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ABSTRACT
This paper addresses some issues in obtaining objective performance measures for surveillance tracking systems. The testing of the tracker that is part of the ATC Radar Tracker and Server (ARTAS) system is taken as an example. The applied methods, however, are applicable to any surveillance tracking system.

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OBJECTIVE QUANTITATIVE TRACKER PERFORMANCE ANALYSIS

by

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Objective Quantitative Tracker Performance Analysis

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Summary

This paper addresses some issues in obtaining objective performance measures for surveillance tracking systems. The testing of the tracker that is part of the ATC Radar Tracker and Server (ARTAS) system is taken as an example. The applied methods, however, are applicable to any surveillance tracking system.

Introduction

NLR is participating in the Eurocontrol ARTAS project, being responsible for the design, implementation and testing of the Tracker sub-system. The ARTAS tracker is based on Interacting Multiple-Model (IMM) filters [ref. [2], [3]] with Probabilistic Data-Association (PDA), in case of non-resolution tracks, and Joint Probabilistic Data-Association (JPDA), in case of resolution tracks. Track height is estimated, based on Seconday Surveillance Radar (SSR) mode-C, or, in the absence of SSR information, a sophisticated triangulation algorithm. It uses reversed-time Multiple-Hypothesis Tracking (MHT) for track initiation. Furthermore, the tracker assesses many radar environment parameters on-line, e.g. the systematic radar errors, radar accuracy, probability of detection c.q. radar coverage and false plot maps.

This paper adresses the issues encountered while testing the ARTAS tracker against the formal specifications.

The specification of the ARTAS tracker is contained in [ref. [1]]. The section on tracker performance requirements contains a detailed description of standard scenarios and the expected tracker performance under these circumstances. These requirements are based on results, obtained with the NLR JUMPDIF prototype tracker and using the prototype TRAQUME tracker analysis tool for statistical analyses. The TRAQUME tool is based on the tracker quality analysis methods described in [refs. [4], [5]], i.e. a statistical analysis of the error behaviour of the tracker as a response on a certain target manoeuvre. The, so-called, Mode-of-Flight (MOF) concept is used to define the target behaviour.

Tracker Performance Assessment

The ARTAS tracker performance requirements are based on a "black box" principle, i.e. the tracker is considered as a "black box". All tests to verify the requirements are performed by analysing the response of the "black box" on different input signals. A very important point with this type of analysis is the proper classification of the tracker input data, i.e. what type of signal is input to the "black box". To that end, the, so called, "Mode Of Flight" concept is introduced. A Mode-Of-Flight corresponds to one element of a whole set of different manoeuvres that are executed by aircraft, i.e. across-trajectory (transversal) changes: uniform motion (UM), slow, typical and expedite left and right turns (Tv-Sc, Tv-Tc and Tv-Fc), along-trajectory (longitudinal) changes: uniform motion (UM), slow and typical accelerations/decelerations (Lt-Sc and Lt-Tc) and vertical changes: uniform motion (UM), slow and typical climbs/descents (Ve-Sc and Ve-Tc). With this Mode-Of-Flight concept, it is possible to unambiguously classify the input of a tracker. Given this classification, it is now possible to measure a "static" accuracy, i.e. the accuracy while remaining in a single Mode-Of-Flight, but also the "dynamic" accuracy, i.e. the response of the tracker on a change in Mode-Of-Flight, e.g. from Uniform Motion (UM) to a typical turn (Tv-Tc).

Based on the experience, gained by the use of TRAQUME, NLR developed the MTRAQ (Multi-Radar Tracker Quality Assessment) facility. MTRAQ distinguishes six levels of abstraction

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- Level 1, being the lowest level, where inspection of the complete state vector of single tracks is possible (as a function of time).
- Level 2, where single tracks are compared against the corresponding reference trajectory. This concerns track accuracy analysis, i.e. track state vector versus reference trajectory state vector, track detection analysis, e.g. track initiation delay and track termination delay, and track MOF analysis, i.e. comparison of the track MOF versus reference trajectory MOF. These analyses can be done as a function of time, but also as a function of time, conditioned on a certain event, e.g. MOF being constant (time in MOF) or being in a resolution situation (time in close approach).
- Level 3, where RMS error statistics are computed for all tracks/trajectories in a certain class, i.e. these tracks/trajectories all satisfy a certain criterion
- Level 4, where the results from level 3 are compressed into a set of abstract parameter values, e.g. RMS peak-error or RMS-convergence value of the course angle as a function of time in MOF, after a transition from uniform motion to a typical turn (UM to Tv-Tc)
- Level 5, where the parameters from level 4 are calculated as a function of the class, i.e. the criteria of which tracks/trajectories are varied.
- Level 6, where level 5 results are compared against an externally supplied reference, e.g. a theoretical result or the results from previous analyses with different tracker-parameter settings or the results from previous analyses with a different tracker.

From each level, it is possible to navigate to the lower levels by selecting an element from the presented statistics, i.e. selecting a peak value at a certain time in level 3 will show a level 2 graph with all contributing tracks. In this way, it is possible to clarify unexpected behaviour with a minimum of effort by going to the successive lower layers and finding the offending track.

Obviously, MTRAQ supports many ways of classifying tracks/trajectories, based on time, position, MOF, orientation w.r.t. a certain radar and so on. A tool, called GRACE, adds classification based on aeronautical information. With MTRAQ, it is assumed that all analyses are done interactively. This is acceptable for normal use, but for the large number of tests that need to be performed for the formal qualification of ARTAS, it is rather impractical and time-consuming, since large numbers of similar analyses have to be done. Therefore, the report generator ORGEM (Off-line Report Generator for MTRAQ) was developed. Using this tool, it is possible to perform large numbers of analyses automatically, resulting in reports, with an adaptable amount of detail, that indicate clearly where the test results deviate from their reference values.

At present, the scenarios, that are used in the statistical analyses, are all simulated scenarios; the final goal, however, is to be able to use traffic of opportunity to analyse the track detection and track accuracy performances of surveillance trackers.

Test Method

The ARTAS tracker tests can be divided into several categories

1. Functional tests, i.e. does the system process the specified inputs, does the system perform the functions that are specified and does the system provide the required output?
2. Capacity tests, i.e. can the system handle the required input and output data rates, can the system handle the required number of input data sources and output data sinks, can the system handle the required maximum load and does the system provide the output data in time?
3. Track detection analysis, i.e. track initiation, track drop, track swap and track deletion, SSR-code acquisition, SSR-code change event analyses.
4. Track accuracy analysis, i.e. the comparison of the track state vector against a reference state vector.

Here, categories 1 and 2 will not be considered, since they are conceptually straightforward. The approach, followed for categories 3 and 4, is to use the system, outlined in the introduction, to do a statistical analysis of the tracker results with several different scenarios. The scenarios are all described in the ARTAS specification [ref. [1]] and consist of mono-radar PR, SSR and mono-pulse SSR scenarios, with different revolution times, mono-radar PR scenarios with low, medium and high false plot densities and multi-radar scenarios. In the latter case, the performance is specified in terms of an improvement over the mono-radar scenarios. The flights in the scenarios all contain a typical manoeuvre, e.g. a 0.6g turn, with a specific orientation to the radar, i.e. radial or tangential. These flights are repeated at different ranges and different azimuth values and at different time intervals to obtain a significant number of samples for the statistical analysis.

Figure 1 shows the test environment as is used for the testing of the ARTAS tracker. It is based on the Eurocontrol RASS-C system, the MTRAQ system and the ORGEM facility. The scenarios are generated through the Simulator for Multi-Radar Analysis for Realistic Traffic (SMART) and stored on disk. They are replayed in real-time and the tracks are captured and recorded on disk. The Object Correlator is used to chain the plots and to make the track-to-chain associations. In principle, the output of the Object Correlator suffices to do most of the track detection analysis, but the current MTRAQ also requires the presence of reconstructed trajectories. So, the next step to be performed after the Object Correlator is to use the Multi-Radar Trajectory Reconstruction II (Muratrec-II) tool to obtain reference trajectories. Apart from the reference state vectors, Muratrec-II also calculates the horizontal and vertical Modes-Of-Flight (MOF).

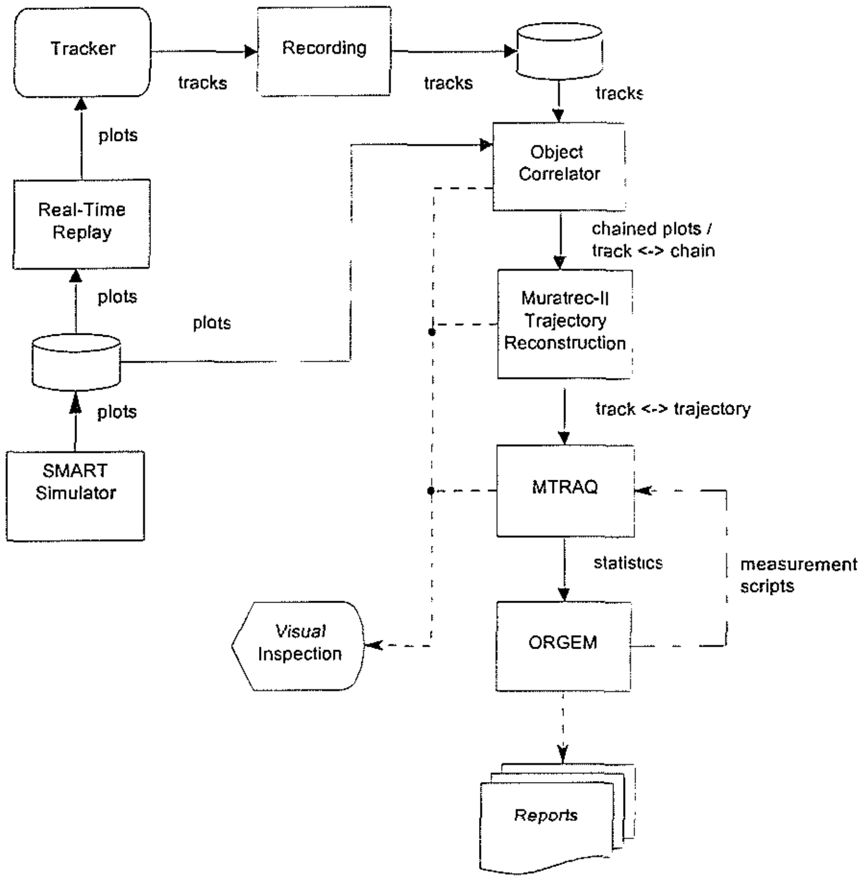

Figure 1: The Tracker Test Environment

Results

Figure 2 and Figure 3 show ARTAS tracker results, obtained with MTRAQ, testing the " static" groundspeed RMS error after convergence. The scenario contains straight flights (UM), that are initiated, so what is shown is the groundspeed convergence behaviour right after track initiation. Figure 2 shows the results of each individual track and Figure 3 shows the averaged statistic. From this averaged statistic, the RMS convergence value is determined (in this case, about 1.6 m/s), which is well below the required figure (2.05 m/s).

The results for track detection analysis are less satisfactory. First of all, the track detection analysis statistics suffer from outlier measurements, that, with the present MTRAQ, cannot be properly handled. A separate track detection analysis program is now being designed by NLR, in co-operation with Eurocontrol, that allows a direct adaptation of the input data filtering with a corresponding update of the analysis results. This allows e.g. an easy weeding of outlier results. A second problem was that, in a number of cases, the reference was no better than the result of the tracker, which obviously led to statistics that are doubtful. Furthermore, it appeared that reconstruction of mono-radar PR trajectories was not possible. The latter problem was recently solved by providing SMART reference trajectory data to MTRAQ, bypassing the reconstruction by Muratrec-II.

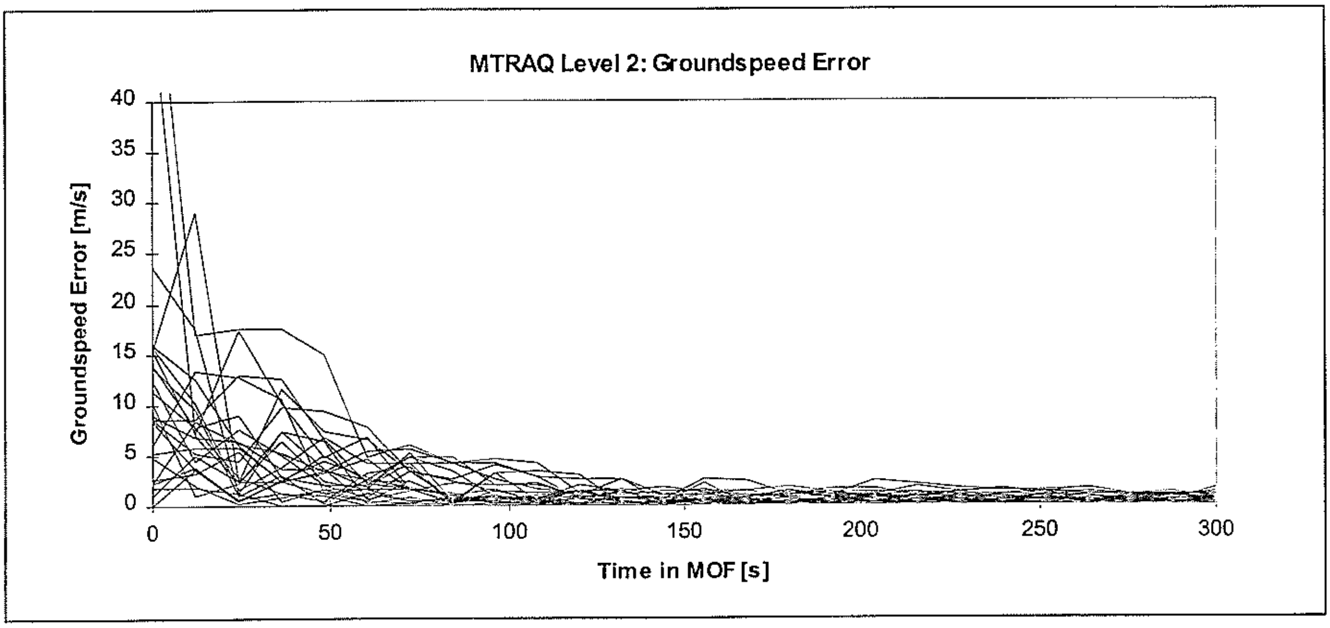

Figure 2: MTRAQ Level 2 Accuracy Analysis Result

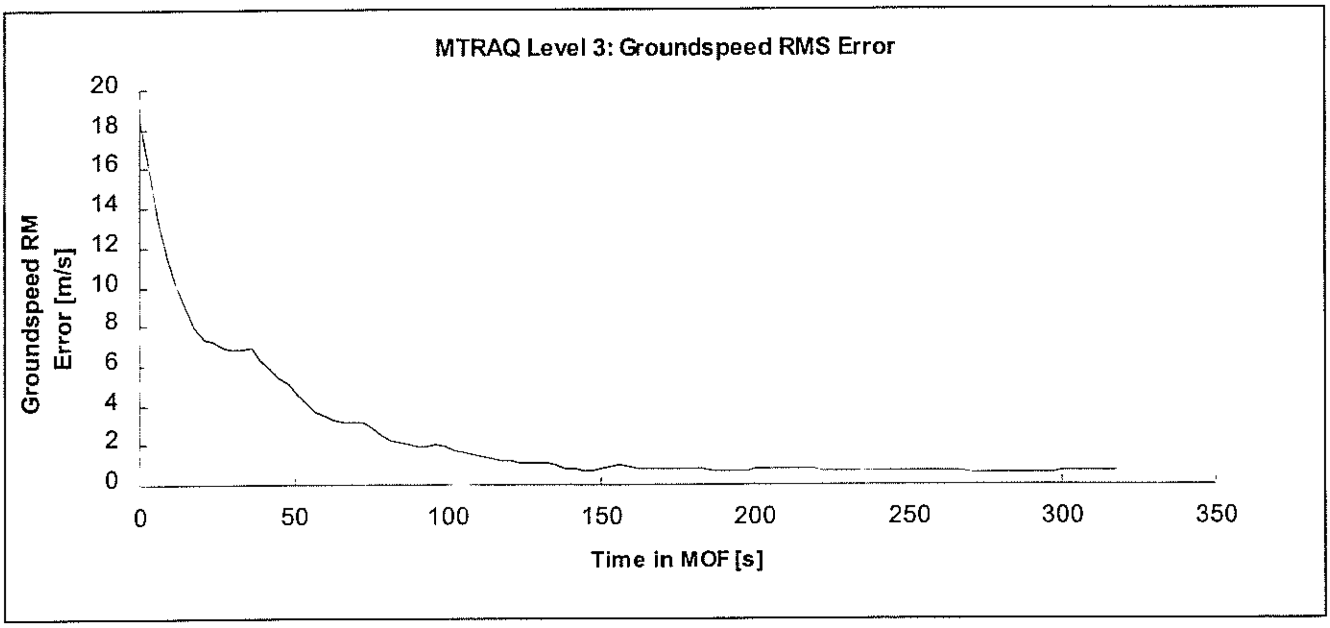

Figure 3: MTRAQ Level 3 Accuracy Analysis Result

Conclusions

The objective analysis of tracker accuracy is feasible, as is demonstrated above. Track detection analysis is, with the present system, not yet feasible. However, based on the experience gained with MTRAQ, a new track detection analysis tool is being developed, that should bypass the identified limitations of MTRAQ. When this tool is available, objective track detection analysis should be possible. Finally, future work should consider quality measures for the tracker input data, such that results can be extrapolated to different radar environments. This is a necessary step to be able to analyse the performance of surveillance trackers on-line, i.e. on traffic of opportunity.

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