Automatic Tracking

Jazmine Boloor
EE 495: Radar in Industry, University of Nevada, Las Vegas
Department of Electrical and Computer Engineering
Email: boloor@unlv.nevada.edu

Abstract: **Automatic tracking is means of target tracking in which the positioning, velocity, and acceleration of an object can be detected while the object of tracking may continuously move. This is commonly used in target detection, as moving targets be tracked as they fly. The tracking cycle loop is generally characterized by an input parameter being measured, filtered, and controlled before its response is given as an output of a parameter such as range, acceleration, or velocity. The range-tracking, doppler-tracking, and angle-tracking loops are commonly used methods of tracking that use the angular positioning of the target to detect information about its range. Track-while-scan is a tool used that combines the tracking and searching of objects or targets. The radar will successively scan for targets through a process of pre-processing, correlating, initiate/deleting, filtering, and forming gates before a new correlation is made with new gates. This filters their data so that new important information can be established for them.**

Index terms: **Angle-tracking loop, automatic tracking, doppler-tracking loop, range-tracking loop, single-target tracking, track-while-scan**

I. INTRODUCTION

Radio Detection and Ranging, also known as radar, is a system that is used to determine the range, angle, or velocity of an object or target. The detection system operates via communication and analysis of radio waves. Therefore, an important aspect to radar is encompassed by tracking objects and their positioning in order for the radio waves to communicate effectively. Automatic tracking is a means of target tracking in which the positioning, velocity, and acceleration of an object can be detected while the object of tracking may continuously move. There are two main detection techniques that will be discussed in this report - single-target track and track-while-scan. These techniques encompass a wide variety of target tracking assets.

This report will detail target detection, and commonly used jargon in the radar industry may be used. This jargon may include discriminant - or the calibration of measurement, and/or estimate - or the word for a value of a parameter that is measurable with interference or not measurable at all [2]. Note that with the nature of radar, almost all of the parameters that will be discussed in the remainder of this report will be estimated values, as radar is almost always accompanied by noise interference.

II. OVERVIEW OF SINGLE-TARGET TRACKING

Single-target tracking is a technique of automatic tracking that allows for data about a chosen object or target's position and movement to be tracked. This can be done while the object is moving, meaning that the data is continuously updating with new detection information. The tracking is performed through semi-independent tracking loops that operate separately. These loops have internal functions that can be best characterized in four general topics: measuring, filtering, controlling, and responding.

A. Tracking Loop Cycle

The block diagram shown in Fig 1 illustrates the overview of the tracking loop cycle.

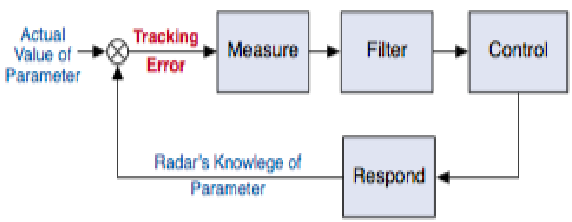

Fig. 1. Tracking Loop Block Diagram [2]

The measurement function in this loop tracks and analyzes the target's range. This is then compared with the current data known on the object to find the tracking error that may arise. The use of measuring range is especially useful for moving targets, as their position is constantly changing.

Filtering is an integral part of the accuracy of target tracking. After the objects range is measured, it is placed through a filter to remove unwanted noise or variations that may corrupt or interfere with accurate processing of the signal. There are many different factors that can contribute to the unwanted variations that the target tracking can create. These could include target scintillation, thermal agitation, and/or other interference [2]. The filter that is used must be able to constantly adapt to the changing factors in the target, such as the signal-to-noise ratio (SNR) and the potential/actual maneuvers of the object [2]. This is commonly referred to as low pass filtering but emphasizes the importance of the adaptation of the filter to the target's range and characteristics. This is especially important in reference to the filter's cut-off frequency and gain, as intuitively, different targets at different ranges/accelerations/velocities will require different levels of filtering. A key factor to consider with filtering in this loop is to eliminate as much lag as possible, as a high precision filter may result in a larger than desirable lag in the data that it is processing. This is a tradeoff that should be considered in single-target tracking. Subsequently, being able to adjust the filter adequately is integral to the accuracy of this type of target tracking.

Shown next in the block diagram in Fig. 1 is the controlling function of the tracking loop. This creates a controller based on the needs of the system. This controller is based on the output of the filter that comes previous to it. Furthermore, the controller is designed so as to reduce any tracking error that may have occurred [2]. This allows for a generated command to further analyze and reduce any error that may arise with tracking, subsequently creating a more reliable system [2].

The last function in the tracking loop cycle is the responding feature. This analyzes the data that is outputted from the controller, and then compares it to the current value that is stored from the controller [2]. The difference between these values is then fed back into the measuring function along with a new actual value, and this four function process repeats [2]. This loop can create a very precise tracking system if used correctly.

III. TRACKING LOOPS

There are several different loops that are used in single target tracking that involve angle tracking. The following section will detail some commonly used ones, namely range-tracking, doppler-tracking, and angle-tracking [2]. In essence, these loops use the angular positioning of the target in question to accurately detect range/speed related information about it. This is a vital tool in radar detection, as the tracking loops can create accurate data on the location of a potential target.

A. Range-Tracking Loop

The range-tracking loop is a method of tracking that focuses on the object in question's echoes. The echoes that it analyzes are used in doppler and angle tracking, mentioned above. The main objective of this loop is to continuously find a target's range [2]. Furthermore, it is to keep a range-gate of adjacent sampling points that are centered around the target's echoes [2].

There are three radar modes that are required to range track. These include search, acquisition, and track [1]. To go further into the operation of the range tracking loop, the general loop can be analyzed. The loop begins with raw video signals being sent into a time discriminator [1]. This is done at sampled intervals that are measured by the pulse width of the signal, creating an "early range bin", R_E, and a "late range bin", R_L [2]. These are then stored and analyzed, and the difference between the two samples produces a video signal which shows the range tracking error, E [1]. Thus,

$$R \propto R_L - R_E \quad (1)$$

where R is the targets range [2]. This information can then be sent though integrators to create output data about the range and positioning of the target in question [1]. Fig. 2 shows this operation pictorially - it is clear that the sampling times are centered on the range gate to produce an accurate tracking range based on the current sample [2].

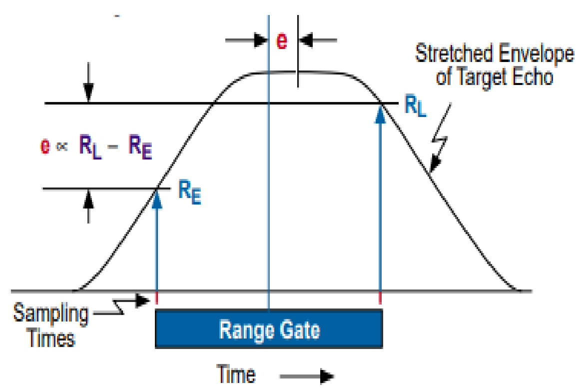

Fig. 2. Tracking Loop Block Diagram [2]

Note that the value must then be divided by the sum of the magnitudes of the samples for a non-dimensional analysis. This produces the range discriminant, ΔR, where:

$$\Delta R = \frac{R_L - R_E}{R_L + R_E} \quad (2)$$

This range is then filtered in comparison to the previously stored value to produce outputs that describe range, range rate, and rage acceleration estimates for the target. The cycle is then automatically repeated with new information that is collected, as the system is continuously operating successively. Though the process of target tracking can either be manual, semiautomatic, or completely automatic, the most accurate data occurs when it is automatic [1]. The automatic cycle will continuously update the tracking information on a target or object that is in question. This allows for a constantly updated and time relative system. For clarity, Fig. 3 is included to show the process of the filtering process of the range tracking loop pictorially.

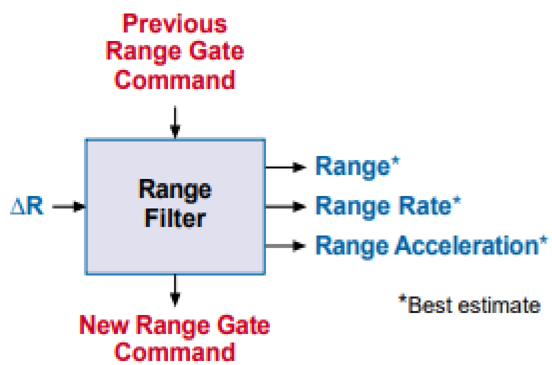

Fig. 3. Range Filter Inputs/Outputs [2]

Note that the range gate is a prediction of the range of the target based on previously collected data. This gives an estimate based on information that is beyond what is already known about the range of the target, as it is inferred based on algorithms with previous range information stored in them. In short, this method of target tracking produces estimates for the range, range rate, and range acceleration of a target that may be moving.

B. Doppler-Tracking Loop

The doppler tracking, or range rate tracking loop has two main goals which include producing a more accurate range rate than the range tracking loop and keeping the velocity gate centered on the targets doppler frequency to extract the targets return [2]. The doppler effect occurs when an observer notices a change in the frequency of a wave due to the change in the objects positioning [1]. This is the basis of this tracking loop. An integral part of this process surrounds estimating the velocity gate. This can be done by finding the crossing point of two doppler filters, commonly called the low (V_L) and high (V_H) frequency filters. The intersection of these two filter frequencies shows the velocity gate point. This is illustrated in Fig. 3 [2].

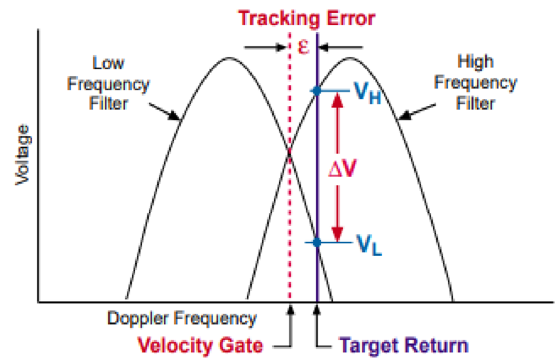

Fig. 4. Velocity Gate Filter Crossing [2]

Furthermore, the difference of these two filters (which is then divided by their sum to find the non-dimensional value), is called the velocity discriminant [2]. This is illustrated below, where the crossing point (velocity gate) and return show the range of the tracking error [2]. Thus,

$$\Delta V = \frac{V_H - V_L}{V_H + V_L} \qquad (3)$$

Then, the filter for the doppler tracking loop operates very similarly to the filter for the range filter described in Fig 3. Moreover, the outputs of the doppler tracking loop have shown to be more accurate than the range tracking loop, particularly in reference to its range rate and range acceleration estimates.

Also shown in Fig. 4 is that the tracking error is proportional to the distance from the velocity gate to the level at which the high and low filters meet each other. The smaller this area is, the smaller the error will be. This further stresses the importance of estimating the velocity gate correctly, as it immediately affects the error that the system will create. For an accurate system, this distance would in turn be very small, and only unchangeable factors would be introduced as noise or error.

The controller function for this tracking loop is usually characterized by a command that is based around the velocity gate [2]. That is, a command that predicts the next tracked doppler frequency of the target in question using the crossing value of the high and low frequency filters. This command is then applied to an RF oscillator whose output is then mixed with a sampled signal to shift the frequency to the center of the new velocity gate [2]. Thus, the predicted doppler frequency is the sum of the oscillator frequency and the gate frequency, shown pictorially in Fig. 5 with an included target reference.

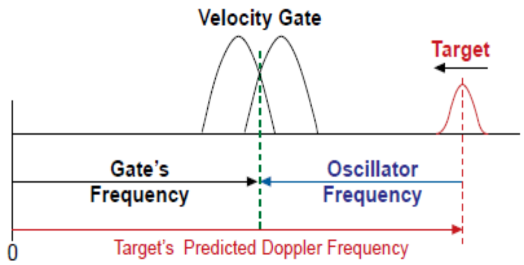

Fig. 5. Doppler Frequency Prediction [2]

A. Angle-Tracking Loop

The main theory that surrounds the angle tracking loop is to determine a targets angle and angle rate in reference to a certain coordinate system, while simultaneously keeping the antenna boresight on the target [2]. This is done by measuring the angel between the antenna boresight and the path to the target in an angular fashion. The angle created by these two measurements is called the angle of boresight, ε. This angle is integral to the positioning information on the object and is normally given in azimuth/elevation coordinates [2]. This angular information can be used for several different data parameters on the target in question.

As mentioned previously, the angle and angle rate of a target is relative to a certain coordinate system. It is important to note that several different coordinate systems exist. Fig. 7 at the top of the following page details some commonly used ones. Note that these obviously differ based on factors such as user, object, and application. Also, the common systems are all three dimensional, similar to an x-y-z plane Aircraft, fixed-nonrotating, stabilized aircraft, and antenna coordinate systems are detailed in this figure along with their associated fixed variables and dimensions. Moreover, a coordinate system must be used in analysis to make sense of the data that is received [3].

There are several different methods that are used to sense and evaluate the angle of boresight (AOB). These include methods such as sequential lobing, amplitude-comparison monopulse, and phase-comparison monopulse [2]. They are very similar techniques, so for brevity, only amplitude-comparison monopulse will be explained. In this technique, antenna radiation is split into two paths, which then cross at their half power points [2]. Fig. 6 shows these two paths, labeled lobes, and shows that the AOB can be estimated by taking the difference between the two lobes.

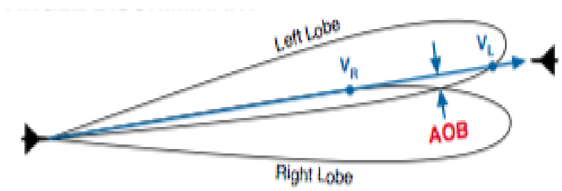

Fig. 6 Left and Right Lobe of AOB [2]

Thus, the discriminant of the AOB can be found by taking the difference of the voltage returns and dividing by the amplitude, or

$$\Delta AOB = \frac{V_R - V_L}{V_R + V_L} \qquad (4) \quad [2]$$

Note that the antenna lobes cross on the line of boresight, thereby making the AOB proportional to the difference between the two voltage returns of the lobes.

The monopulse concept originated from tracking systems and are now commonly used in PSR and SSR systems worldwide [3]. The theory behind it states that a target will be seen by the radar as soon as it enters the area of which the radar antenna beam reaches [3].

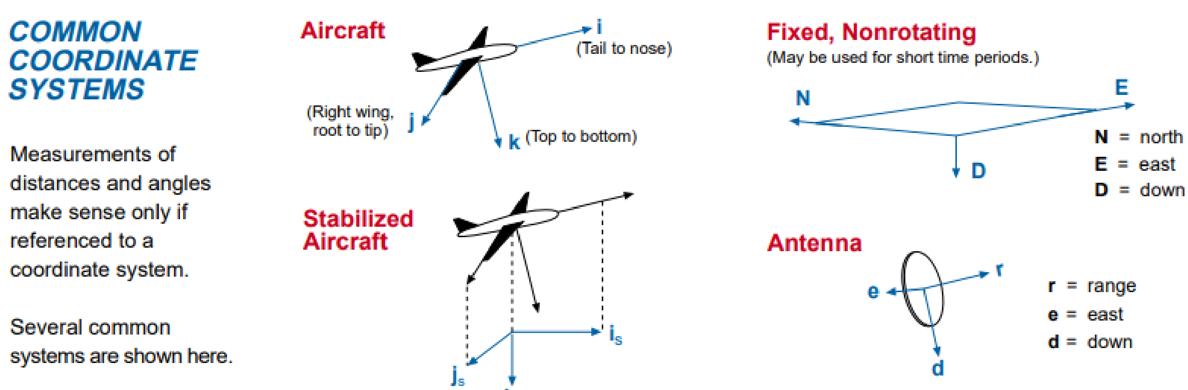

Fig. 7 Common Coordinate Systems Used in Angular Tracking

The angle tracking method requires the azimuth angles positioning, which again, is only an estimate. This adds additional error into the data detection information that it is processing. It must be noted that this, along with thermal noise errors and target fluctuation errors may slightly distort the data that is being processed, and any countermeasure than can be taken should be enacted in order to prevent any noise [3]. Note that the error that is in question is any distance from the object that is not calculated. This is shown in Fig. 8.

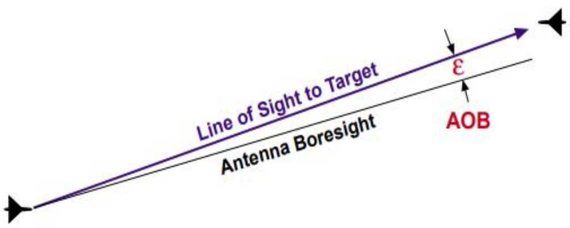

Fig. 8 Where Error Occurs

The filtering feature of the angle tracking loop has several inputs, the first of which is the AOB. In addition to this, the SNR, velocity, target range, range rate, and antennas angle rate must also be inputted [2]. With these inputs, the filter can estimate the azimuth and elevation of the AOB, as well as the angle rate of the line of sight and the acceleration of the target [2]. These estimations further improve the accuracy of the target detection that can be made after the command step is taken, which occurs next.

The command feature of the angle tracking loop has the main function of creating the azimuth and elevation rates based on the information that the filter provides. This data is then sent into a control system that stabilizes the antenna information [2]. In turn, the output of this control system is the estimate of the boresight angular rate. It should be noted that electronically modified antennas, another command system would have to be implemented to correct any unwanted noise or interference [2]. These commands would have to be inputted into the antenna at very high rates in order to keep up with the flow of data and accurately track the target. Nonetheless, the systems would work after the commands were perfected.

IV. TRACK-WHILE-SCAN

Track-while-scan (TWS) is another form of tracking an object that involves searching and pinpointing the range of the object. Moreover, in this method of search and track, satellite imagery is analyzed repeatedly by the radar in attempt to independently store data on each scan. In this process, if a scan detects a target, the radar provides the TWS function with estimates of the range, doppler, azimuth, and elevation [2]. Each scan that does indeed show to detect a target will have its own associated observation data.

When searching, the operator has an integral role in determining the status of the targets. That is, the operator must decide whether or not the targets detected are the same as those detected by the previous scans [2]. This is one of the advantages of TWS - it performs this action automatically. This automaticity is incredibly complex and is sighted as “one of the most complex algorithms in the radar” [2].

There are five basic steps in the process of TWS in order to accurately track the flight path of a target [2]. These steps are illustrated in the loop they take in Fig. 9. Namely, these steps are preprocessing, correlation, track initiation and deletion, and they are detailed just below the figure. [2].

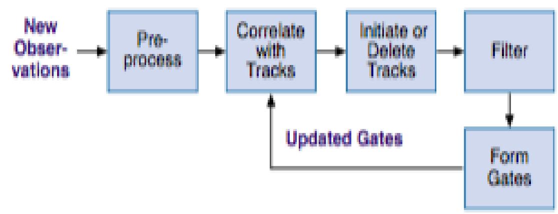

Fig. 9 Track-While-Scan Block Diagram [2]

Preprocessing is the first step that a new observation will go through in the process of TWS. Hereby, the scanned data will be analyzed, and if two observations have the same range, range rate, and angular position, the two are combined so as to not have repeats of the exact same observations [2]. Then, the observations are transferred into a coordinate system such as the ones shown in Fig. 7. The fixed, non-rotating NED coordinate system is common for this function, as the cosines of angels are easily found given the north, east, and down directions.

After preprocessing, the observation is sent through a state that involves correlation. That is, whether or not the observation should be assigned to an existing track is determined [2]. This is done through a filtering process that predicts the parameters of the next component. Then, a gate scaled to the maximum error in measurement and prediction is used as a reference for the parameters in the observation. That is, if an observation is within the bounds of the gates for the track, it will be assigned to it [2]. Fig. 10 shows the gates predicted positioning, and the entire process as a whole. It should be noted that some error may occur with assignment but can be resolved using an algorithm that takes into account all of the components of the observation.

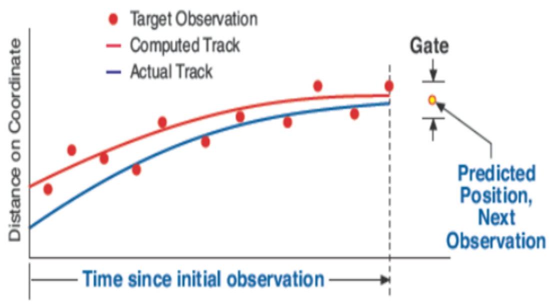

Fig. 10 TWS Correlation and Gate Prediction [2]

It is important to note that problems with correlation may occur. For example, Fig 11 shows a common issue that may arise when correlation is occurring. It is clear that observation O_1 is in the middle of two tracks. In instances like this, oftentimes O_1 will be assigned to T_1 because it does not have any other observations assigned to it. Observations O_2 and O_3 will be assigned to T_2, as they are clearly a smaller distance away from the center of track 2 than they are from track 3.

After correlation is completed, the tracks are either created or deleted. To be more specific, if another scan is conducted and an observation confirms the track, it is a created track. If another scan does not confirm the track, it is deleted. This occurs because the observation is said to be showing a false alarm, or a false positive [2]. Fig. 11 shows the error observation O_4, which does not fit in one of the existing tracks. This means that in the case that the next scan does not include a track around it, it will be deleted and thought of as a false alarm [2].

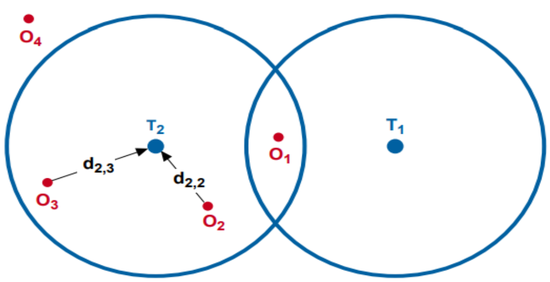

Fig. 11 Example of a Correlation Conflict [2]

Before the eventual creation of the gates, filtering must occur. This filtering step is similar to that of single-target tracking. It will update the predictions and analyze them to create new ones for the future scans. This allows for accurate data on the scans, as the predictions are made by an algorithm that is updated after each scan. The information becomes increasingly accurate as the cycle continues.

The last step in the TWS cycle involves forming gates. Moreover, with the information about the tracks known and filtered, new and updated gates can be formed and then inputted into the correlation function [2]. Repetition of this cycle allows for accurate data about the target to be recovered. As the cycle is performed over and over, its results can be observed more clearly. This is because the gates will be updates so that they are newly positioned into a better place for analyzation of the target. As this positioning changes, the computed track becomes much closer to the actual one.

V. CONCLUSION

Automatic tracking is a vital resource in target location and analyzation. Single-target tracking generally optimizes semi-independent tracking loops [2]. These loops have functions that allow for them to measure, filter, control, and respond to its input data in order to produce accurate data about its targets range and range-related information.

The three introduced tracking methods are range tracking, doppler tracking, and angle tracking. The difference between these systems, beyond some makeup and mechanics, lies mostly in the way that they calculate error. Range tracking produces error that surrounds the time the sample was taken. That is, each scan is compared to those previous to it. Doppler tracking produces error because it is comparing adjacent doppler filters. Angle tracking produces error because it compares the data that is returned from two antenna lobes. These obviously have different operations, and for this reason, the application of each should be based on the scenario at question.

The return of the measurements are sent through a low pass filter to exclude any data that is beyond the gain and cut off frequency [2]. These filters are constantly being controlled and updated so as to keep the information it is passing through accurate as an object may move through space. This is done by keeping a close eye on the signal to noise ratio and movements of the target in question. This can reduce any unwanted noise, but the lag of the system that may occur with very accurate return information must also be kept in mind during the design of the controller with respect to its application.

The output of the filters then goes through an algorithm to reduce their tracking error further. In radar tracking, the sampling times are adjusted, while in doppler tracking, the frequency is shifted and in angle tracking the rate gyros are reanalyzed.

Track-while-scanning is another target detection method that finds targets by constantly automatically tracking and scanning for them. This scanning occurs successively, and accuracy comes with more scans. Each discovered observation within a track builds a gate based to further improve the system. That is, as observations are recognize and added, the system has a better idea of how to operate. As new observations are detected, new tracks are added/deleted if necessary, based on the new data. All in all, automatic tracking is integral to accurate radar tracking of objects that may be flying in the air.

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