System Complexity

Abstract

I graduated from the University of Aberdeen with a degree in electronics and electrical engineering. As part of the finial year of my degree I completed an undergraduate thesis where I considered the concept of a multi static passive radar system capable of tracking commercial civil aircraft using transmitters of opportunity. In this entry I will discuss the complexity of such a system while tracking multiple targets, discuss the difference between real and ghost targets and approaches to reduce overall system complexity.

w w w . c h i p r a t e . c o . u k

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Acronyms

SESAR	Single European Sky ATM Research
RADAR	Radio Detection and Ranging
TDOA	Time Difference of Arrival
2D	Two Dimensions
3D	Three Dimensions
FPGA	Field Programmable Gate Array

Introduction

As part of my undergraduate degree at the University of Aberdeen I completed an undergraduate thesis. In my thesis I considered the concept of a multi static passive radar system capable of tracking commercial civil aircraft using transmitters of opportunity.

One possible obstacle for a multi-static TDOA radar system is solving a system containing multiple targets. Solving the system quickly enough to enable a quick refresh rate, and real time operation is envisioned as a major obstacle as it could be prohibitive in terms of cost. In this entry I will discuss system complexity while tracking multiple targets, discuss the difference between real and ghost targets and approaches to reduce overall system complexity.

System Complexity

Given the real time requirements of the system and that computing resources available to any system are finite, it is important to have an idea how expensive in terms of computing power the system might be. The system will be required to compute the location of all the targets in range and again for each refresh to maintain a real time view of the targets of interest. Using an indiscriminating brute force approach would be inefficient in terms of computing power. Solving the system in this way has a complexity of approximately

$$O(N^r).$$

Where N is the number of targets and r is the number of unique transmitter-receiver pairs in the system. Using an alternative approach the approximate complexity of the system could be reduced to

$$O(N).$$

In this entry I will discuss system complexity while tracking multiple targets, discuss the difference between real and ghost targets and approaches to reduce overall system complexity.

Target Solutions for Multiple Targets

Locating multiple targets is difficult, as multiple returns will be detected from each transmitter. For a system using a 2D position algorithm and 3 transmitters as described in previously, the number of possible target solutions can be shown using Equitation 1.

Equation 1

$$ps_{2D} = n^3,$$

where n is the number of returns, excluding the direct path signal from each transmitter. For a system using a 3D positing algorithm using 4 transmitters as described previously, the number of possible target solutions can be shown using

Equation 2

$$ps_{3D} = 2n^4,$$

where n is the number of returns, excluding the direct path signal from each transmitter. In this thesis, two possible methods are presented to reduce the number of possible target solutions. The first method is to analyze the behaviour of the possible solutions. The second is the use of additional transmitters to test the possible targets.

Tracking of Multiple Targets in 2D

To analyze system performance when tracking multiple targets, a simulation was devised tracking two simulated targets. The parameterized targets vectors are shown in Equation 1 for target 1 and 2 for target 2. The target vectors are chosen to demonstrate the tracking two aircraft with different bearings and velocities.

Equation 1

$$x_1 = t$$
$$y_1 = 100 - t$$

Equation 2

$$x_2 = 100 - 0.5t$$
$$y_2 = 100 - 0.5t$$

The simulation runs from $t = 0$ to $t = 100$.

There are two returns from each transmitter not including the direct path signal, as there are two targets as shown in Table 1.

Table 1

Transmitter	Returns
1	T1_1, T1_2
2	T2_1, T2_2
3	T3_1, T3_2

Initially the system does not know which return corresponds with which target so every combination is plotted. As per Equation 2 there is 8 possible solutions for a system tracking 2 targets using 3 transmitters. The 8 possible solutions are listed in Table 2.

Table 2

Trace	Positing Arguments			Label
1	T1_1	T2_1	T3_1	Target 1
2	T1_1	T2_1	T3_2	Ghost 1
3	T1_1	T2_2	T3_1	Ghost 2
4	T1_1	T2_2	T3_2	Ghost 3
5	T1_2	T2_1	T3_1	Ghost 4
6	T1_2	T2_1	T3_2	Ghost 5
7	T1_2	T2_2	T3_1	Ghost 6
8	T1_2	T2_2	T3_2	Target 2

The traces are plotted in Figure 1. The traces representing genuine targets are coloured blue (Target 1) and green (Target 2). In Figure 1 the traces that consist of components of target 1 and target 2 are shown to have wild trajectories. These are clearly out with the performance of any aircraft. This is further analyzed in Figure 2.

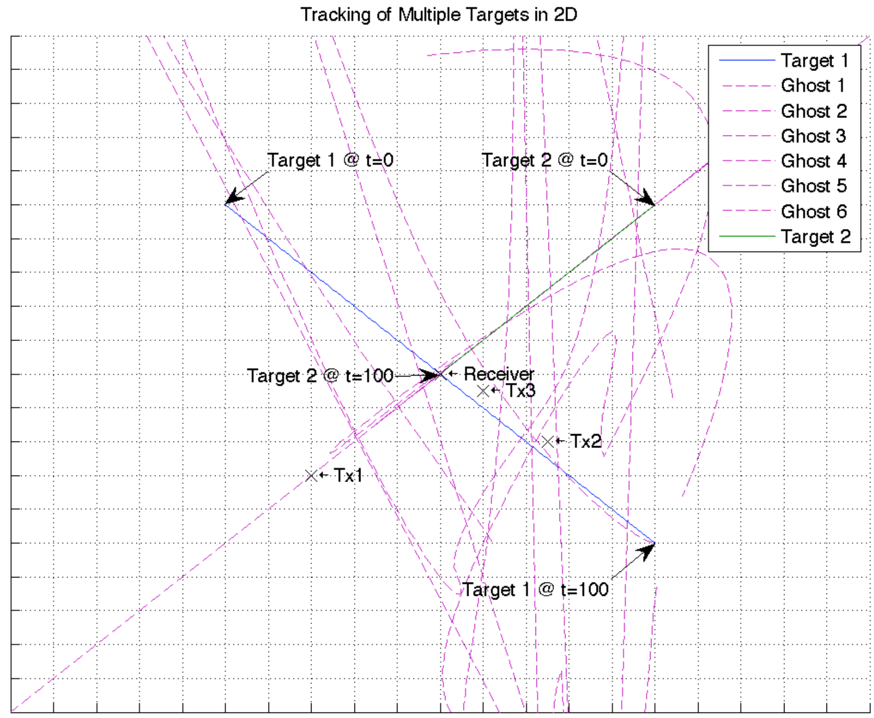

Figure 1

The speeds of possible targets as a multiple of the constant speed of target 1 are plotted in Figure 2. The Ghost traces can be clearly distinguished from the genuine targets as their speed is magnitudes higher that that of the fastest genuine target.

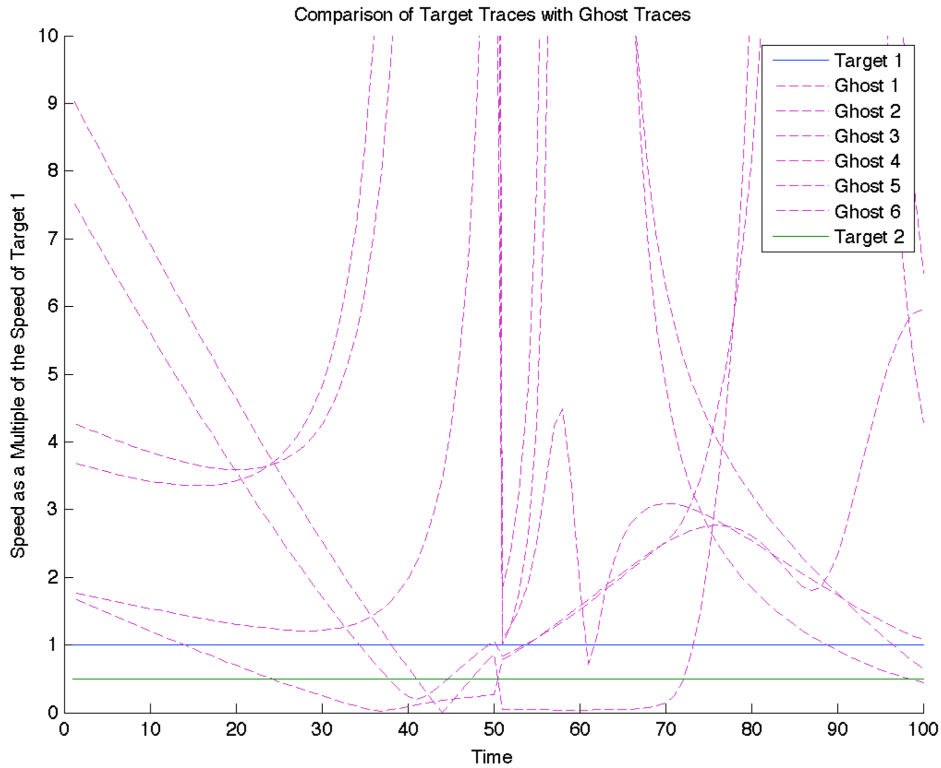

Figure 2

Analyzing Possible Target Behaviour

This solution exploits the limited range of behaviour that genuine targets show. False target can be identified when they show behaviour that is not within the range expected from a genuine target. Components such as velocity, position, acceleration and change in direction can be used to distinguish targets.

Analyzing Possible Targets with Additional transmitter References

Additional transmitters can be used to corroborate possible target solutions. Using the 2D positioning algorithm to track two targets, the result is eight possible solutions as described in Equation 2. For each of these possible targets, the bi-static range is calculated giving the TDOA for each target. The synthesized TDOA is then compared to the actual returns from the additional transmitter. The error is defined as the difference between the TDOA of the synthesized return and the actual returns from the additional transmitter. As there are two targets, there are two returns received from the additional transmitter. This means that each synthesized TDOA has to be compared with two returns from the additional transmitter. Genuine targets will be distinguished from false targets, as they will have a zero difference from their corresponding return from the additional transmitter.

Corroboration with a Fourth Transmitter

An additional transmitter can be used to corroborate the possible solutions. All the possible solutions for the target solutions are calculated as in Table 3.

Table 3

Transmitter	Returns
1	T1_1, T1_2
2	T2_1, T2_2
3	T3_1, T3_2
4	T4_1, T4_2

Table 4

Target Solution	Positing Arguments			Label
$1	T1_1	T2_1	T3_1	Target 1
$2	T1_1	T2_1	T3_2	Ghost 1
$3	T1_1	T2_2	T3_1	Ghost 2
$4	T1_1	T2_2	T3_2	Ghost 3
$5	T1_2	T2_1	T3_1	Ghost 4
$6	T1_2	T2_1	T3_2	Ghost 5
$7	T1_2	T2_2	T3_1	Ghost 6
$8	T1_2	T2_2	T3_2	Target 2

Table 5

Target Solution			Label
	T4_1	T4_2	
$1	=	≠	Target 1
$2	≠	≠	Ghost 1
$3	≠	≠	Ghost 2
$4	≠	≠	Ghost 3
$5	≠	≠	Ghost 4
$6	≠	≠	Ghost 5
$7	≠	≠	Ghost 6
$8	≠	=	Target 2

Using the known locations of the additional transmitter and receiver, the bi-static ranges are calculated for each possible target solution. Using the bi-static ranges, the equivalent TDOA timings are calculated. These are then compared to the actual returns received from the additional transmitter T4_1 and T4_2 as shown in Table 5. All solutions that have an equivalent TDOA that is not close to equal to the measured bi-static ranges T4_1 and T4_2 can be excluded. The remaining two are the genuine target solutions.

Contact Me

I would appreciate any feedback on my work, positive or negative. I would be especially interested to hear for people in industry or academia as I am currently looking for an opportunity in engineering. I am particularly interested in digital signal processing, FPGAs, algorithm design, MATLAB and system design. By far the easiest way to contact me is by e-mail andrew@chiprate.co.uk. A PGP public key for this address can be found at www.chiprate.co.uk in the contact me section.