DATA FUSION II, Radar Trackers

Date: January 19, 2006 **Time:** 5:00 – 7:30 PM
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Credits: 1 **Course Code:** 0901-504-04 **Registration Number:** 13459

Today's topics:

1 Course Overview

1.1 Radar Trackers from Different Viewpoints

Radar user: The tracker is a function that provides target location in real time at the ATC controller's station.

C2 Engineer: The tracker is a function in each radar system that converts detections into target positions and provides this information once per antenna rotation for each target. Position errors are uncorrelated. The SSR (secondary site radar or transponder system) has a separate tracker that provides other information such as aircraft type and ID, altitude, and other information as available from the aircraft's transponder system. The scan converter has an additional tracker that fuses the data from these two trackers in its own tracker, and provides this data to the ATC console.

Software engineer: The tracker is a set of functions and modules that accepts data from the detection software and possibly other data sources and maintains a database of radar contact position information.

1.2 Role of tracker in data fusion

The key function of the scan converter is support of the ATC consoles. This is provided by a data formatting function. The scan converter includes a data fusion, tracking, and data formatting subsystems that accept data from multiple sources (primary site radar(s) and secondary site radars, ARSR) and provides a unified database to this data formatting function.

1.3 System Engineering and Trackers

1.3.1 The System Engineering Process

The system engineering process is defined by international agreement in ANSI/EIA-632, and is evaluated in organizations with processes defined in ANSI/EIA-731. This process is characterized by a structured definition and traceability of requirements of each system function, identification and management of risk during development, design, manufacture, deployment, support, and system retirement. Requirements and risk impacts included in the tracking and management process include total life cycle cost, performance risk, system performance and reliability, and other impact on interests of users, customers and other stakeholders in the system.

Software system engineering is defined separately in the Carnegie-Mellon Institute Software Management Institute standards. See http://www.sei.cmu.edu/ and links. Process flow is similar, including requirements and risk tracking and management, but these standards have more detail than the system engineering standards.

1.3.2 Trackers and Requirements Flowdown

Tracker requirements are determined by the user. For the FAA, these include

- The tracker must be absolutely reliable when provided the correct inputs.
- The accuracy of the target position must be sufficient to allow the air traffic controller to manage air traffic and ensure safety

Implied requirements, or requirements that necessarily follow from the user requirements, include:

- The tracker must provide a reliable means to associate the radar contact data with the proper track file.
- The radar data must be formatted uniformly for consistent and correct use by the track file maintenance software.
- The radar contact data base must be maintained correctly and the data made available to the scan converters in the proper format.

1.4 Enabling Technologies

Trackers are basically simple digital filters that operate with radar data as the input and provide target position as the output. The radar data is typically in the form of target ranges at specific times, about once per antenna rotation. The tracker must provide information on target position, so it typically keeps track of radar contacts in terms of range and azimuth. The scan converter data is typically in terms of latitude, longitude and altitude. Thus we have three coordinate systems that must be accommodated in FAA trackers:

- Range at specified times, which requires antenna azimuth versus time for interpretation.
- Range versus azimuth, which is relatively straightforward. Target velocity and heading are derived from position versus time.
- Latitude and longitude versus time, which is found using range and azimuth, with radar position. Altitude is provided by the SSR and integrated with the radar contact data in the scan converter.

We achieve this, while keeping everything simple, by handling variables in more than one direction at a time – range and azimuth and latitude and longitude, for example. The algebra for doing this is the use of vectors and matrices, or linear algebra.

1.4.1 Linear Systems (Vectors and Matrices)

Vectors and matrices provide the basic notation that we need to formulate even the simplest trackers, such as alpha-beta trackers. We will show that this notation simplifies the understanding and implementation of simple range trackers, and make extension to tracking velocity and heading seamless and simple.

1.4.2 Probability and Statistics

One of the key tracker requirements is accuracy. In older FAA systems the tracker accuracy is managed through definition of the radar pulse width and antenna beamwidth so that the radar data meets accuracy requirements. This ensures that even the simplest trackers will meet radar contact accuracy requirements. However, estimating tracker errors is part of the process of ensuring that the tracker meets requirements.

Kalman filters keep track of noisy errors introduced in the input data, and use this information to weight the effect of new data on position estimates in an existing track. This means that error tracking in inherently a part of a Kalman filter, not just a way of analyzing its performance. The process uses simple statistics in mapping noisy errors through the algebra of the tracker implementation. This process, with the help of vectors and matrices in the algebra, allows tracking these errors into velocity and heading estimates in the track file.

1.5 Traditional FAA Radars

The ASR (airport air space surveillance) and ARSR (route surveillance) series of FAA radars are MTI radars. These radars use a Klystron and COHO to coherently integrate a series of pulses. The interval between pulses, the pulse repetition interval or PRI, varies from pulse to pulse. The reason this is done is so that radar contacts at a particular range or velocity will not be blanked, or self-jammed by the radar transmitting the next pulse while the radar return is coming back, and that a similar problem will not occur for any given Doppler. This is called a moving target indicator (MTI) pulse train.

MTI radars were used in early air surveillance radars, and the robustness and reliability requirements of FAA radars dictated that the first few generations of these radars be simple MTI radars. This technology has been specified for new radars and has grandfathered to the present day.

The ASR and ARSR radar series use rotating antennas without monopulse. This means that the azimuth of the radar contact is taken from the direction that the antenna was rotating through when the strongest target return is detected, or through simple measures such as sidelobe blanking, which reject returns that are not received in the direction that the antenna is pointed. The secondary site radar (SSR), or transponder system, does use monopulse and this data provides accurate azimuths for radar contacts.

The consequence of MTI radars is that Doppler information is not available to the radar trackers. In addition, as an FAA engineer at MITRE once said, "they don't have blind ranges but they do have *dim* ranges. The same applies to Doppler. Thus signal strength of radar returns varies with range and range rate.

The blind ranges and blind speeds problem is an issue with low pulse repetition frequency (PRF) radars. Most military air surveillance radars use medium PRF pulse-Doppler waveforms, which use series of pulse bursts with PRFs that vary slightly between bursts. The PRF is high enough so that there are a few blind ranges within the radar range, but the variations in PRF between bursts ensures that no range is blanked by more than one burst. Likewise, several Doppler frequencies within the range of interest are blanked because the PRF is low enough to cause this, but variations in PRF ensure that no radar contact velocity is blanked by more than one burst. Variations in apparent range and Doppler with PRF changes are used to resolve ambiguities in second-time-around radar returns, where the radar return is from the previous transmissions rather than the last one. Likewise apparent changes in Doppler frequency with PRF is used to resolve folded Doppler frequency. These techniques have been used since the 1960's and are very mature. This type of radar is called a medium PRF pulse-Doppler (PD) radar. These radars also typically use monopulse, and short-range versions use monopulse for elevation as well as azimuth. These radars provide information on range, Doppler, azimuth, and, for short-range targets with radars equipped with elevation monopulse, elevation data.

1.6 Tracker Technologies

1.6.1 Alpha-Beta, Alpha-Beta-Gamma, and Extensions

The trackers in the earliest radars were simply asking the operator to watch an A-scan or PPI and keep track of the target position. The next generation passed PPI screen data to a scan converter to provide a uniform display for air traffic converters. When radars began using digital trackers, simple hard-wired trackers implemented what amounts to one-pole digital filters. The inputs were one number – radar ranges, and the outputs were two numbers – radar ranges and range rates. The simplest formulation of how this works uses linear algebra. Although error tracking using sophisticated statistics is at the heart of how these trackers were designed, error tracking was not part of the tracker itself. Advantages of these trackers include, but are not limited to:

- Near absolute reliability is achieved.
- Near optimal accuracy performance in benign scenarios.
- Good accuracy performance is achieved in nearly all scenarios of interest to the FAA.
- Simplicity in implementation allowed its use in the earliest radars that used digital trackers.

Disadvantages of the alpha-beta and alpha-beta-gamma trackers include:

- These are basically range trackers; the classical formulations accept range data, but Doppler and azimuth data is not part of the theory.
- Extensions to accept Doppler have a complexity comparable to Kalman filters without the versatility and optimality across all scenarios.
- Extensions to accept azimuth as well as Doppler are not competitive with the simplicity of the Kalman filter.

1.6.2 Kalman filters

The Kalman filter is basically the same as the alpha-beta or alpha-beta-gamma filter, in that it implements basically a one-pole digital filter on input data to provide smoothed estimates of position of a radar contact. Differences include

- The radar measurements are posed as a vector of numbers, and the position and velocity of the contact as another vector.
- The formulation of the filter coefficients is found from the coordinate systems used in the measurements and radar contact positions.
- The filter gain weights new data to be used to update an existing track using the signal to noise ratio of the data, and the amount of noise in the track file data, so that the noise in the updated track file data is minimized.

A simple Kalman filter is indistinguishable from an adaptive alpha-beta filter that has been modified to account for signal to noise ratio.

1.6.3 Multiple Hypothesis Tracking and Track-before-detect

Dense radar contact environments are a fact of life for airport environments, and crossing tracks of similar aircraft at similar altitudes and other scenarios that cause difficulties in classical trackers are an increasing issue in tracker reliability. Multiple hypothesis tracking and other track-before-detect technologies keep “what if” tracks in the software and bring them to the forefront when it becomes obvious that they are correct.

1.6.4 Interactive Multiple Models, Particle Filtering, and Other Technologies

Interactive multiple models (IMM) is a way for a tracker to account for different possibilities in the motion of a radar contact, such as turning or straight flight, flaps up or down, etc.

2 Review of Linear Algebra

Today’s lesson will be based on Gelb, Chapters 1 and 2. The linear algebra review will be from Gelb, pages 11-24. Please take notes form the board.

3 Review of Probability and Statistics

The probability review will be from Gelb, pages 1-9 and 24-50. Please take notes from the board.

4 Homework

4.1.1 Introduction to optimal estimation

Work through Example 1.0-1 on pages 5 and 6, and use this to work Problem 1-1 on pages 7 and 8.

4.1.2 Introduction to linear algebra

Problems 2-2 page 46 and 2-5 page 47.

4.1.3 Introduction to probability and statistics

Problem 2-11 page 49.