. Schubert, R. Körber, A. Giere, “Miniaturized and low/cost obstacle warning system”, European Rotorcraft Forum, Amsterdam, The Netherlands, 04-07.09.2012

[4] V. Ziegler, F. Schubert, B. Schulte, A. Giere, R. Koerber, T. Waanders, “Helicopter Near-Field Obstacle Warning System Based on Low-Cost Millimeter-Wave Radar Technology”, IEEE Transactions on Microwave Theory and Techniques, Vol. 61, Issue 1, Part 2, pages 658 -665, Jan 2013

[5] ETSI TR 103 137: „Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Surveillance Radar equipment for helicopter application operating in the 76 GHz to 79 GHz frequency range“

[6] ECC Report 222: „The impact of Surveillance Radar equipment operating in the 76 to 79 GHz range for helicopter application on radio systems“