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Contents

9 Figures

(11 pages in total)

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Summary

ARTAS (an acronym for ATC Radar Tracker and Server) is currently in pre-operational test at four different sites in France, Germany and the Netherlands. The ARTAS system consists of a tracker, responsible for maintaining up-to-date target state vectors, and a server, which handles client subscriptions (e.g. from the ATC display system) and delivers the target state vectors to these clients. An ARTAS system co-operates with adjacent ARTAS systems by exchanging target state vector information.

The main features of the ARTAS Tracker are

- tracking with up to thirty radars (PR, SSR or CMB)
- on-line estimation of the radar systematic errors
- on-line estimation of the radar accuracy and coverage
- high-accuracy position and velocity-vector estimation
- responsiveness to target manoeuvres
- insensitivity to clutter
- target classification

The tracking filters are interacting multiple-model (IMM)-based filters, a four-model filter for high-speed and highly manoeuvring targets and a two-model filter for low-speed targets [1]. The plot-to-track association is based on probabilistic data association (PDA), with special joint probabilistic data association (JPDA) algorithms in case of target close approach situations [2]. Track initiation is done by time-reversed multiple-hypothesis tracking. Target classification is based on Shafer- Dempster reasoning.

Introduction

ARTAS is designed as a track data server. Track data users can subscribe to a certain service and receive the track data in ASTERIX format via a local-area or wide-area network (LAN/WAN, figure 1). Users can be ATC centres, flightplan processing systems, air-traffic management units and so on. Each user can have a dedicated service, taking into account requirements with respect to data contents and update frequency. An ARTAS unit also receives its input data from the radars via the local-area or wide-area network. Furthermore, an ARTAS unit can communicate via the network with other, adjacent, ARTAS units in order to provide a continuous air-picture to its users. Track data from adjacent units is used to accelerate the initiation of tracks at the border of the unit’s own domain of interest (DOI) and to smooth the over the surveillance in case of an own unit failure. Thus, enhancing the overall reliability of the surveillance.

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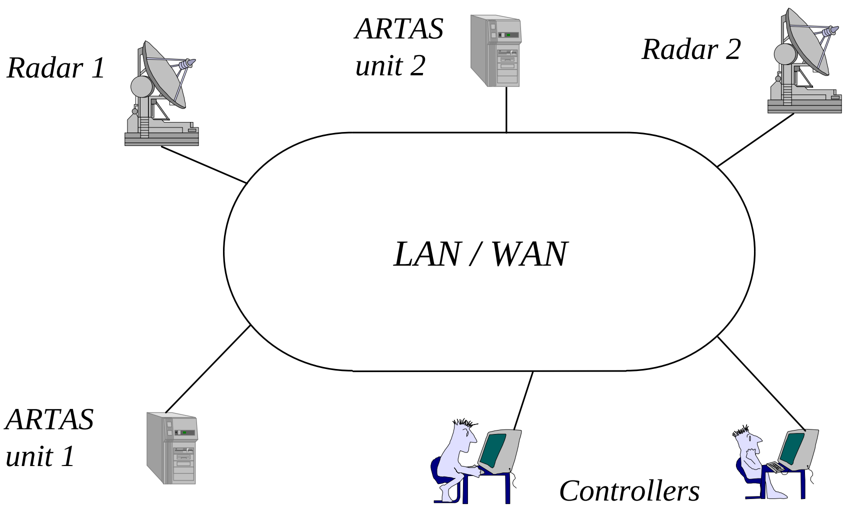


Figure 1.The ARTAS Environment

The internal structure of an ARTAS unit is shown in figure 2. The Router Bridge is the interface to the external network. It pre-processes the incoming radar data, i.e. it performs format checks and sectorisation of the plot data and keeps track of the operational status of the radars. The Server is responsible for the handling of ARTAS user requests and the distribution of the track data, according to the different user services. The most simple service that is provided is a regular broadcast of all track data. MMI/Supervision is the man-machine interface and supervision unit. It provides a basic display of the unit tracks and control functions for the ARTAS unit. The Tracker, finally, is responsible for keeping an up-to-date air picture. An ARTAS unit consists of two identical chains of a Router Bridge/Tracker/Server/MMI/Supervision subunits. All subunits operate in a multiple-computation redundancy mode; that is, there is a master and a slave subunit that both perform the same processing, except that the slave subunit does not provide any output. Instead, the slave performs some additional processing to keep master and slave in synchronisation.

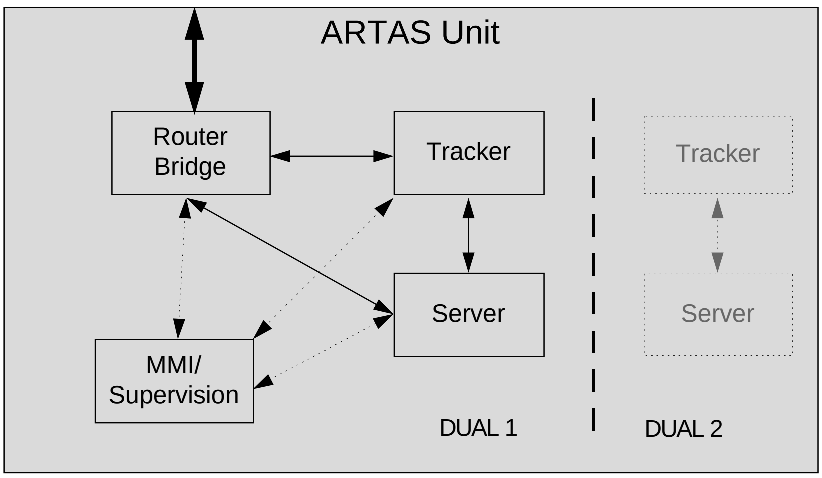


Figure 2. ARTAS Unit Internal Structure

All the ARTAS subunits run on off-the-shelf hardware and are programmed in ADA, except for the MMI, which is programmed in C++.

The ARTAS Tracker

Basically, the task of the tracker is to provide estimates of the state of aircraft in the domain of interest of the ARTAS unit. It makes use of maximum 30 sensors; present types are primary radar (PR) and secondary surveillance radar (SSR). Extensions to incorporate Mode-S and automatic dependent surveillance (ADS) data are foreseen for 1998.

A prime requirement for handling multisensor data is the ability to cope with sensor alignment errors, i.e. systematic radar errors like position bias, range- and azimuth bias, but also time-stamping bias and transponder-delay error. The latter is an example of a, so-called, micro-error; a systematic error that depends on the object being tracked. The former errors are macro-errors; they only depend on the sensor involved. Unfortunately, systematic errors may change in time, due to e.g. changing atmospheric conditions and radar maintenance. Therefore, the ARTAS Tracker contains an on-line systematic-error estimation module that is able to track varying systematic radar errors.

Another requirement for handling multisensor data is a proper treatment of coordinate transformations. This becomes a more obvious problem when the size of the system area becomes large. ARTAS uses WGS84 as a reference system. Measurement processing and track update processing are done in local Cartesian systems, such that the error, induced by coordinate transformations, is minimised. This implies that all sensors and all tracked objects have their own local Cartesian system that may change in time when objects move.

Track continuation uses the reports of all available sensors to estimate the state of a target. Each track extrapolation/update cycle is based on the reports of a single sensor, though. Subsequent cycles, however, may be of entirely different sensors. Prior to the track update, all the relevant reports are corrected for micro-errors (systematic errors that vary from target to target) and slant-range effects. Track continuation is discussed in more detail below.

Track initiation is done based on the reports of single sensors only. It is based on multiple-hypothesis tracking (MHT) and is done retrospectively [3]. Considering the fact that a new target generally enters the coverage of only a single radar, the gain of a shorter track initiation delay did not warrant the additional complexity of a multi-radar initiation in a civil ATC environment. This trade-off may not be valid in a military environment, though.

The ARTAS Tracker maintains aircraft and non-aircraft tracks since, in many cases, the best way of dealing with anomalies, like reflections and sidelobes, is to track them and to classify them as being non-aircraft. To that end, the ARTAS Tracker contains a track classification module, which classifies tracks using Shafer-Dempster reasoning [4]. The criteria, used in the classification, are based on radar environment characteristics, target behaviour and a set of models for specific anomalies, like reflections and sidelobes. An advantage of Shafer-Dempster reasoning is the ease with which additional criteria, like target signature information, can be incorporated into the classification process.

Track Continuation

For the ARTAS Tracker, a Bayesian approach to track continuation was adopted. This approach did prove to yield a high-performance tracker, as experience with the NLR JUMPDIF prototype tracker has shown [1].

Basically, there are four major problems that occur during track continuation

1. Non-linear aircraft dynamics during a turn
2. The association of measurements with existing tracks
3. The occurrence of outlier measurements (non-Gaussian measurement noise)
4. Sudden starts and stops of manoeuvres

For each of these problems, adequate solutions were already developed for the JUMPDIF prototype [1]; the result, an Interacting Multiple-Model Probabilistic Data-Association (IMMPDA) algorithm with Extended Kalman Filters (EKF) [6] was used in extensive performance tests. The results of these performance tests were used as a basis for the ARTAS Tracker performance requirement specification. A number of improvements, with respect to the JUMPDIF tracker, were made in the ARTAS Tracker, though.

For target resolution situations, new joint probabilistic data-association (JPDA) algorithms were developed [2] that perform considerably better than the probabilistic data-association (PDA) algorithm, that is used in JUMPDIF. These JPDA algorithms, however, require more computations than the PDA algorithm. In order to save CPU-load, these JPDA algorithms are only used when a target resolution situation is detected.

The ARTAS Tracker is required to track targets down to zero groundspeed. In general, it is not necessary to track low-groundspeed targets with an advanced four-model (left turn, right turn, change of groundspeed, straight flight) IMMPDA filter to get a good tracking performance. Therefore, a simplified two-model (manoeuvring flight, straight flight) IMMPDA filter is used to track these targets.

JUMPDIF contained a two-model (climb/descent, level flight) IMMPDA filter for SSR mode-C measurements. In the ARTAS Tracker this filter was replaced by a three-model (climb, descent, level flight) IMMPDA filter in order to be more responsive to changes in the rate of climb/descent. Furthermore, two algorithms to estimate the target altitude in absence of SSR mode-C information were implemented. One algorithm, Triangulation, is discussed in more detail below. The other algorithm, Height-from-Coverage, uses the assessed coverage of each radar, that detects or does not detect the target, to calculate a height interval for the target. Although not very accurate, using the result of this algorithm is often better than using a default altitude.

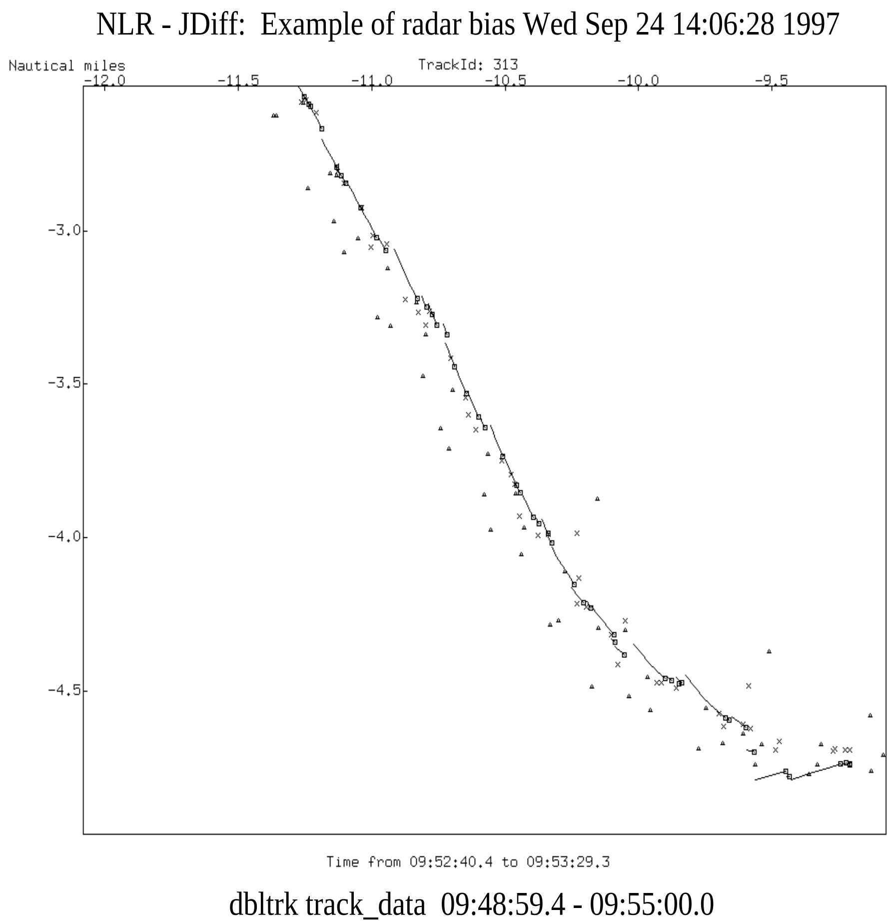
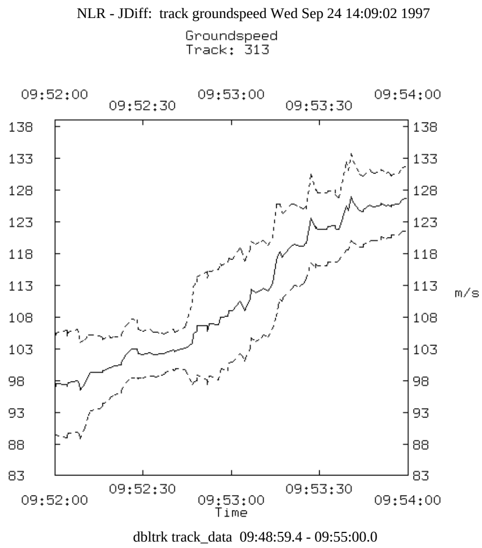


Figure 3. Example of biased plots

The key solution to the multisensor track continuation problem that is applied in the ARTAS Tracker is a proper correction for the macro- and micro-systematic errors of all involved measurements, before they are used within the track extrapolation/track update cycle. This essentially reduces the multisensor problem to a single-sensor problem. The time sequence of track extrapolation/track update cycles, obviously, contains track extrapolation/track update cycles for all the available sensors. The difference between cycles for different sensors is the use of a different measurement matrix for the Extended Kalman filters.

Figure 3 shows a track, departing from Schiphol airport, that uses biased measurements from three different radars. Triangles indicate the raw plots, crosses the nearest-neighbour plot positions (corrected for the estimated radar biases) and the squares the updated track position. The vectors indicate the predicted flightpath up to the next measurement instant. Figures 4 and 5 show the ARTAS Tracker estimates of the groundspeed and SSR mode-C height of this track, respectively.



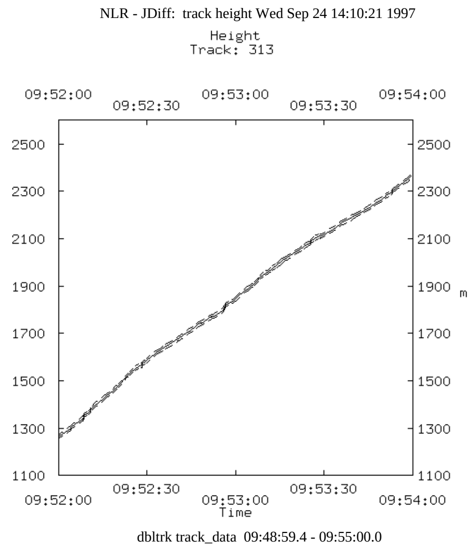


Figure 4. Track groundspeed estimate

Figure 5. Track mode-C height estimate

Systematic Radar-Error Estimation

The ARTAS Tracker estimates the following (macro-)systematic errors:

- range bias
- azimuth bias
- range gain (a range bias that increases with increasing range)
- antenna squint (non-verticality of the plane of the radar beam)
- verticality error (antenna rotation axis not perpendicular)
- time-stamping bias

The problem with dynamic estimation of the (macro-) systematic errors is that, in principle, the filter equations are coupled with the track continuation equations of the individual tracks. It is, of course, very well possible to make a selection of a small number of well-behaved tracks and to solve the resulting set of equations. In [5], a different approach is taken, which decouples the equations for (macro-)systematic error estimation from the track continuation equations. Effectively, it comes down to integration of the innovations of all tracks and filtering these innovations with a Kalman filter. Due to the larger timeconstant of the systematic error process, the filtering equations become independent of the individual track maintenance equations. This algorithm is implemented in the ARTAS Tracker and uses a selection of non-manoeuvring tracks in order to save CPU-load and to increase the speed of convergence of the estimation process. Figures 6 and 7 show results of the (macro-) systematic-error estimation process on a 2-radar PR scenario.

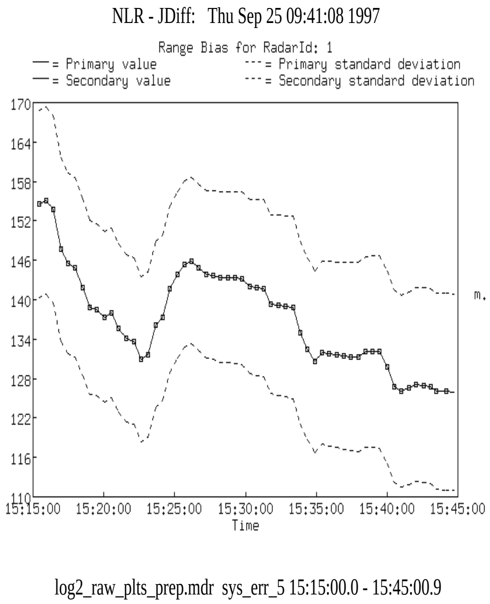


Figure 6. TAR estimated range bias

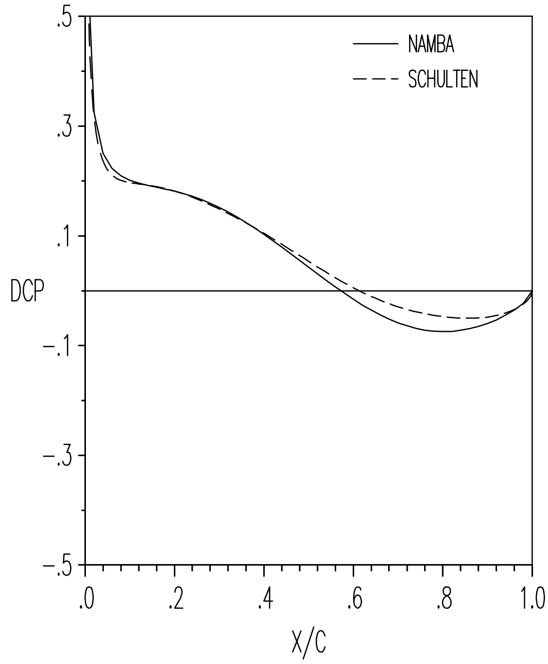


Figure 7. LAR estimated range bias

Triangulation

After estimation of the systematic radar errors that are radar-dependent only (macro errors), the track-related errors (micro errors) can be estimated. Within the ARTAS Tracker, these micro errors consist of the transponder delay error (i.e. the difference between the actual delay and the nominal value of 3 microsecond as specified by ICAO) and the geometric height, estimated from range-azimuth position measurements in a multi-radar environment.

A general solution to this problem is to extend the state vector of an object with these components and to extend the corresponding extended Kalman filter equations accordingly. Since this is a very costly solution (in terms of CPU), we have looked for a robust method that is not coupled with the track continuation equations. In situations where an SSR radar has a co-located primary radar, a robust method to estimate the transponder delay error is to average the difference in range measurements of the two radars. In other situations, the transponder delay error and geometric height estimations are coupled.

Consider the situation that two non-co-located radars observe an object at the same moment in time. To perform triangulation, we use the difference between the projections of the plots to a common 2-dimensional Cartesian coordinate system (the track-local coordinate system) as the innovation term in a Kalman-like filter update step for the estimation of the transponder delay error and the geometric height.

Since a simultaneous measurement of one object by two non-co-located radars is quite unusual, we perform a triangulation on the basis of a triplet of projected plot positions (under the condition that the track groundspeed and course are constant): the first and third projected position are interpolated to the time of the middle plot.

The performance of this algorithm depends, among others, on the geometric configuration of the radars involved: the middle plot should be from a different radar than the other two plots, with a line-of-sight opposite to that of the other radars, and as close to the object as possible.

In figure 8, we see a part of a track from a live data collection. The recording was made for 3 secondary and 2 primary radars, but the Tracker was run with only the primary plot data. The track is flying at FL 290 (8839.2 m); the plots are not corrected for systematic radar errors. The estimate of the geometric height and the 1-sigma margin are given in figure 9; the initial estimate is 6000 m.

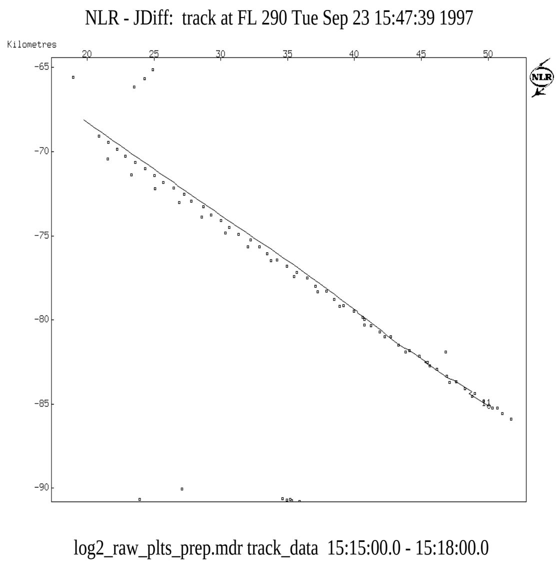


Figure 8. Track observed by 2 PR radars

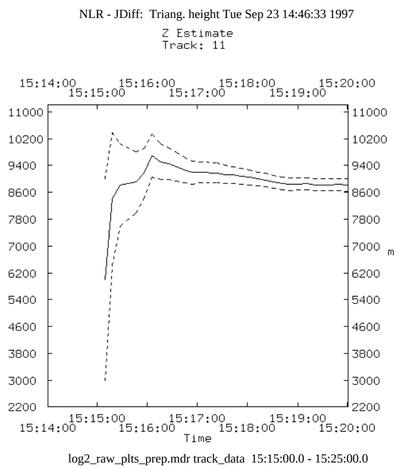


Figure 9. Triangulated height as function of time

Conclusion

Adequate systematic error estimation is a pre-requisite for accurate multisensor tracking. In the ARTAS Tracker, several powerful methods are employed for the on-line estimation of both macro- and micro-systematic errors. These methods provide accurate estimates of the systematic errors as shown by a number of examples. By having accurate systematic error estimates, the multisensor problem is essentially reduced to a time-sequential single-sensor problem, which is, obviously, much easier to solve.

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