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A REVIEW PAPER ON RADAR TRACKING

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ABSTRACT

Tracking refers to a radar following the position of one or multiple targets in space. Before the tracking process, the radar has to detect targets and find their range, angular location, and sometimes velocity. The requirements on the accuracy of angle measurement for a tracking radar are more strict than those for a search radar. The principle of tracking radar is to use the error signal to adjust the antenna's pointing direction. The difference between the target direction and the reference direction, usually the axis of the antenna, is defined as the angular error. The tracking radar attempts to position the antenna with zero angular error (i.e., to locate the target along the reference direction). Tracking radars are classified by how the tracking errors are developed. The principal tracking schemes include lobe switching, conical scan and monopulse tracking.

1. INTRODUCTION

A classical rotating air surveillance radar system detects target echoes against a background of noise. It reports these detections (known as "plots") in polar coordinates representing the range and bearing of the target. In addition, noise in the radar receiver will occasionally exceed the detection threshold of the radar's Constant false alarm rate detector and be incorrectly reported as targets (known as false alarms). The role of the radar tracker is to monitor consecutive updates from the radar system (which typically occur once every few seconds, as the antenna rotates) and to determine those sequences of plots belonging to the same target, whilst rejecting any plots believed to be false alarms. In addition, the radar tracker is able to use the sequence of plots to estimate the current speed and heading of the target. When several targets are present, the radar tracker aims to provide one track for each target, with the track history often being used to indicate where the target has come from.[1]

When multiple radar systems are connected to a single reporting post, a multiradar tracker is often used to monitor the updates from all of the radars and form tracks from the combination of detections. In this configuration, the tracks are often more accurate than those formed from single radars, as a greater number of detections can be used to estimate the tracks. In addition to associating plots, rejecting false alarms and estimating heading and speed, the radar tracker also acts as a filter, in which errors in the individual radar measurements are smoothed out. In essence, the radar tracker fits a smooth curve to the reported plots and, if done correctly, can increase the overall accuracy of the radar system. A multisensor tracker extends the concept of the multiradar tracker to allow the combination of reports from different types of sensor - typically radars, secondary surveillance radars (SSR), identification friend or foe (IFF) systems and electronic support measures (ESM) data.[2]

A radar track will typically contain the following information

- Position (in two or three dimensions)
- Heading
- Speed
- Unique track number

In addition, and depending on the application or tracker sophistication, the track will also include

- Civilian SSR Modes A, C, S information
- Military IFF Modes 1, 2, 3, 4 and 5 information
- Call sign information
- Track reliability or uncertainty information

2. General approach

There are many different mathematical algorithms used for implementing a radar tracker, of varying levels of sophistication. However, they all perform steps similar to the following every time the radar updates:

- Associate a radar plot with an existing track (plot to track association)
- Update the track with this latest plot (track smoothing)
- Spawn new tracks with any plots that are not associated with existing tracks (track initiation)

- Delete any tracks that have not been updated, or predict their new location based on the previous heading and speed (track maintenance)[3]
- Perhaps the most important step is the updating of tracks with new plots. All trackers will implicitly or explicitly take account of a number of factors during this stage, including:
- a model for how the radar measurements are related to the target coordinates
- the errors on the radar measurements
- a model of the target movement
- errors in the model of the target movement[4]

Using this information, the radar tracker attempts to update the track by forming a weighted average of the current reported position from the radar (which has unknown errors) and the last predicted position of the target from the tracker (which also has unknown errors). The tracking problem is made particularly difficult for targets with unpredictable movements (i.e. unknown target movement models), non-Gaussian measurement or model errors, non-linear relationships between the measured quantities and the desired target coordinates, detection in the presence of non-uniformly distributed clutter, missed detections or false alarms. In the real world, a radar tracker typically faces a combination of all of these effects; this has led to the development of an increasingly sophisticated set of algorithms to resolve the problem. Due to the need to form radar tracks in real time, usually for several hundred targets at once, the deployment of radar tracking algorithms has typically been limited by the available computational power.[5]

3. Plot to track association

In this step of the processing, the radar tracker seeks to determine which plots should be used to update which tracks. In many approaches, a given plot can only be used to update one track. However, in other approaches a plot can be used to update several tracks, recognising the uncertainty in knowing to which track the plot belongs. Either way, the first step in the process is to update all of the existing tracks to the current time by predicting their new position based on the most recent state estimate (e.g. position, heading, speed, acceleration, etc.) and the assumed target motion model (e.g. constant velocity, constant acceleration, etc.). Having updated the estimates, it is possible to try to associate the plots to tracks.

This can be done in a number of ways:

- By defining an "acceptance gate" around the current track location and then selecting:

- The closest plot in the gate to the predicted position, or
- The strongest plot in the gate
- By a statistical approach, such as the Probabilistic Data Association Filter (PDAF) or the Joint Probabilistic Data Association Filter (JPDAF) that choose the most probable location of plot through a statistical combination of all the likely plots. This approach has been shown to be good in situations of high radar clutter.

Once a track has been associated with a plot, it moves to the track smoothing stage, where the track prediction and associated plot are combined to provide a new, smoothed estimate of the target location.

Having completed this process, a number of plots will remain unassociated with existing tracks and a number of tracks will remain without updates. This leads to the steps of track initiation and track maintenance.[6]

4. Track maintenance

Track maintenance is the process in which a decision is made about whether to end the life of a track. If a track was not associated with a plot during the plot to track association phase, then there is a chance that the target may no longer exist (for instance, an aircraft may have landed or flown out of radar cover). Alternatively, however, there is a chance that the radar may have just failed to see the target at that update, but will find it again on the next update. Common approaches to deciding on whether to terminate a track include:

- If the target was not seen for the past M consecutive update opportunities (typically M=3 or so)
- If the target was not seen for the past M out of N most recent update opportunities
- If the target's track uncertainty (covariance matrix) has grown beyond a certain threshold.

5. Track smoothing

In this important step, the latest track prediction is combined with the associated plot to provide a new, improved estimate of the target state as well as a revised estimate of the errors in this prediction. There is a wide variety of algorithms, of differing complexity and computational load that can be used for this process.

6. Tracking with radar

There are at least four different radar methods for obtaining the track of a target, as described below.

6.1 Single-Target Tracker (STT)

The single-target tracker continually engages one target with a high data rate. Ten target observations per second is a typical data rate for military tracking radars. Tracking in range and angle is performed with a closed-loop servo system so as to keep the radar positioned on a moving target. Monopulse trackers are the most accurate tracker and have a high degree of resistance to deliberate countermeasures, which is why it has been the preferred tracking method for military air defense systems based on the STT. In a monopulse radar, the angle measurement in one coordinate is determined by using two beams slightly displaced (squinted) in angle. Transmission occurs on the sum of the two squinted beams and reception on both the sum and the difference of the two beams. The angle measurement is obtained with the difference pattern. The sum pattern provides detection and the measurement of range. The sum pattern signal also acts as a reference signal to determine in which direction is the angle error. To provide angle measurements in two angle coordinates, four squinted antenna beams are required. A monopulse tracker has three receiving channels: a range channel and two angle channels.

The *conical scan* STT is much simpler than a monopulse tracker in that it needs only one receiving channel to extract the angle measurement in two angle coordinates. A single offset (squinted) antenna beam is rotated typically at a rate of about 30 Hz. The conical scan tracker time-shares a single beam to sequentially obtain the angle measurements in two coordinates; whereas, a monopulse radar obtains its angle measurements simultaneously. Conical scan radars are used where accuracy and vulnerability to electronic counter- measures are less important than a simpler, lower cost system.

6.2 Automatic Detection and Track (ADT)

A conventional rotating air-surveillance radar such as employed for air-traffic control obtains an azimuth angle measurement on each rotation, or scan, of the antenna. Tracks can be established based on this lower scan rate (revisit times from 4 to 12 s). Automatic tracking is combined with automatic detection and is called automatic detection and track. The data rate is considerably slower than that of a single-target tracker, but a single ADT system might be able to hold in track many hundreds or thousands of aircraft targets. Tracking is done open loop in that the position of the antenna is not controlled by the processed tracking data as it is in a closed-loop STT.

6.3 Phased Array Radar Tracking

Multiple targets can be tracked on a time-shared basis with an agile electronically steered phased array radar. Tracking is not closed loop, but it combines the high data rate of a STT with the ability of an ADT to hold a large number of targets in track.[7]

6.4 Track While Scan (TWS)

This term has been applied to both the ADT and to a radar which rapidly scans a limited angular sector to maintain tracks with a moderate data rate on a modest number of targets. TWS is now almost always applied to the latter meaning rather than to an ADT system. Angle information can be obtained in a TWS radar by using two scanning fan beams perpendicular to each other, one for the azimuth angle measurement and the other for the elevation angle measurement. A TWS radar can also be obtained with a single cluster of four monopulse beams scanning in a raster fashion to provide the required volume coverage.[8]

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