Pilot Assistance Systems: Enhanced and Synthetic Vision for Automatic Situation Assessment

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Abstract

DLR has set up a number of projects to increase flight safety and economics of aviation. Within these activities one field of interest is the development and validation of systems for pilot assistance in order to increase the situation awareness of the aircrew. The basic idea behind these systems is the principal of an "electronic co-pilot". All flight phases ("gate-to-gate") are taken into account, but as far as approaches, landing and taxiing are the most critical tasks in the field of civil aviation, special emphasis is given to these operations. Especially under adverse weather conditions the situation awareness of pilots is decreased in these critical flight phases due to the reduced visual range. Therefore, an Enhanced and Synthetic Vision System (ESVS) is integrated into the assistance system. Data acquired by weather penetrating sensors are combined with digital terrain data and status information by application of data fusion techniques. The resulting description of the situation is given to the pilot via head-up or head-down displays. One promising sensor for Enhanced Vision application is the 35 GHz MMW radar "HiVision" of EADS.

This paper is focused on the automatic analysis of HiVision radar images with regard to the requirements for approach, landing, and taxiing. This includes the integrity monitoring of navigation data by conformity checks of database information with radar data, the detection of obstacles on the runway (or/and on taxiways) and the acquisition of navigation information by extracting runway structures from radar images.

Introduction

The continuous growth of civil air traffic, accompanied by new ATM procedures and philosophies, on the one hand and the growing complexity of military missions on the other hand all put new demands on the aircrews. Many systems have been designed in the past to solve individual tasks, but this approach is reaching its limits. One approach to overcome those limits is a pilot assistant system, an integrated system which combines all required assistant functions under a single human machine interface. This system can be regarded as an "electronic co-pilot" (Figure 1), which performs the same tasks as the pilot, but leaving the decision to the pilot.

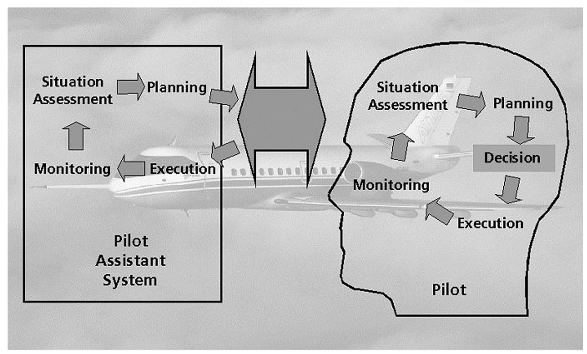

Figure 1. Concept of DLR´s "electronic co-pilot"

Key features of such systems are situation assessment functions, which allow automatic reaction in critical situations. These features greatly reduce pilot workload in situations where support is most needed and where conventional systems require too much input, since they don't recognize the situation and therefore are unable to derive the required actions themselves. A generic architecture for such assistance system has been developed at DLR´s Institute of Flight Guidance (Helmke, Höppner, and Suikat 1997). In this architecture the assistant functions are implemented in function modules grouped around a core system consisting of a central data pool and a module manager. Sophisticated data handling methods are implemented in this architecture to allow modules to be notified whenever relevant data have been changed. This mechanism is used to achieve the situation assessment and even automatic response to critical situations. In civil aviation critical situation occur relatively often during approach, landing and taxiing, especially under adverse weather conditions. Therefore, Enhanced Vision Systems (EVS) play an important role within pilot assistance systems. But within most of the EV-Systems, images acquired by forward looking, multi-spectral sensors (IR, MMW-Radar) only are displayed head-up or head down to the pilot (Brown 1996, Bui et al. 1997, Connor 2002, Grimberg 2001). Consequently, the pilot must interpret the sensor data and has to extract the necessary information from the sensor data without support from the assistance system. Thus, there is no feedback from the pilot into the assistance system about the derived information. For a sophisticated assistance module as mentioned above the analysis of the sensor data has to be done automatically. In our system data acquired by weather penetrating sensors are combined with digital terrain data and status information by application of data fusion techniques to assess the external situation of the aircraft automatically. Due to the lowest weather dependency, radar systems seem to be the most adequate EV sensors. In our system, the HiVision radar (Tospann, Pirkl, and Gruener 1995, Pirkl and Tospann 1997, Hellemann and Zachai 1999) from EADS, Ulm, a 35 GHz MMW radar with a frame rate of about 16 Hz is used as the primary EV sensor (Figure 2).

Figure 2. HiVision radar sensor on DLR´s Do 228.

It is an imaging FMCW radar with center frequency of 35 GHz, field of view of 40°/3.5 km, RF output lower than 1 W, azimuth resolution 0.25° per pixel, range resolution 6.67 m per pixel, vertical beam width about 8°, and a frame update rate of about 15 Hz.

The position of the aircraft relative to the runway is one of the most important information during approach for both, the pilot and the pilot assistance system. Under adverse weather conditions this information cannot be verified by the pilot visually. Therefore, this has to be done by analyzing the on-board sensor data. Furthermore, the sensor data analysis has to detect unknown objects/obstacles as well as to determine the position of the aircraft relative to the runway if the navigation is not correct or if there exists no precise knowledge about the runway location. Thus, the core part of the automatic situation assessment is the fusion of database information and navigation information with data acquired by forward looking imaging sensors (Figure 3). In the following sections the analysis of the HiVision radar data for automatic situation assessment during approach and landing is described in more detail.

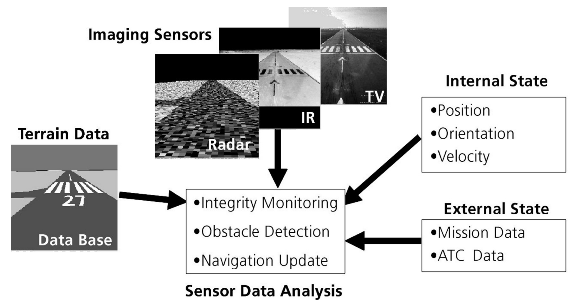

Figure 3. The main tasks of the sensor analysis for automatic situation assessment

Integrity Monitoring and Obstacle Detection

Sensors like (D)GPS and INS deliver the position and the attitude (INS) of the aircraft in world coordinates (e. g. in WGS84 coordinates). Together with a-priori knowledge from databases about the target airport (approach trajectory, runway location and direction, airport topography) an estimation about structures of the environment ahead can be generated. On the other side these structures are sensed by e.g. a MMW radar. A comparison between the expected structures known from databases and the sensed structures acquired from on-board sensors gives an idea about the integrity of the system. In ***Figure 4*** our concept (Korn, Döhler, and Hecker 2001) for integrity monitoring is depicted in a schematic way.

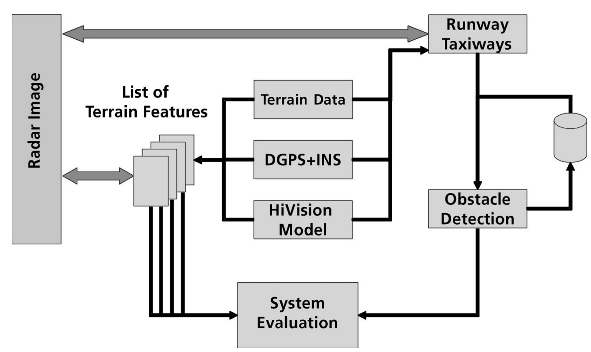

Figure 4. Concept for obstacle detection and integrity monitoring of navigation and database information

With regard to the imaging capabilities of the used HiVision radar sensor adequate structures are extracted from the database. Besides the geometric dimensions the characteristics of the objects´ surfaces with respect to the wavelength of the HiVision sensor have to be known in advance.

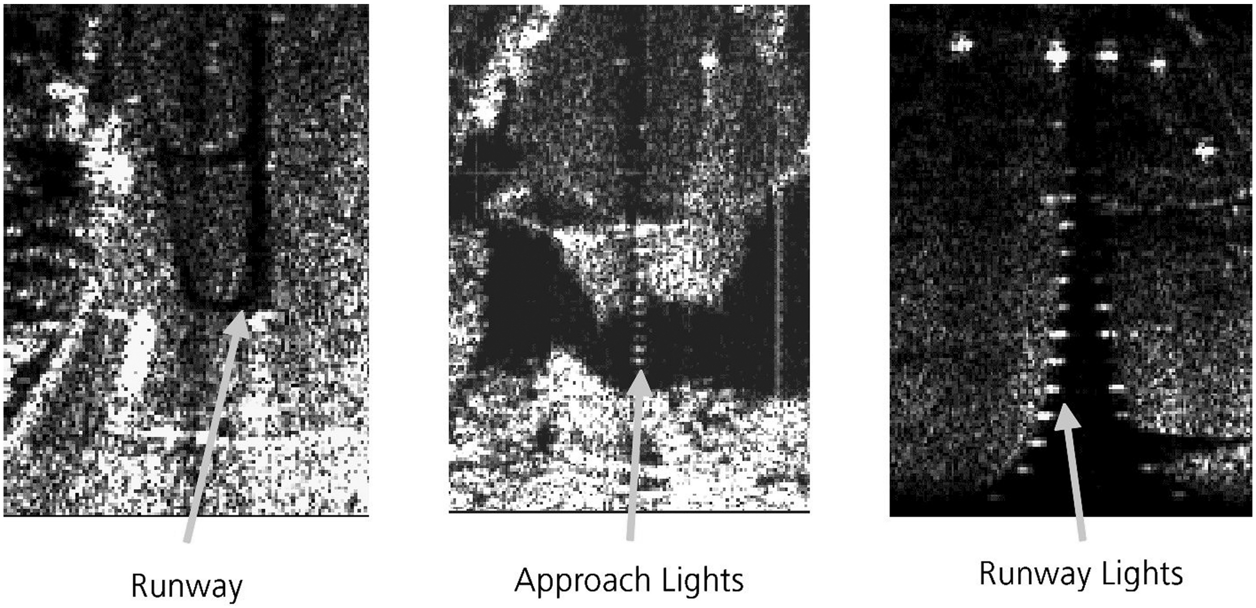

Figure 5. Runway structures in radar images

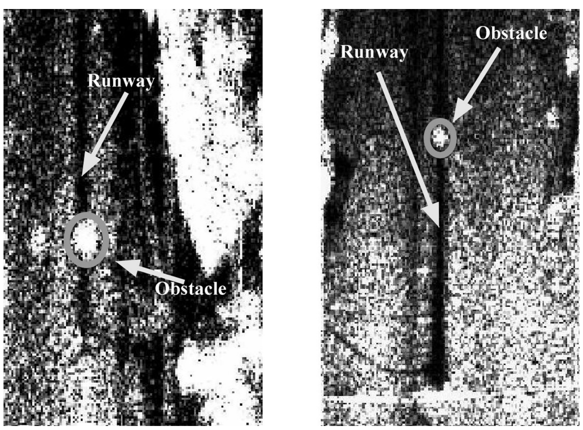

Figure 6. Obstacles on runway.

Left: transportation aircraft on runway 14L in Cologne/Bonn, *right:* van on runway 26 in Braunschweig.

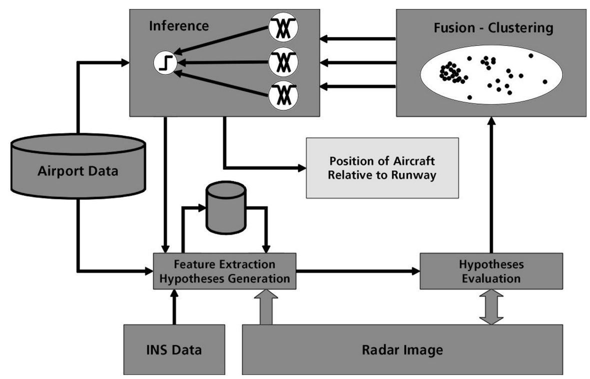

Figure 7. Concept of a radar image based navigation system for approach and landing.

This leads to a list of test structures, whose locations, sizes and intensity distributions within the radar images can be estimated to a certain degree. For each test structure its estimation is verified within the actual radar image. In the inference process these singular evaluations are combined to an overall evaluation of the integrity of the system. As it can be seen in Figure 5, the runway itself as well as the approach light system and the runway lights can serve as such test structures. Depending on the size of and the traffic on the airport additional objects can be extracted from the radar image. But for landing only those objects are of interest which are on or next the runway and which might lead to a dangerous situation. Thus, this part of the radar image, in which the runway is expected to be, is searched for objects, which could endanger the aircraft.

Potential obstacles are compared to objects/obstacles, which have been extracted from previous radar images to get stable hypotheses for obstacles on the runway or on the taxiways. Figure 6 shows two radar images from runways with obstacles. The obstacles can be identified as bright "blobs" within the dark stripe of the runway. The left image shows the radar signature of an aircraft on the runway 14L in Cologne/Bonn, in the right image, the blob belongs to a van on the runway 26 in Braunschweig. It can be seen easily that an obstacle on the runway can be detected because of its intensity distribution but it is hardly possible to classify what kind of object (e.g. an aircraft) is on the runway only because of the radar signature.

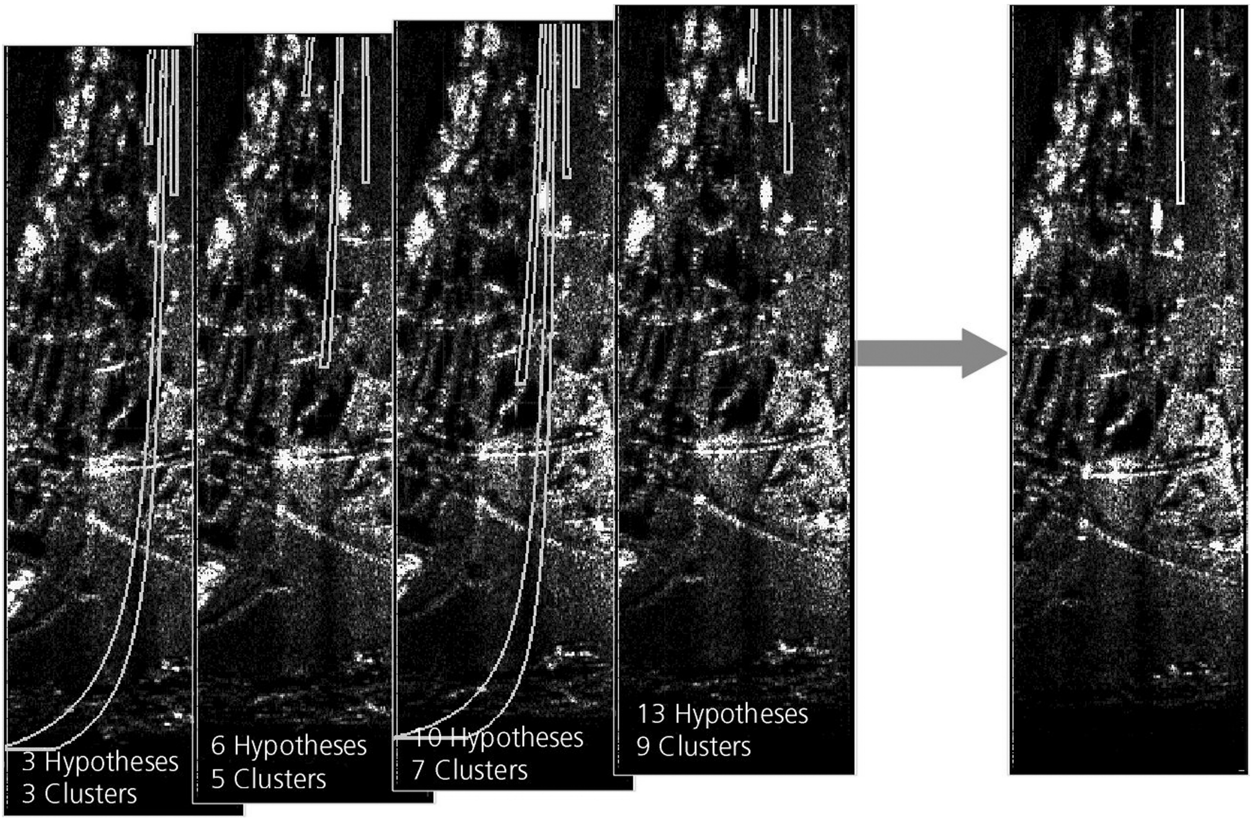

Figure 8. Result of the fusion process of several runway hypotheses of different frames during an approach to Hannover 27R

Radar Image Based Navigation

If there is no sufficient information about the exact position of the runway relative to the aircraft due to non-precise databases and/or non-precise onboard navigation this navigation information has to be derived from the radar images for a board autonomous approach and landing operation under adverse weather. The concept of our sensor based navigation system (Korn, Döhler, and Hecker 2000b) is depicted in Figure 7. It consists of two layers, the inference and fusion layer and the extraction layer. Within the extraction layer the radar image is searched for radar structures as they are depicted in Figure 5. The main feature hereby is the contrast between the image of runway asphalt and its surrounding grass area. Normally, the sensor data analysis process of the extraction layer generates more than one runway hypothesis from a single radar image. These hypotheses are evaluated with regard to the quality of their features in the image and then sent to the inference layer. Because of this hierarchies additional sensors or sensor data analysis processes can be integrated in the system quite simple (Korn, Hecker, and Döhler 2000). In the inference layer, incoming runway hypotheses are clustered using adapted fuzzy (Dunn 1973, Bezdek 1987) or possibilistic (Krishnapuram and Keller 1993) clustering algorithms. This clustering consolidates the set of runway hypotheses

$$X = \{x_1, \ldots, x_n\}$$

to a set of cluster prototypes

$$V = \{v_1, \ldots, v_c\} \text{ , with } c << n.$$

In Figure 8 the effect of information consolidation is depicted for an approach to Hannover 27R. Within a single frame several runway hypotheses are extracted. The fusion of all these hypotheses from several frames using the clustering algorithm ends up in the correct determination of the runway. The output of each cluster is used as input for a common rule based fuzzy controller (Kruse, Gebhardt, and Klawonn 1993) to judge the state of the system and to determine whether runway structures should be searched for within the entire sensor data in the extraction process or in certain regions-of-interests (ROI) or even tracked, when there is a high reliability for only a few runway hypotheses. Furthermore, the position of the aircraft relative to the runway threshold is calculated (Korn, Döhler, and Hecker 2000a) if the output of the clustering allows a reliable and unique determination of the runway. From this calculated position, information such as the deviation from an optimal 3° glide path can be derived and be displayed head up or head down by ILS-like localizer and glide slope indicators (Figure 9).

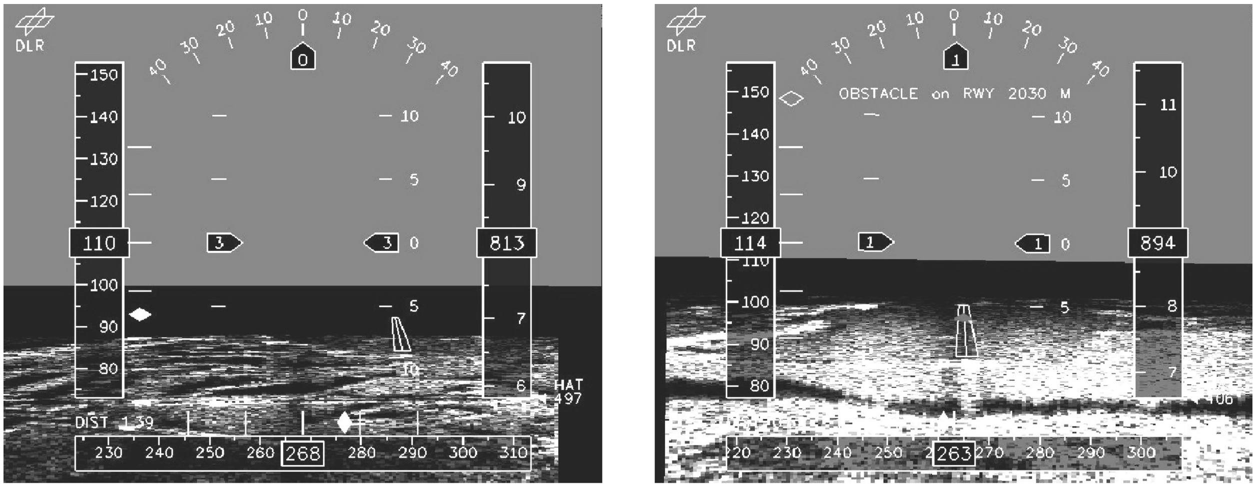

Figure 9. Depiction of radar image and extracted runway within a modified Primary Flight Display.

The ILS localizer and glide slope indicators have been calculated in the runway extraction process. Left image: Approach to Hannover 27R. Right image: Approach to Braunschweig 26 with an obstacle detected on the runway in a distance of 2030 m from the aircraft

Airport	RWY	RWY Width (m)	Approa-ches	Extraction Distance (m)		
				Average	Minimum	Maximum
Braunschweig	08	30	8	1491	1203	1725
	26	30	18	1645	867	2351
Bremen	09	45	1	2209	-	-
	27	45	1	2197	-	-
Celle	08	45	1	1423	-	-
	26	45	1	1882	-	-
Cochstedt	08	45	2	1656	1607	1705
	26	45	2	1849	1793	1904
Faßberg	27	30	3	1682	1475	1843
Hannover	09L	45	3	2050	1962	2184
	27R	45	3	2245	1883	2603
Köln-Bonn	14L	60	1	2383	-	-
	14R	45	1	1954	-	-
	32R	60	1	2177	-	-
	32L	45	1	1891	-	-
Peine	07	30	2	1588	1463	1712
	25	30	2	950	941	959
Together			51	1719	867	2603

Table 1. Results of runway extraction for 51 radar image sequences acquired during approaches to runways of several airports in Gemany

During our flight tests we acquired about 90000 radar images within more than 50 radar image sequences from approaches to several runways from different airports in Germany (e.g. Hannover, Cologne-Bonn, Braunschweig). In every sequence the runway was extracted correctly. The average distance between runway threshold and aircraft at time of extraction was about 1700 m, which is larger than the minimum RVR (Runway Visual Range) for a non-precision approach. Table 1 gives a detailed overview about the results of the runway extraction process.

Conclusion

A promising approach to improve the situation awareness of the aircrew is to introduce pilot assistance systems. DLR developed an overall concept including a generic system architecture in order to provide pilot assistance during all flight phases “gate-to-gate”. Individual assistances functions are implemented as modules grouped around a core system. An Enhanced and Synthetic Vision system was integrated into the assistance system for automatic situation assessment especially in flight phases close to terrain (approach, landing, taxiing). The core part of this assistance module is the fusion of terrain data and navigation sensor with information generated by the automatic analysis of sensor data form weather penetrating forward looking imaging sensors. Within our system the HiVision MMW-radar sensor of EADS, Ulm, was used as primary EV-sensor. The main tasks of the image analysis is the integrity monitoring of navigation data by conformity checks of data base information with radar data, the detection of obstacles on the runway (on taxiways) and the acquisition of navigation information by extracting runway structures from radar images. The Enhanced Vision module was validated and tested very successfully in extensive flight tests with more than 50 approaches to different airports in Germany.

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