Combination of Low Power Radars and Non-Rotating Sector Antennas for Surveillance of Ground Moving Traffic on Airports

K.-H. Bethke  
German Aerospace Center (DLR)  
82230 Wessling, P.O. Box 1116, Germ.  
email karl-heinz.bethke@dlr.de

B. Röde  
German Aerospace Center (DLR)  
82230 Wessling, P.O. Box 1116, Germ.  
email bernd.roede@dlr.de

A. Schroth  
German Aerospace Center (DLR)  
82230 Wessling, P.O. Box 1116, Germ.  
email arno.schroth@dlr.de

Abstract

This paper describes relevant technical principles of construction of a novel radar system. This so-called Near-Range Radar Network (NRN) is a modular structured low power radar system designed as a candidate for the non-co-operative surveillance of ground moving traffic on airports in completion to existing surveillance systems or as single sensor, alternatively. A prototype system comprising four locally distributed radar stations, each equipped with non-rotating antennas, has been developed. Typical results from field experiments at different airports demonstrating the system performance are presented and discussed.

Keywords

Near-range Radar Network (NRN), primary radar, airport surveillance, A-SMGCS, non-co-operative sensor

INTRODUCTION

Presently, many major airports are working at their capacity limits. Extensions of additional runways are an enormous cost factor and permissions are becoming rare due to protests of population. Modern, efficient measures are necessary and presently under investigation and under development [3] to cope with the future air traffic for controlling aircraft at the ground.

As defined by ICAO (International Civil Aviation Organisation) [1] an “Advanced Surface Movement Guidance and Control System (A-SMG’CS) is the term used to describe a modular system consisting of different functionalities to support the safe, orderly and expeditious movement of aircraft and vehicles on aerodromes under all circumstances with respect to traffic density, visibility conditions and complexity of the aerodrome layout, taking into account the demanded capacity under various visibility conditions.”

In order to meet this approach, the aspect of surveillance will play a key role. Generally, one single sensor is not able to detect ground movements in all parts of a complex airport layout maintaining high reliability. Therefore, the philosophy of an A-SMGCS is the fusion of different sensor types [2] complementing one another.

The presented Near-Range Radar Network (NRN) has been developed as a non-co-operative sensor candidate for the future generation of A-SMGCS. It was developed at the Institute of Communications of the German Aerospace Center in co-operation with industrial partners. It provides actual traffic situation reports for a sensor data fusion (SDF) of an A-SMGCS within the NRN covered area.

Novel concepts have been treated in developing the prototype system. Varying from traditional radars, the NRN operates with staring sector antennas covering wide angular sections in the azimuth. Additionally, the NRN operates with extreme low peak powers of about 10 W, only. Sophisticated signal and data processing are mandatory for reliable detection and tracking of even low scattering targets in maximum measurement distances of up to about 1500 m. The NRN concept is adjusted to low mechanical maintenance effort, high flexibility and adaptation capability to certain scenarios by modular structures, and, finally, low pollution by electric smog and high acceptance by staff and passengers.

Within this context, the NRN is specified for the surveillance of sub-areas of large airports. Four low power radars are forming a common cell of surveillance, also called module. The cell size depends on adaptation to a given scenario (buildings, road map, etc.). Several modules can be combined to a so-called radar network for surveillance of wider areas or complex airport layout.

At the end of 1997 a prototype module has been constructed. In the framework of several projects sponsored by the DLR and the European Commission [3] the NRN has been tested in real airport environments, and its performance and integration capability in different A-SMGCS could be proven.

Although, the NRN has been developed as a non-co-operative sensor for the surveillance of ground moving traffic on airports it can be applied to any other scenario of surveillance.

In the following section an overview about major technical features of the NRN is given. In section 3 typical results from field experiments at Braunschweig, Zürich, and Prague Airport are presented demonstrating the system performance.

MAJOR CONCEPTS AND TECHNICAL ASPECTS

The NRN system operates with fixed, non-rotating sector antennas. That means, each radar station of a module provides only the information of radial distances of targets. For resolution in azimuth, measured range profiles of at least two stations are required in order to determine the position via triangulation. From early computer simulations [4] we found that four radar stations forming one module in
its basic configuration are necessary for a reliable surveillance of a common area (Figure 1). A very convenient side effect is the fact that the multilateration procedure provides target positions in a digitized format.

![Figure 1. Location results from a computer simulation for a time period of 30 seconds.](image)

Each radar station permanently illuminates the complete section in azimuth, given by the geometry of the module size. For further enhancement of reliability, with respect to the suppression of ghost targets especially for operations on airports, the sector of observation for the receiving case can be divided into two adjacent sub-sectors (beam splitting) so that e.g. busy sections as aprons can be physically separated from sensitive areas like runways. Therefore, each radar station is equipped with one transmitting and two receiving sector antennas (Figure 2). The radar stations are operating at 9.05 GHz with a maximum peak power of typically 10 W using solid state technology.

![Figure 2. Typical examples of antenna installation.](image)

From the four radars of an NRN module a so-called master station synchronizes the operation of the three slave stations (see [5], [6]). Because of permanent illumination and utilization of staring sector antennas, the master station is in permanent contact to the slave stations. During cycles of non-radar-operation the slave stations transmit measured range profiles at a rate of 10 Hz via the existing RF link. This concept in combination with staring antennas allows a high flexibility with respect to the installation or, if necessary, to a repositioning of single radar stations. The installation of radar stations needs no digging of cable trenches and their operation is completely independent from local infrastructure, only power supply is needed.

A Motorola PowerPC at the master station computes the position of detected targets at a rate of 10 Hz and transmits the situation reports to a remote central network computer. For the prototype module this is solved by an Ethernet connection, because master station and network computer are both sited inside our working container. In practical applications a commercial radio link can be used.

For the integration of the NRN in an A-SMGCS the network computer is interfacing the sensor data fusion via LAN using a protocol derived from the ASTERIX standard. In case of several operating NRN modules all individual situation reports are fused inside the network computer before the final report is transmitted. The typical update rate for airport application is 1 Hz. Finally, from the network computer the operation of the complete system can be controlled.

Although, relevant measurement ranges are not far extended additional process gain is mandatory because the transmitted maximum peak powers of about 10 W are distributed over wide angular sectors which can achieve dimensions of 120° or even more. Several stages of process gain have been implemented.

Each radar station operates with a new developed pulse compression technique which serves for sidelobe-free compressed pulses (see also [5]) which is mandatory in order to detect a small aircraft in the vicinity of a strong reflecting target. For range measurements bursts of bi-phase modulated signals are transmitted with a repetition frequency of 140 Hz. The code length of an expanded pulse can be variably adjusted from 8 to 64 chips (in terms of 2). The chip length is 14 ns. Dependant on expected maximum target speeds up to 6 expanded pulses of a burst are coherently integrated before compression processing. The intra-burst frequency is 33 kHz which serves for an unambiguous range of 4.5 km.

For the purpose of target location only magnitude range profiles are evaluated so that additionally 14 profiles are incoherently superimposed to result available range profiles at 10 Hz rate. For typical code lengths of 32 chips the achievable process gain is of the order of 26 dB.

The effective range resolution given by the 14 ns chip length (2.10 m range cell size) is better than 3 m. It is stated that this resolution is, in contrast to a classical radar, quite constant over the surveillance area. This relative high range resolution gives precise location results, even for large rolling aircraft, because each target is seen from four different aspect angles. It will be shown in the following section, that measured centroids of aircraft in comparison to D-GPS measurements may exhibit mean value errors of less than ±2.5 m. On the other side it renders a target classification process feasible [5].
For the reduction of permanent clutter a simple but effective cut-off frequency digital impulse response high pass filter has been implemented which reduces clutter contribution by 40 dB [7]. In the meantime, a modern approach of an adaptive filter is available which overcomes some disadvantages of the implemented solution [8].

RESULTS FROM FIELD EXPERIMENTS
After pretests at the airport site in Oberpfaffenhofen, first real field experiments started at Braunschweig Airport in 1998.

Braunschweig has a small but, with respect to the performance of field tests- very convenient regional airport. Here, the DLR Institute for Flight Guidance has implemented a test bed for testing A-SMGCS components (see [2], [3]).

For the quantitative estimation of the NRN measurement accuracy two vehicles were utilized, a Mercedes bus and a DO228 aircraft both equipped with a D-GPS reference system and a data recorder. A photo of both test vehicles is given in Figure 3. Figure 4 displays a snapshot from the monitor of the network computer during an experiment for which the bus accomplished four runs considering all relevant moving areas of the airport inside the module area. The corresponding frequency curve of all NRN location errors in x/y-co-ordinates is inserted in the plot. The standard deviations of 2.60 m in x-direction and 1.80 m in y-direction (while the maximum absolute error was about 7.40 m) demonstrate the accuracy of measured target positions.

From other measurements it could be observed that for larger aircraft sometimes point track fluctuations of several meters occurred. Due to the fact that contributions of single reflection sources may be strongly dependant on aspect angle such unstable sources on an extended object may cause a shift of the center of location. But this is a physical problem to be observed with any radar sensor. Within the location process of the NRN, however, this effect is being smoothed and averaged because objects are seen from four different aspect angles. Different field trials proved the real-time capability of the NRN. During integration tests in the local test bed the measured typical latency of NRN reports received at the SDF were in most cases better than 0.5 seconds.

Field test at Unique International Airport Zürich
During the second half of 2000 in co-operation with the airport authority of Unique Airport Zürich an extended field test was performed in a real environment of an international airport. Together with the airport authority,
with respect to traffic situation, a sensitive part of the airport was selected, which was characterized by the main runway 28 comprising two runway crossings. The selected area shows the highest traffic density, more than 20000 runway crossings per year and a crowded ground traffic in the apron areas.

The photo in Figure 5 shows our working container on the roof of terminal A carrying the antenna mast of the master station. From the top of the roof the master station as well as from our working place there was an excellent view on to the airport field. The photos of two slave stations can be seen in Figure 2.

The field test at Zürich Airport provided extensive new experiences. As main result it can be stated that the NRN has proven to handle difficult scenarios of high traffic densities and a broad variation of target sizes. In Figures 6 and 7 representative results are shown. It could also be proven that calculated positions of tracked targets generally correspond to the normal movements of aircraft along center lines on taxi and runways independently of target size.

![Figure 5. Master station and working container at Zürich Airport on the roof of a terminal.](image)

An important lesson learnt is the fact that an airport is a very lively thing, what means that obstacles in form of dumps of earth, container buildings etc. (see photo in Figure 6), may be grown up in shortest time scales.

In order to prevent shadowing of single radar stations the antennas should not be positioned ground near as to be seen from Figure 2. Furthermore, the capacity of the NRN has to be carefully adapted to the characteristic of a given surveillance area. In apron areas smaller targets like follow-me cars are often hidden for far away positioned radar stations. Therefore, a module size as shown in Figure 6 is suited for surveillance of outer traffic on runways and taxiways but not for a simultaneous reliable detection and target tracking in apron areas.

![Figure 6. Typical measurement result during a situation of critical runway crossings. The labels at an actual measured target position carry the information of target velocity](image)

So, if even possible, the geometry of an NRN module should be adapted to the major requirement of surveillance of macro or micro traffic areas. Otherwise, areas of lower location reliability have to be masked because the ground traffic of service cars on the regular lanes inside apron areas is not of interest for controllers or a planning tool of an A-SMGCS, well knowing that traffic activities in those areas will be still seen from single radars and therefore, will enhance the computational load and also the readiness for contributing to false target generation. This fact may not
be interpreted as a disadvantage of the NRN because this problem is common with any other radar. Moreover, NRN modules are predestinated for the ability of adaptation to even difficult scenarios.

**Field Test at Prague Airport**

In the framework of the project BETA (operational Benefit Evaluation by Testing an A-SMGCS) funded by the European Commission DGVII [3], presently, the NRN is installed at Prague Airport and contributing to an ASMGCS under test. Figure 8 presents an older aerial photo of the airport showing the positions of the NRN radar stations.

In agreement with the partners of the BETA project the NRN module covers an area including part of airport surface where the central airport radar (ASDE) can generate ghost targets. Due to certain limitations, the extension of the module with maximum distances of about 2000 m became larger than originally specified. Although, the transmitted peak power was increased up to 20 W the capability of detection of low scattering targets at these distances is being reduced.

In consideration of the experience from the Zürich field test the NRN provides excellent location results in all areas where the NRN radars have clear insight as represented by the measurement plots in Figure 9. Similar as in Zürich, detection and tracking of ground traffic in apron sites show lower reliability. Situation reports from those areas are masked for the transmission to the SDF.
Presently, the radar positions have been rearranged. During the first BETA test phase at the end of last year it could be observed that the sensor data fusion lost the tracks of taxiing aircraft passing terminal A (northern terminal outside of the NRN coverage, see Figure 8) for some 10 seconds. The central ASDE (Airport Surface Detection Equipment) has no insight on the taxiway behind terminal A. The shadowed area is sketched in Figure 8. Therefore, the BETA team felt the decision to rearrange the NRN module in preparation for the second test phase in June 2002, so that this shadowed area will lie inside the NRN coverage. The new geometry of the NRN module is indicated by the dashed lines in Figure 8.

CONCLUSIONS
The prototype of a novel non-co-operative radar system (NRN) was presented as a candidate for an A-SMGCS. Principle concepts and major technical aspects were discussed. In contrast to traditional radars, this sensor operates with non-rotating sector antennas which permanently observe the ground traffic. Four low power radars transmitting 10 W pulse peak power at 9,05 GHz form a common cell of surveillance – a so-called NRN module - with a maximum extensions of up to 1500 m. Wireless communication data flow between all stations using the normal RF channels guarantees a high flexibility and mobility with respect to the adaptation of the module size to a given scenario.

The qualitative good location results could be quantitatively verified with the aid of reference systems. Evaluated 1σ-values of location errors of the order of 2.5 m for small as well as for extended objects were determined in different test series. The capacity and the flexibility of the NRN system could be proven in field tests at Braunschweig, Zürich, and Prague Airport. The utility as an efficient sensor for an A-SMGCS could be demonstrated.

Operating as a single surveillance system in form of one or more combined modules the NRN presents an interesting alternative solution for the surveillance of smaller airports or for any other need of traffic surveillance.

REFERENCES