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Advanced Data Fusion for Airport Surveillance

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Summary

The surveillance function plays a key-role within an Advanced Surface Movement Guidance and Control System (A-SMGCS) since it provides essential information to the air traffic controllers as well as to other A-SMGCS functions. This paper presents an overview of airport surveillance research at the National Aerospace Laboratory NLR of the Netherlands. It builds on the advanced Multi-Sensor Multi-Target tracking approach, which NLR developed for Eurocontrol's ATM Surveillance Tracker and Server (ARTAS). The aim of the paper is to provide an overview of the key extensions towards airport surveillance.

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Abstract
The surveillance function plays a key-role within an Advanced Surface Movement Guidance and Control System (A-SMGCS) since it provides essential information to the air traffic controllers as well as to other A-SMGCS functions. This paper presents an overview of airport surveillance research at the National Aerospace Laboratory NLR of the Netherlands. It builds on the advanced Multi-Sensor Multi-Target tracking approach, which NLR developed for Eurocontrol's ATM Surveillance Tracker and Server (ARTAS). The aim of the paper is to provide an overview of the key extensions towards airport surveillance.

1 Introduction

Due to the current traffic growth at airports and the need to increase capacity while at the same time enhancing safety, a clear demand is emerging for an advanced surveillance function for A-SMGCS to provide essential information to the air traffic controllers as well as to other A-SMGCS functions.

NLR has gained in depth expertise in ATM surveillance through extensive in-house research and external projects, one of which has been the development of the ARTAS tracker for Eurocontrol [14], [15], [18]. The current ARTAS environment is presented in figure 1. ARTAS is operational in ATC centres of Schiphol-Amsterdam, Eurocontrol Maastricht, Toulouse, Padova and many others. Driving forces behind this ARTAS development were efficiency and safety considerations; efficiency because cross-sector multi-sensor tracking and serving reduces the number of sensors needed and thus the operational costs. Safety because the advanced tracking techniques provide much better quality of surveillance.
The approach taken towards ARTAS tracking development is characterised by a powerful combination of

- Mastering generally applicable Bayesian surveillance algorithms, and
- Mastering dedicated application specific models that fully exploit the power of the algorithms.
- Early on prototyping and evaluation on live data.

As a result a suite of advanced Multi Sensor Data Fusion techniques is available:

- Advanced Multi-Sensor Tracking algorithms
- Advanced Multi-Sensor Environment Assessment algorithms
- Dedicate sensor models
- Dedicated object models
- Dedicated environment models

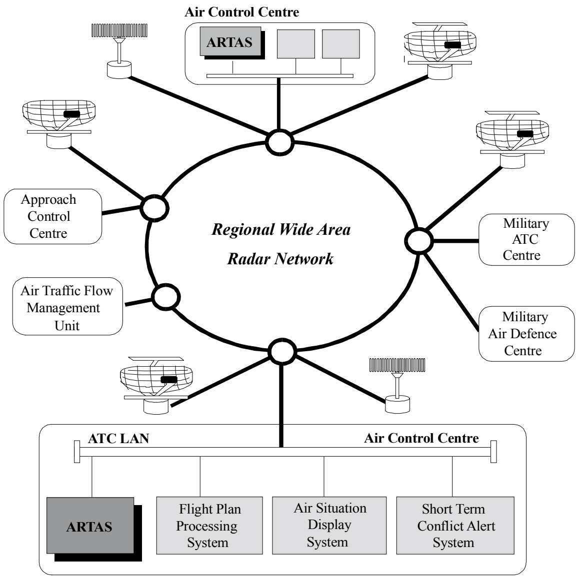

Figure 1. Current ARTAS environment

In this paper the particular extensions are discussed that pave the way towards seamless gate-to-gate surveillance.

The paper is organised as follows. In section 2 the airport needs are first identified. Then an outline the current ARTAS environment is presented followed by extensions towards the gate-to-gate ARTAS environment. In section 3 an overview of the ARTAS Surveillance function Architecture is presented. In section 4 extensions for additional sensors are discussed. Besides typical airport sensors for ground surveillance, also modern sensors for air traffic surveillance are discussed. In section 5 extensions for airport objects such as taxiing aircraft and vehicles are discussed. And finally in section 6 some concluding remarks are presented.

2 Gate-to-gate extension

2.1 Background

Surveillance quality mainly determines the performance of any other A-SMGCS function. Typical Surveillance systems at present-day airports consist of one Surface Movement Radar (SMR, or Aerodrome Surface Detection Equipment, ASDE) with analogue or occasionally digital plot presentation for the controllers. Labelling or identification of objects is not done, and if it is there, manual input and corrections are needed. Through pilot projects it has become clear that effective surveillance at airports is a challenging application.
With the knowledge and experience of current ARTAS applications, the airport tracking domain was entered some five years ago. An analysis was made about the constraints and state of the art of airport surveillance. The safety at airports and its improvement by using A-SMGCS required much better surveillance. Main research areas were defined: need for better models of taxiing aircraft, need for tracking at low speeds, need for tracking in highly cluttered areas and need for further sensor models and extension of fusion algorithms. Several R&D paths were set up, resulting in insight knowledge of the problem area. These findings have motivated the development of advanced multi-target multi-sensor tracking techniques for the airport. From theory and models, prototypes were developed and pilot systems built. The test results were fed back into improvements of theory and models, e.g. in a similar way as ARTAS tracking had been developed.
It appeared that the novel solutions matched in theory and in architecture very well with the current ARTAS application. This has the advantage, that airport tracking solutions are easily integrated and will not need maintenance differently from the current ARTAS applications.

2.2 Airport needs

At airports special attention has to be paid to the labelling/identification and runway incursion problems. Identification, should be highly reliable, for safety reasons. With the current state-of the art availability of sensors, the only way to obtain sufficient quality of identification is to apply sensor types that use complementary sensing principles. Such dissimilar sensors should be applied, especially in highly cluttered areas like aprons. The runway incursion detection and alert function also requires highly reliable and accurate data, especially at low speed with aircraft holding position. Moreover runway incursion should be detected in time to enable the controller and pilot to react as required.
The main needs for airport surveillance improvements have been identified, such as:

- Digital tracking on top of analogue radar presentation
- Clutter suppression still having high probability of detection
- No track drop, swap, false tracks
- Coverage on blind spots
- Object dynamics tracking
- Identification, i.e. reliable labelling
- Data fusion based on raw sensor data, instead of track fusion, even when data arrives late
- Development of new and extended object sensor models
- Provide reliable object states estimates
- Seamless coverage of aircraft in the air and on the ground.
- Early detection of aircraft movement
- Accurate aircraft state vector estimation

2.3 Gate-to-gate ARTAS

The current surveillance environment outlined in the introduction will evolve in the context of the transition towards the future CNS/ATM system. The gate-to-gate system will be required to process and integrate data from a more heterogeneous set of surveillance data sources and provide processed surveillance data to users.
The main enhancement in the surveillance environment, which influences the transition from the current "conventional" environment towards the future CNS/ATM system, is the introduction of new types of sensors (e.g. SSR Mode-S, ADS-B, ADS, ASDE, and Multilateration Systems) and the resulting capability of acquiring on board data through the various air-ground data links. The advanced features of the future CNS/ATM environment create the need for modifications, both in the internal functionality and the interfaces with the functional entities of the environment, namely the data sources and users. An overview of a gate-to-gate ARTAS environment is presented in figure 2.
The following list of extensions to the Tracker and its Databases are covered:

- Extensions to incorporate new sensors
  - SSR Mode-S
  - ADS-B
  - ADS
  - SMR/ASDE
  - MLT (Multilateration)
- Airport extensions to incorporate new object dynamics
  - Taxiing Aircraft (including runway acceleration, hold, push-back, and turning on the spot)
  - Vehicles
- Airport extensions with respect to the new geographical environment
  - Infrastructure information (e.g. airport maps)
  - Specific areas (reflection areas, blanking areas, etc.)
- Airport extensions to deal with typical anomalies of the new sensors
  - Clutter plots
  - Split plots

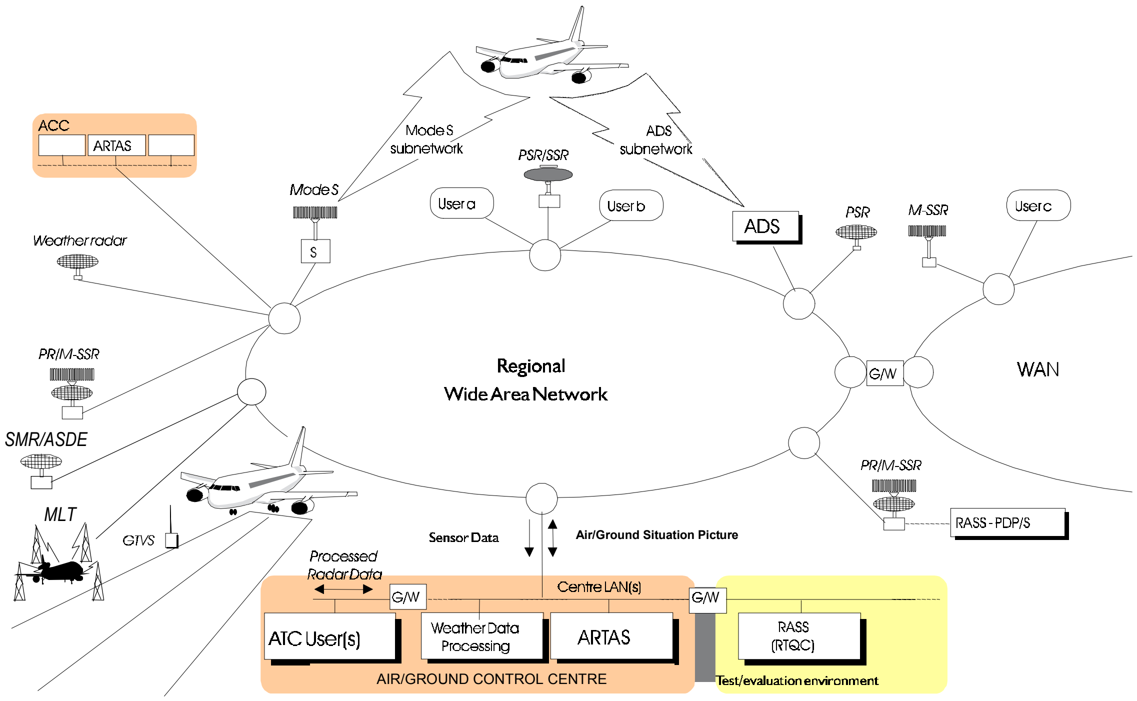

Figure 2. Gate-to-Gate ARTAS environment

- Merged plots
- Reflections
  - Static reflections (e.g. buildings)
  - Dynamic reflections (e.g. the tail of an aircraft)
- Side-lobes

3 Gate-to-gate tracking

3.1 Architecture

The main task of the surveillance function, namely to provide accurate state estimates of the objects under surveillance based on the reports of the contributing sensors, is performed by the tracker. Within the Tracker a distinction can be made between *Multi-Sensor Tracking* and *Multi-Sensor Environment Assessment*. The main task of the Multi-Sensor Tracking function is to provide estimates of the state of aircraft on the basis of incoming measurements from all contributing sensors. To this end, the *Multi-Sensor Tracking* function uses the following main (sub-) functions:

- Track Initiation
- Track Continuation
- Track Classification

The *Track Initiation* function uses the reports of the contributing sensors, that are not associated (in a nearest neighbour sense) with an existing track, to provide the first state estimate of a new track.

The *Track Continuation* function uses the reports of all contributing sensors to estimate the state of an object based on the object's previous estimate.

The Track Classification function deals with anomalies, like reflections and side-lobes. An effective way of dealing with these anomalies is to track them and to classify them as being non-aircraft.

The main task of the *Multi-Sensor Environment Assessment* function is to dynamically assess sensor characteristics that are critical to the performance of the tracker, such as false plot maps, probability of detection maps, sensor accuracy information, and systematic errors.

To optimise the performance of the surveillance system, sufficiently detailed mathematical models of the contributing sensors, the objects under surveillance, and the environment are integrated within the system.

The management of all requests from the users, and the corresponding transmission of the relevant sets of track data to these users, is performed by the Server.

A schematic overview of the architecture of the advanced surveillance tracker is presented in figure 3.

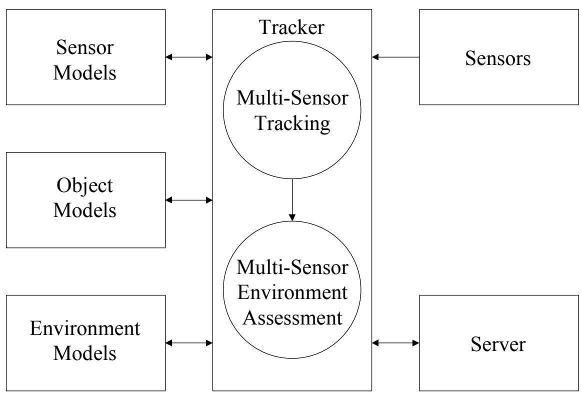

Figure 3. Overview of the architecture of the advanced surveillance function.

3.2 Advanced algorithms

Track Initiation

Track initiation is based on Multiple Hypothesis Tracking (MHT) and is done retrospectively [6]. Though a multi-sensor track initiation function is more complex than a mono-sensor track initiation function, in areas with multi-sensor coverage, multi-sensor track initiation generally yields better performance with respect to track initiation delay, extra tracks and false tracks. This is particularly true for airport environments.

Track Continuation

A Bayesian approach to track continuation is adopted which incorporates state of the art combinations of IMM and JPDA, [1], [2], [3], [5], [8], [9], [11], [13], [19], [23]. The key issue that is mastered is to handle multiple suddenly manoeuvring targets in clutter, outlier, and missing plots, while avoiding track coalescence. Full theoretical understanding allows this modular usage; avoids the need to derive new filter equations for each change in sensors, or object model.

Track Classification

An effective way of dealing with anomalies, like reflections and side-lobes, is to track them and to classify them as being non-aircraft. To that end a *Track Classification* function has been developed. The track classification function classifies tracks using a computationally efficient (Bayesian) approximation of Dempster-Shafer reasoning [7]. The criteria used in the classification are based on radar environment characteristics, object behaviour and a set of models for specific anomalies, like reflections and side-lobes. An advantage of Dempster-Shafer reasoning is the ease with which additional criteria, like object signature information, can be incorporated into the classification process.

The tracker maintains both aircraft tracks as well as non-aircraft tracks. At the output of the tracker non-aircraft tracks may be filtered out based on their classification.

The classification function has been proven to be very effective in the ARTAS tracker.

4 Extensions for additional sensors

For optimal use of all sensor information within a surveillance system, sufficiently detailed mathematical models of the contributing sensors need to be integrated within the system. Generic mathematical models for the following additional sensor categories have been developed:

- SSR Mode-S, ADS and ADS-B,
- SMR/ASDE
- Multilateration Systems

The typical use of these models is in the Tracking function and in the Multi-Sensor Environment Assessment function to dynamically assess sensor characteristics for these sensors.

SSR Mode-S, ADS and ADS-B

Generic parametric stochastic models have been developed [17], for three types of modern surveillance systems, namely for *SSR Mode-S, Automatic Dependent Surveillance (ADS)* and *Automatic Dependent Surveillance - Broadcast (ADS-B)*. In contrast to the “classical” radars, these “modern” surveillance systems are able to provide airborne parameters information.

The *SSR Mode-S* is a co-operative surveillance system that provides access to a large number of airborne parameters. These parameters include, for example, Flight identification (call-sign), aircraft intention, way-point related information, ground and air referenced vectors and meteorological data, in addition to improvements to the basic surveillance information such as unique identification and 25ft altitude coding.

Automatic Dependent Surveillance (ADS) is a surveillance application in which an aircraft automatically transmits data derived from on-board systems, via a data link. The transmission of ADS data will be based on a contract between a ground system and an aircraft.

The *Automatic Dependent Surveillance Broadcast (ADS-B)* Surveillance application allows the transmission of on board data to air and/or ground based users via a data link using a broadcast mode.

ASDE

A generic parametric stochastic model has been developed for the Airport Surveillance Detection Equipment (ASDE) sensor [22]. Use has been made of an analysis of live data from an ASDE Surface Movement Radar sensor. ASDE is basically a primary radar. The position accuracy of an ASDE is generally much better than the “classical” primary radar and the rotation time usually lies in the order of one second. Split plots may occur when two or more parts of an object are detected as separate parts by the sensor. Merged plots may occur for instance when two objects are close to each other. Furthermore, object orientation information, object size information, and signal strength information can be taken into account. Also effects that occur when objects are close to the sensor is considered.

Multilateration (MLT)

A multilateration system (MLT) basically consists of a number of antennas located at different positions and a processing unit. The antennas receive messages from object transponders that are to be located and the processing unit calculates estimated positions of the transponders. To this end the processing unit associates for each transponder message the times at which the message arrives at the different antennas to an estimated position of the corresponding transponder. This process, which uses the Differences in Times of Arrival (DTOA) of a transponder message at the different antennas to calculate the position of the transponder, is called “multilateration”. A multilateration system based on Mode-S squitter usually also provides aircraft identity

information (e.g. the unique aircraft address). A multilateration system based on Mode-S extended squitter may also provide additional information about certain aircraft parameters.
Two prototype models for a *multilateration system* have been developed [22]. The first model considers the multilateration system as one sensor providing position measurements. The second model considers the multilateration system as a small multi-sensor environment by itself, providing timestamps or difference-in-time-of-arrival (DTOA) measurements.

Multi-Sensor Environment Assessment

A Multi-Sensor Environment Assessment function has been developed to dynamically assess sensor characteristics that are critical to the performance of the tracker, such as false plot maps, probability of detection maps, sensor accuracy information and systematic errors.
The systematic error estimation runs parallel with the track continuation process [10], [11], [12]. It uses Extended Kalman Filtering to estimate the systematic errors of the sensors. Besides the estimation of the systematic sensor errors that are sensor dependent only (macro errors), the Multi-Sensor Environment Assessment function also performs estimation of the track-related errors (micro errors). These micro errors may consist of the transponder delay error (i.e. the difference between the actual delay and the nominal value of 3 microseconds as specified by ICAO) and the geometric height, estimated from position measurements in a multi-sensor environment.
The Multi-Sensor Environment Assessment function has been proven to be very effective in the ARTAS tracker.
This approach has been extended to ADS, Mode-S, ASDE and MLT.

5 Extensions for airport objects

NLR's approach towards object modelling is based on aircraft switching mode models [4], [11], [16]. The trajectory of an object is assumed to consist of a sequence of segments, during which the type of evolution of the aircraft does not change. Combined with generalised IMM, [3], [8], [9], [11], this approach has been proven to be very effective in ARTAS.
To apply these algorithms on the airports, switching mode models have been developed for taxiing aircraft [16]. This allows the surveillance tracker to quickly respond to object manoeuvres while maintaining a highly accurate estimate of the object's state vector throughout the duration of the object's track.

5.1 Taxiing aircraft model

Just as for flying aircraft, at low speeds (relative to the sensor accuracy) some typical high-speed object characteristics may become unobservable. Therefore, for taxiing aircraft also, separate models are developed for high-speed objects and low-speed objects. Note that the sensors that are used to detect aircraft on the ground, such as ASDE or a multilateration system, have a much higher accuracy than the sensors (e.g. classical radars) that are used to detect airborne aircraft. This means that compared to flying aircraft, the typical object characteristics of a taxiing aircraft are still observable at speeds that are very low in comparison to the average speed of flying aircraft.

High-speed taxiing aircraft model

For high-speed taxiing aircraft an object model based on four modes that characterise different horizontal manoeuvres has been developed. The four different manoeuvre modes are *Uniform motion, Left turn, Right turn,* and *Speed change*. The state vector consists of *x-position, y-position, ground speed, course,* and *direction of nose wheel*.

Low-speed taxiing aircraft model

For low-speed taxiing aircraft an object model has been developed that is based on three modes characterising different horizontal manoeuvres. These are *Uniform motion, Speed change*, and *Hold*. The horizontal state vector component consists of *x-position, y-position, x-velocity,* and *y-velocity*.
The advantage of using this low-speed taxiing aircraft model is that when an aircraft suddenly starts to accelerate in some direction, the tracker is very well able to follow the aircraft.

Stand still model

Clearly at a complete stand still, the course becomes unobservable. However, during taxiing, it is not very likely that an aircraft will immediately start rotating at very low speeds, so it seems reasonable to maintain the heading of the aircraft in the same direction as before.

5.2 Extensions for airport environment characteristics

For enhancing the tracking performance related to the initiation, continuation and classification of tracks, environment information may be used. To this end a model of the environment is stored in a geographical database.
For ARTAS the geographical database contains amongst others:

- Possible Temporary Reserved Areas
- TMA (Terminal Movement Area) boundaries
- Military areas
- SID (Standard Instrument Departure) and STAR (Standard Arrival) procedures
- Runways
- Route structures

For application within A-SMGCS the environment modelling techniques developed for ARTAS can serve as a basis for further development. Airport route structures and boundaries can be used for A-SMGCS surveillance similarly as route structures and area boundaries are used within ARTAS.

Furthermore, the parameter tuning of the surveillance function may be made area dependent.

6 Conclusions

In the present paper an overview is presented of the key extensions towards seamless gate-to-gate surveillance. It was clarified that the main needs for airport surveillance improvements are well served by NLR's fusion and tracking techniques based on ARTAS' architectural approach. The main extensions towards seamless gate-to-gate surveillance comprise the integration of advanced models of the new sensors, the new object dynamics, and the new environment. For optimal performance in a live environment, these models are preferably derived from live data analysis. The open architecture of the ARTAS tracker and the in depth knowledge of how the tracking algorithms can be combined allowed straightforward integration of the gate-to-gate developments.

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