Seminar Speech

(1800 – 2400 words) closer to 2400

Good afternoon, my name is Lewis Chambers and I’m here to talk to you today about my thesis topic, Passive Radar detection.

Passive radar detection or passive coherent location as it is also known is the problem of locating unknown targets in an area of interest using only a single, or an array of, static radar receivers. Using these spatially separated radar receivers, the goal is to resolve the location of target objects nearby. The challenge lies in the fact that an active signal is not broadcast by the receivers, so they must make use of signals already permeating the air, so called illuminators of opportunity. This differs from standard or active radar, because in the active radar case, we have absolute control over the broadcast pulses.

As these signals are not generated by the receivers, they are unknown ahead of time, so must somehow be resolved from noise and reflected signals received by the radars to determine the position of targets in the area of interest.

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Before delving too deeply into the world of passive radar, a brief summary of active radar, and indeed radar in general is warranted. First of all, the term radar is an acronym for radio detection and ranging, and is a system of detection that utilises pulses of radio waves to determine the distance, altitude or speed of an object. It is most commonly depicted in film as a tool for locating enemy ships or planes. The basic principle of operation of radar is fairly simple.

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The set-up consists of a transmitter and receiver, usually in the same location and nowadays thanks to duplexing radar technology, using the same antenna. The transmitter generates short pulses of radio waves in the microwave spectrum, which are broadcast in the direction of interest. These waves propagate through the air and spread until they reach a target of interest, where they bounce against its surface and return to the receiver. From the transit time and Doppler shift of the received waves, the targets distance, speed, and direction can be calculated.

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Active radar was first demonstrated in 1904 by The German inventor Christian Hülsmeyer. He called his invention the telemobiloscope, and it could detect a ship in an area, but could not tell its distance. From here the technology developed greatly and by World war 2, radar systems were a staple item in a countries military.

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Since then, it has been developed into a sophisticated technology with applications in many fields, such as aviation for ground controlled approach, marine radar for vessel traffic services, meteorology for weather forecasting, and geology to map the composition of the earth’s crust.

So with all of the information we know about active radar, it begs the question: If active radar works and has all of the current infrastructure associated with it, why should we change to passive radar, and why hasn’t it been done sooner.

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Well to answer that question we must consider the differences between the two technologies. The main difference between passive and active radar is the lack of transmitting antenna in the passive case. This leads to a number of distinct advantages of passive over active radar.

First and foremost, passive radar has the ability to detect covertly. Because no pulses are generated by the passive detection system, there is no way for an enemy to detect that radar is being used. It uses third party signals that are always present, so passive radar is also immune to electronic counter measures, such as jamming.

Also, because passive radar has the transmitter source and receiver antenna widely geometrically spaced, it naturally inherits the ability to detect stealth operations for free. So passive radar systems are unjammable, undetectable anti-stealth systems, naturally leading to their tendency towards use in the military.

Another consequence of not generating your own pulses is that passive radar is a more eco-compatible choice. Less energy is needed to run a passive radar system, and its initial start-up cost is cheaper, due to it only needing receivers, leading to some branding it as “Green radar”.

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So if passive radar has all of these advantages over active radar, why isn’t it more widely used? Why is it not standard?

There are 2 main reasons for this. Firstly, as you would expect, passively detecting targets is a very computationally expensive exercise. Only recently (last 20 years) have the digital signal processing technologies become available to quickly and accurately implement a passive radar system up to the standard of active radar.

Secondly, for passive detection to work there needs to be a strong broadcast signal, an Illuminator of opportunity. The recent advent of digital television broadcast has made passive radar detection more viable as it provides many wideband, high strength, high frequency signals. These DVB-T signals are perfect for passive detection. Previously FM radio, cell phone base stations and digital audio broadcast were possibilities for use in passive radar and have been shown to have detection ranges in the order of several 10’s of kilometres. With the higher signal power from digital television broadcast, this range can be vastly extended.

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So where did passive radar come from?

The earliest passive radar systems can be found as far back as 1935, with Sir Robert Watson-Watt detecting a Heyford bomber aircraft 8km away using the illumination signal from the shortwave BBC empire transmitter [5, 6]. The interest in passive radar continued on the German side from 1943, with the ‘Klein Heidelberg’ receivers used to detect British incoming aircraft. Interest continued to grow in the following years and many projects followed, including Lockheed Martin’s *‘Silent Sentry,’* an all-weather passive surveillance technology. This system was released in 1998 and was the first commercial passive radar technology on the market. The passive system uses transmissions from multiple commercial FM radio stations to detect airborne targets in real-time. Around this time the awareness and interest in this technology started growing rapidly, and a spate of passive systems emerged.

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Apart from the obvious current military applications, passive radar has also been used for civilian applications. PARASOL is a project sponsored by the German ministry of environmental affairs that uses passive radar for collision warning of wind power plants. It employs a passive radar system that uses the DVB-T illuminators to detect aircraft approaching wind farms and also to reduce the collision of birds.

So we can see that passive radar detection is a superb technology, but how does it work?

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Now, I will talk about the nuts and bolts of how a passive radar detection system works, but first, it is important to note that there are many different signal models and configurations that can be used, and these differ depending on the given application and known information.

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So there can be a lot of variation between scenarios. However, there are a few constants for all systems. All system models consist of at least one passive receiver (will be denoted Rx), at least one non-cooperative transmitter or illuminator of opportunity (will be denoted Tx) and at least one target that may be stationary or moving

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Before getting in depth, we will work through a simple scenario. A single receiver, a single transmitter and a single target. Assume that in the following scenario there is a target at an unknown location. The receiver will hear the normal broadcast signal, known as the direct path signal and shown here in black. But then after a short time delay it will hear a diminished, frequency shifted version of the same signal. This signal will have travelled along one of the red paths from the transmitter, to the target, and then to the receiver. This is known as the target path and is shown as the red lines here. If we could determine that time delay between the direct path and target path, we would know the difference in path lengths. From here we can solve for the location of the target, and the result is an ellipse, shown in blue. All of the red lines represent signal paths of the same length. So our target could lie at any point on the blue ellipse.

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If there were 2 receivers, or 2 transmitters, there would be 2 ellipses and their intersection points would be the points where the target could be. Again, all points on the red circle have the same target path length from red to green and similarly for the blue circle.

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A more complex case again can show how these intersections can changes if the path difference is different between the 2 transmitters. Obviously if we were to extend to more transmitters or receivers, we would be able to reduce the number of possible points of intersection down to a single point per target.

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So if there was more than 1 transmitter or receiver, and we knew the exact locations of them (which is plausible because they are fixed structures), and we could somehow determine the difference between the direct path and target path signals, we could specify the exact location of a target.

The process behind this is relatively straightforward. First we assume a signal model. Then we guess the location of a target. Then from our signal model, we can derive a likelihood that the target actually was where we guessed it was. This is the step that varies greatly between passive radar approaches.

Obviously, if we systematically work out the probability for every position and velocity that a target could be in, we would have a likelihood map for the location of our targets.

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The specific signal model I will be discussing today is one fixed transmitter and an array of fixed receivers. Let the unknown signal generated by the transmitter be called s(t). If we assume that the receiver Rx does not get the direct signal path, we can call it’s received signal via the target path x(t).

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Now x(t) is a time shifted (tau), frequency shifted (omega) version of s, that also has a lower amplitude.

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If we guess the targets position and velocity, we can calculate tau for that position and omega for that velocity and we can undo these operations, giving us x bar of t. If we then sample these at an appropriate rate, we can get x bar of n, which is closely related to s of n.

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Now this is where the methods differ. The approach I will be discussing today is called generalised canonical correlation analysis and is closely related to generalised canonical correlation in multivariate statistics. For a case with 2 receivers, we take our sampled values in each x bar of n from the previous slide, and make them column vectors. We can then determine the likelihood that we would get these vectors, given a certain mu1 mu2 and s. Our goal is to maximise this likelihood condition with respect to s. This is done be setting mu1 and mu2 as following.

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Substituting this in and taking the log likelihood, and then comparing this to the case where we would expect just noise, we get the following. Now in this case, the first 2 terms are constants, not dependant on s, so maximising L is the same as maximising the third term. As it turns out, this is known as the Rayleigh quotient,

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and is maximised by the largest eigenvalue in F. This is also equal to the largest eigenvalue in this bottom term, which is a 2 by 2 matrix because we only have 2 receivers.

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So essentially, we pack our corrected signals into a matrix. Multiply the complex conjugate of the matrix with itself, and compute the largest eigenvalue of this. We can do this for every position and velocity point in our search area, we get some cool maps of likelihoods that there is a target in a given area.

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Now, onto what I have achieved. I have done all of my simulations and algorithms in MATLAB, and I can simulate and detect automatically the following cases, for arbitrary positions. The first Example I will show you has

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5 receivers, 1 transmitter and 1 target. The area that I choose to scan over is a 400 by 400m area, and the resolution is 1m spacing. This means that I guess and determine the likelihood for a particular point, then move 1m and guess again for all 1m boxes in the search area.

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As you can see, we get a map of normalised likelihoods. We can detect that our target is in a given location.

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If we simulate a larger area, we can see that we actually get a lot of hits in the area that our transmitter is. This is a problem, and can be solved by removing the direct path signal from the received signals once it is known. That has yet to be implemented.

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It can also detect multiple targets, and I have also managed to get it to automatically sort the information and return the position or positions of the targets. We can see here that it has automatically circles the location of our 2 targets.

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There are a number of further features that need to be implemented. talk about them

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SO the plan for the rest of my thesis is as follows.

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This seems like a lot of work, but I believe this plan is achievable because a lot of the code for the different methods is the same and is re-useable. Most of the work will come from deriving equations for solving the systems that are already set up.

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Thankyou for listening to my presentation, I hope it has been informative and interesting.

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If there are any questions from the audience, I will gladly take them now.