Modelling Angular Deception of a Sequential Lobing Radar

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Sixty-five percent of the population learns through visual stimuli such as pictures, notes and diagrams with a further five percent being kinaesthetic learners who can retain knowledge through touch and imitation. Despite the importance of RADAR systems, both in a civilian and military context, very limited open source learning tools cater for this category of student. Simulators can be used to model the outside world in a safe environment, giving the user the ability to test ideas and confirm understanding without educational and training institutions needing to purchase expensive equipment to do so. To fill this gap in RADAR education and training, this thesis looks to design and implement a high fidelity, accurate, sequential lobing RADAR in MATLAB with the ability to also model the angular deception of this tracking technique. This thesis will include a literature review into relevant RADAR concepts and literature before discussing the design of the simulator and its performance. To conclude the thesis, its ability to assist in the chosen area of research will be discussed as well as recommendations of related future research.

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I. Nomenclature

R = Distance to the target

Pt = Transmitter power

Gt = Gain of the transmitter antenna

Ae = Effective aperture (area) of the receiving antenna

σ = Radar cross section, or scattering coefficient, of the target

T = Time (seconds)

c = Speed of Light (meters per second)

m = Meter
II. Introduction

Since the first successful range finding experiment using electromagnetic waves conducted by Sir Edward Victor Appleton in 1924\textsuperscript{27}, Radio Detection and Ranging (RADAR) has been a huge part of our modern society. One area in which RADAR is crucial is the aviation industry, both military and commercial, because, in the commercial sense, it ensures positive separation and orderly progress in daily operations. In all situations where a RADAR is used it is trying to achieve one of three things: locate the target, track the target, or reveal the physical properties of the target.\textsuperscript{9} With the ability to track targets, especially those considered hostile in a military context, the ability to deliberately deceive the RADAR has been highly researched.\textsuperscript{31}

Many attempts have been made to improve tracking and countermeasure techniques with numerous patents having been submitted which attempt to solve the issue of a counterproof RADAR tracking technique. The clear majority of patents for the design and counter designs of RADAR techniques\textsuperscript{28} were submitted during the 1960’s\textsuperscript{16} with later patents and research being focused on improving the manufacturing and physical design of the RADAR. Although the 60’s appears to be the period where majority of the higher-level tracking techniques in use today were designed, the technology was being invented as early as 1934,\textsuperscript{11} with the invention of devices such as the horn antenna which can created multiple beams.

During WWII, an increase in research effort into RADAR was seen out of necessity for an early warning system against hostile aircraft. The military uses quickly progressed to accurate anti-aircraft gun laying and ranging, locating of enemy bomber forces as well as the guidance of friendly forces to intercept such imminent threats.\textsuperscript{2} It is for these reasons that the current literature on RADAR tracking techniques is quite extensive with many military and civilian articles and reports summarising the content well.

Sixty-five percentage of the population however consists of people who learn through visual stimulus and as such, a subject which is taught through verbal and written communication leads to the content being directed towards less than half of the audience.\textsuperscript{29} Despite tracking RADAR techniques being in use for many years there are very few open source RADAR simulators that incorporate countermeasure techniques which can be used to cater for the sixty-five percent of those learning through visual interaction. Given the importance of RADAR in both military and commercial sectors, it is necessary to ensure that the quality of educational tools available to this area of learning reflect this. To assist in fulfilling this educational gap, this thesis aimed to produce an accurate and realistic simulator that utilises sequential lobing tracking techniques and demonstrates angular deception of this.

III. Literature Review

A. RADAR

RADAR is an acronym for Radio Detection and Ranging and describes a method of finding the position and velocity of an object by transmitting a signal to the target and analysing the reflected response.\textsuperscript{6} The benefit of using RADAR over the conventional method of sight is a much more precise measurement of an objects range, velocity and bearing as well as the ability to provide this data in conditions where the human eye fails such as fog, rain and other environmental factors.\textsuperscript{9} There are many designs for RADAR systems however the same four basic subsystems are used in all; a transmitter, receiver, antenna system and interfaces.\textsuperscript{30}

The transmitter generates the electromagnetic (EM) signal to be transmitted through the antenna toward a target area. Upon reflection off a target, a portion of this EM signal is received at the antenna and passed to the receiver. The receiver amplifies, processes and analyses the collected return signal and sends the analysed signal to an interface. Interfaces such as displays, alarms and other systems is what allows a user to interpret the data through a varying amount of data representation techniques.\textsuperscript{13}

RADAR systems are characterised into two categories, primary and secondary; the three variations of primary RADARs can be seen in Table 1 below.\textsuperscript{9} The name Primary RADAR is the collective term for RADAR system which operates by transmitting a signal and analysing the reflected return from a target.\textsuperscript{2} Secondary RADAR systems don’t rely on reflections of transmitted EM waves to detect signals as the system relies on the target receiving the EM waves and then transmitting a response via a separate transmitter.

<table>
<thead>
<tr>
<th>Primary RADAR Types</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monostatic RADAR</td>
<td>Transmits and receives through the same antenna.</td>
</tr>
<tr>
<td>Bi-Static RADAR</td>
<td>Transmits and receives through two different antennae which are separated by a large distance.</td>
</tr>
<tr>
<td>Multi-Static RADAR</td>
<td>Utilises an array of antennae for both transmitting and receiving.</td>
</tr>
</tbody>
</table>

Table 1. A sample of the Primary RADAR types.
The three applications of RADAR are search, track and image capture with each function requiring RADARs of varying characteristics to achieve their function. Searching aims to locate a target without any prior knowledge of its location or existence. To do this the beam of this RADAR must be comparatively large compared to the search area to efficiently acquire the target’s general location. A tracking RADAR requires the opposite characteristics with a small narrow beam required to track the target with high accuracy. The final application requires the RADAR to be able to distinguish features of a target and thus must have a small comparative wavelength to the size of the target. If the target is much smaller than the wavelength, the radar cross section (RCS) information gathered shows a smaller estimation of the target and if the wavelength is comparable to the target size then the results vary in accuracy.

Noise is a core consideration of RADAR operation which affects real world RADAR calculations. The technical definition of noise is “unwanted electrical or electromagnetic energy that degrades the quality of signals and data”. Noise can occur in both digital and analogue signals and can affect all types of communication and data sets including text, images, audio and telemetry. Noise in RADAR can be measured by analysing the input to the receiver without a return signal from the target. Due to the low power of noise, its effect is significant when receiving signals which are comparable to the level of noise present. Noise sources can be internal and external to a system. The noise sources internal to a system are due to semiconductor noise, thermal noise of ohmic resistances or conductance or lastly, the noise current of charge carrier currents. External noise sources such as background noise contribute to noise in the signal during travel through free space.

Some well know external noise sources include:
1. Cosmic Noise caused by the EM radiation of the galaxy and is maximised when a RADAR system is directed towards the centre of the galaxy. This noise is negligible above 1GHz.
2. Atmospheric Absorption Noise is a product of the black body radiation theory which states that any body that absorbs energy (including the atmosphere) must also radiate the same amount. Therefore, this energy is constant through the atmosphere in all directions which includes towards the receiver.
3. Atmospheric and Urban Noise is generated by naturally occurring instances such as lightning as well as electronic equipment, EM traffic, and fluorescent lights. These noise sources are negligible at 50MHz and 1GHz respectively.
4. Solar noise is caused by the sun and increases with frequency and so it is a consideration in all RADAR systems.
5. Attenuation due to rain increases linearly with frequency and once the rain reaches a certain rate of rainfall it becomes impenetrable to RADAR.

Of these External Noise sources, rain, atmospheric and solar noise are those most likely to affect the operation of a RADAR. Solar and Atmospheric noise are considered to cover the full spectrum of frequencies due to their randomness and as such these are called white noise or Johnson noise. This form of noise can be modelled in electronic simulations with Additive White Gaussian Noise (AWGN). Computing tools such as MATLAB have functions to assist with this, like MATLAB’s AWGN function, which takes an input signal and a signal to noise ratio (SNR) and adds a noise value based on the SNR to the input. The SNR is a ratio of signal to noise in dB, a SNR of 0dB represents a level of noise that is equal to that of the signal whilst an SNR of 20dB represents a signal strength that is one hundred times that of the noise level.

RADAR uses two different operating methods; pulse and continuous wave (CW) RADAR. CW RADAR systems emit a continuous signal and can measure the instantaneous rate-of-change in the targets range by a direct measurement of the Doppler Shift of the return signal. This shift is a change in the frequency of the signal due to the relative motion of the target. Pulse RADAR transmits a series of pulses at a set time interval called the pulse repetition interval (PRI) (see Figure 1) and measures how long it takes for the signal to return so that the range of the target can be calculated. The range of the target is calculated using equation 1. By knowing the speed of the EM signal (speed of light) and the time it took for the signal to return to the RADAR the range can be calculated.

![Figure 1. Representation of EW waves accompanied by relevant measurements [33].](image-url)
\[ R = \frac{c_T}{2} \]  

Equation (2) shows how the received signal power is calculated.

\[ P_r = \frac{P_t G_t}{A_e} \times \frac{\sigma}{4\pi R^2} \times \frac{4\pi R^2}{A_e} \]  

Equation 2 has been broken into three factors; the first factor results in the power density at a given range and the second factor describes the divergence of a signal reflecting off a target based on its cross-sectional area. Together these two factors give the received signal per square metre and so multiplying this by the effective aperture area of the receiving signal gives the total power received. This effect is called free space path loss (FSPL)\(^2\) and describes the loss of signal over the line of sight path between the RADAR and the target.

By manipulating equation 2 into equation 3 the maximum possible range of the target can be calculated. This is achieved by substituting \( S_{\text{min}} \) in for \( P_r \) as it describes the minimum detectable signal which is a parameter of the receiver.

\[ A_e = \frac{G_r \times \lambda^2}{4\pi} \]  

\[ P^4_{\text{max}} = \frac{P_t G_t A_e \sigma}{(4\pi)^2 S_{\text{min}}} \]  

In the case when a RADAR transmits and receives using the same antenna, equation 5 is applicable. This is achieved by substituting equation 3 into equation 4 and replacing \( G_r \) with \( G_t \) as the gain is now the same for the transmitter and receiver.

\[ P^4_{\text{max}} = \frac{P_t G_t \lambda^2 \sigma}{(4\pi)^3 S_{\text{min}}} \]  

Analysing this equation, it can be seen that maximum range is dependant of the minimum detectable signal and the cross-sectional area of the target, both of which are predetermined parameters.

**B. Tracking Techniques**

Sequential lobing was one of the first pulse RADAR tracking techniques utilised by the early generation of RADAR systems.\(^18\) It is very simple to implement as it utilised one or multiple beams that oscillate either side of the transmitters line of sight, also known as the boresight. Sequential lobing is a sub category of angular difference tracking and is able to follow the target by comparing the returned signal power from both beams. If the return power from both beams is equal, the target is located on the boresight. As the target moves away from the boresight, the power difference between the two received signals is increased. This power difference translates to an instruction to the RADAR tracking system to move the boresight of the transmitter towards the current location of beam A; the exact angle of movement is defined by the magnitude of the difference.

Figure 2.b shows if the target moves towards beam A, the return signal will be stronger than the return from beam B. To utilise the technique for the orthogonal coordinate, two more switching positions must be added and as such both azimuth and elevation movement of a target can be tracked using a cluster of four beams. The accuracy is limited by the beamwidth as well as the noise generated by either mechanical or electronic switching mechanisms.\(^9\)

The other two major angular tracking techniques are conical scanning RADAR and Monopulse RADAR. Conical scanning RADAR tracks by revolving a single beam around the boresight and moving the boresight towards the location of the beam at the point in which a return signal is received. It is limited by the RPM of the beam and noise due to vibration and wear and tear of rotating mechanical parts.
Monopulse RADAR operates the same way as sequential lobing however all four beams are constantly transmitting. The advantage this has over sequential lobing is that it is free of mechanical vibrations and it is less limited by the width of the beam as the returns are received more often.\textsuperscript{9}

C. Angular Deception
Sequential lobing tracks a target using the difference between two return signal powers and as such, manipulating the return signal power allows an outside source to deceive the tracking RADAR. If a target can recognise that sequential lobing is being used to track it then the target can use an on-board transmitter to match the reflected signal to deceive the tracking RADAR.\textsuperscript{7} This requires the target to measure the incoming signals frequency to transmit the signal at the correct time and frequency to perform the counter measure.

Figure 3 shows four different cases of return signals seen at the receiver. In case one, the RADAR has received two equal returns and thus the target is on the boresight and has not moved. The second case shows a higher beam A return which equates to a boresight shift towards beam A. In case three, the RADAR is receiving equal returns due to ECM making the RADAR believe the target is stationary when it has the same velocity seen in case 2. The final case shows the ECM being used to make the target appear to be moving with a lower velocity as the return from B is higher than the actual return but not enough to show a stationary target as in case 3. If the target can transmit and ECM large enough to make the beam B return larger than the beam A return, it can deceive the RADAR into believing it is travelling in the opposite direction to its actual trajectory.

Other countermeasures used currently include:\textsuperscript{3}
- noise jamming which increases the noise at the receiver.
- false target generation which uses jammers to introduce additional signal to deceive the RADAR.
- chaff which is an artificial cloud of reflective debris which return a strong reflection over a large enough area to mask the presence of real target echoes.\textsuperscript{21}
- decoys which are small inexpensive objects designed to act as additional targets.\textsuperscript{3}

IV. RADAR Simulator

A. Assumptions
i. The user inputs are constant throughout the simulation.
ii. There is only one target being tracked and its original position is known, therefore there is no search RADAR implemented.
iii. The noise being modelled is equitable to white noise and can be modelled using AWGN.
iv. The target is the only form of physical interference within the 3D space simulated.
v. Only one target is being tracked.
vi. Only beaming targets are modelled (constant range)
vi. The user has the knowledge and understanding to input reasonable and realistic values into the simulator.
vii. Larger than usual SNR ratios are considered realistic as signal processing techniques are said to be used at the receiver.
B. System Structure and Processes

Figure 4 shows a block diagram of the simulator, which was designed and built from scratch using MATLAB. The simulator is divided into three separate sections; parameter collection, simulator and data analysis. The parameter collection portion of the code first asks the user for the fundamental RADAR parameters and then uses RADAR equations to calculate more complex parameters.

To represent the beam structure, sinc functions were used because the central peak can be used as the main lobe of the beam with side lobes represented by the trailing peaks of the sinc function. When written as \( \text{sinc}(\alpha x) \) the \( \alpha \) is a scaling factor that either expands or contracts the function which in turn influences the width of the central peak, which in the case of the simulator, is the beamwidth. To find the value of \( \alpha \) which correlates to the required 3dB beamwidth, a 2x3,000,000 value look-up table was generated. Given a 3dB beamwidth, the binary search function finds the \( \alpha \) required for a beamwidth within three decimal places of the required value.

The search function uses the binary search method (also known as the halving method) as it has a run-time complexity of \( O(\log n) \). This translates to an exponential increase in search speed when used with large arrays. This will allow the fidelity of the look-up table to be high while maintaining a fast simulator run-time. The fidelity of the simulator tracking system is set in the initial parameters and refers to the number of segments per degree used to estimate the targets position within the simulator section of the code. The final data provided by the user is the speed and direction of the target in both azimuth and elevation as a function of time.

The simulator section is where all the tracking data is calculated. The first step sets the boresight of the RADAR to the last known location of the target, this is supported by the assumption that the initial location of the target is known. The transmission of the signal is then sent and ECM is added to the return signal when countermeasures are activated. Between transmission and receive, FSPL is calculated and AWGN is added to simulate external noise which is like white noise.

The MATLAB function, AWGN, takes the input signal and the defined SNR and adds a noise value based on the SNR to the input. The target movement is then estimated based on the two return signals and the controller functions then move the beams and data arrays relevant to tracking to the new estimated position. The accuracy of this estimation is defined by the number of segments per degree defined by the user prior to the initiation of the simulator.

If defined as active in the parameter collection section, a countermeasure for the appropriate beam is added at the time of reflection with the assigned power value. The same calculation of FSPL and addition of AWGN is performed on this countermeasure. The power of the countermeasure will define how the accuracy of the simulator is affected. If the power is high enough to move the estimated position outside of the 3dB beamwidth then the RADAR will cease to track the target entirely. If the countermeasure power remains low enough to keep the estimated position within the 3dB beamwidth, the target can be estimated to be ahead or behind its actual position, thus it is still tracked but with a large positional error.

The Data Analysis section is when the Simulator data is stored and plotted with the structure seen in Figure 4. The tracking process is structured with two cases of 2D sequential lobe tracking, one in elevation (beam A and B) and one in azimuth (beam C and D). This is reflected in the top two plots of the subplot shown in Figure 4 known as Plan Position Indicators (PPI). On these polar plots, the location of the RADAR is the central point and the circles radiating around it represent the range from the RADAR and the axis that circles the plot is the degree of azimuth/elevation. The data from angular and range positions of both the actual and estimated positions of the target are combined and converted to Cartesian coordinates before being plotted in 3D in the bottom half of the primary plot. The iterative loop iterates per PRI and at each iteration a return signal is received and processed by the active beams. To reflect this process, the primary plot also iterates with respect to the PRI and displays the active beams on the polar plots.

The beams are distinguished by colour, beam A and C are plotted as blue beams and beam B and D are plotted as red beams.
C. System Performance Validation

To validate the system a series of tests were carried out to measure the performance of the simulator at simulating sequential lobing tracking and angular deception within the assumptions stated. Table 2 shows the tests conducted as well as the results.

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking in both Azimuth Directions</td>
<td>The simulator tracks in both azimuth directions. This is achieved by inputting a positive or negative function of t for the azimuth trajectory.</td>
</tr>
<tr>
<td>Tracking of Elevation Between 0-180 Degrees</td>
<td>The simulator tracks the elevation trajectory between 0-360 degrees. The 3D Cartesian plot defines elevation between 180-360 degrees as the negative direction of travel between 0-180 degrees.</td>
</tr>
<tr>
<td>Tracking a Stationary Target</td>
<td>This simulator successfully tracks a stationary target.</td>
</tr>
<tr>
<td>Target Loss</td>
<td>By setting the azimuth and elevation trajectories to $t^2$, it was confirmed that the target was lost when the trajectory exceeded half the 3dB beamwidth per PRI.</td>
</tr>
<tr>
<td>Beaming Targets</td>
<td>Through all simulations, the range of the target remained constant which aligns with assumption (i) and (vi).</td>
</tr>
<tr>
<td>Noise Model</td>
<td>The noise generated by the AWGN does simulate a constant source of SNR moderated white noise, aligning with assumption (iii).</td>
</tr>
<tr>
<td>ECM Function</td>
<td>When defined in the parameters as being active, the ECM generates an additional signal power added to the reflection from the target as expected.</td>
</tr>
</tbody>
</table>

Table 2. System performance validation test cases.

D. Simulator Performance

This testing was performed by choosing critical variables, varying them and then plotting the results. The error measured to quantify the simulator performance is defined as the separation between the actual and estimated target position in metres. The variables chosen as the most important to the simulator are the fidelity, SNR, range, RADAR transmission power and countermeasure power. Figure 5 shows the effect the fidelity (segments per degree) has on the estimation of the actual target location. The conditions for the test, seen in Table 3, were taken from an example in a RADAR course run by Dr. Neda Aboutorab at UNSW Canberra as a test of the simulators ability to simulate given realistic parameters.
<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRI</td>
<td>1/600</td>
<td>Hz</td>
</tr>
<tr>
<td>SNR</td>
<td>60</td>
<td>dB</td>
</tr>
<tr>
<td>RCS</td>
<td>3</td>
<td>m²</td>
</tr>
<tr>
<td>Range</td>
<td>100</td>
<td>m</td>
</tr>
<tr>
<td>Frequency</td>
<td>5x10^9</td>
<td>Hz</td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>10x10^3</td>
<td>W</td>
</tr>
<tr>
<td>Antenna Area</td>
<td>50</td>
<td>m²</td>
</tr>
</tbody>
</table>

Table 3. RADAR parameters used to test the system error due to the implementation of sequential lobing.

![Graph](Error Due to Tracking Process.png)

Figure 5. Error due to the angular estimation fidelity as a straight line in 3D space.

![Graph](Error Due to Tracking Process.png)

Figure 6. Angular error due to the angular estimation fidelity in Azimuth and Elevation.
Figure 5 shows that an angular fidelity above one are unpredictable and should not be used for general simulations. For this data and the following, the Y-axis refers to the average distance in metres between the estimated position and actual position of the target. This does not refer to the angular difference but the straight-line distance in 3D space. In figure 5, the target was travelling at 5 degrees per second (31.32 km/h) in both azimuth and elevation to ensure the target was not lost due to excessive speeds throughout the simulations. The SNR was set to 60dB (signal power is 1000 times the noise power) to align with assumption viii as 40dB or higher is considered excellent in transmission networks. The data shown in Figure 5 leads to the conclusion that an angular estimation fidelity that above 1 degree is unreliable as the estimations are too large. The recommended maximum angular fidelity is 0.25 degrees as an error of 13.04 cm was measured at 100m which is was deemed as a reasonably low error. The effect of the AWGN can be seen for selected cases where it had enough power to estimate the signal to a higher error such as an angular fidelity of 1.25 degrees where there was a difference in the average error of 1.5125 m.

The error plotted in Figure 6 is the angular estimation error for both Azimuth and Elevation. The velocity for Azimuth and Elevation differs to highlight the effect that the velocity has on error. For lower angular estimations (i.e. a higher accuracy) the error is larger as the targets higher velocity means that the target has travelled a greater distance between measurements. As the estimation becomes larger and the accuracy cruder, this difference is less visible.

Figure 7 shows the error over range for three different RCS values using the parameter values in Table 3. The only exception is the SNR parameter which was set to 80dB to ensure the linear error due to range was visible. The error due to the angular estimation fidelity is linear as range increases which is seen up until 300m for all RCS values. After 300m the RCS values begin to exponentially increase in error at different rates. This exponential increase is due to the AWGN of the simulator. As range increases, the power received decreases at a rate of $R^{-4}$ as seen in equation 2. As the power received decreases it the difference between the power of the received signal and the power of the AWGN decreases which results in an exponential increase in error. The point of exponential increase is reached later by a simulation with a higher RCS as the return signal is higher, meaning the return signal becomes comparable to the AWGN at a larger range.

Figure 8 confirms that a low transmitted power (and hence a low received power) results in an exponential error due to the AWGN function used. The exponential decrease in error as the power increases further elaborates on this. The spacing between range data is exponential decreasing as the transmitted power increase and slowly becomes linear for all ranges as expected after the Figure 6 analysis of the error due to range. The lowest range has the faster transition between exponential and linear error decrease as the decrease in power due to FSPL decreases with range.
Figure 9 shows the error due the SNR using the parameters from Table 3 at a range of 500m which was chosen as a relevant range from Figure 6. Below 50dB, the target was tracked unreliably due to the level of noise in the signal. At 48dB the target was tracked for 50% of the simulation before the AWGN produced a power capable of losing the target and tracking stopped. Generally, 40dB or higher is an excellent signal however it takes an SNR of 50dB to begin tracking a target at 50m for parameters capable of tracking up to 8.5km with and RCS of 3m$^2$. As stated in the assumption viii, it can be considered normal to use high SNR values as the RADAR simulator does not model signal processing techniques used to operate in lower SNR levels.

Figure 8. The error change as the transmitted power increases.

Figure 9. The error change as the SNR increases.
Figure 10 shows the error due to ECM applied to the ‘beam A’ signal reflection at a range of 100m, 300m and 500m using the parameters specified in Table 3. As expected, the plot shows a linear increase as the ECM power is linearly increased and as Beam A is the trailing beam in this simulation, the estimated target position is constantly behind the actual position. Each of the three range measurements stop once the target is lost to the radar. The order in which the data sets end, as well as the scalar error seen on the y axis between the three ranges, confirms that as range increases, the linear effect of the angular estimations increases as well.

V. Conclusion

Concluding the data analysis, it was seen that simulator could accurately track a single target using sequential lobing and the target was able to implement effective angular deception using realistic parameters. The aim of this thesis was to create a simulator which modelled sequential lobing and angular deception for the purposes of the education and training of students with a focus on those who learn through visual stimulus.

Numerous simulations were run and it was confirmed that theoretical principles are adhered to and non-theoretical principles such as angular estimation fidelity are characterised enough to allow the user to manipulate them. Parameters taken directly from a RADAR course given at the University of New South Wales were used as the primary data set to ensure that both realistic and educationally proven parameters could be used by the simulator with basic knowledge of RADAR. This thesis could be used in future research which considers the educational value of simulators in education and training and It is hoped that this thesis will help research into this area.

V. Future Work

Future work on this thesis could involve the enhancement of the current simulator or the addition of other tracking, ECW and ECCW techniques. To enhance the current model, the accuracy, number of variable parameters and GUI could be added as well as more comprehensive supporting documentation. Enhanced documentation could include a tutorial booklet which compliments the function of the simulator to aid in the completeness of the simulator as an educational tool. The addition of other RADAR topics both tracking, ECW and ECCW would progress the simulator towards it being a completely stand-alone educational tool that doesn’t rely on other sources for information. The effectiveness of this simulator could be tested by an audience group to confirm the perceived benefit mentioned.

VI. Acknowledgements

I would like to primarily thank Dr. Neda Aboutorab, my thesis supervisor, for her continual support and encouragement throughout the length of this thesis. Without your efforts, this project could not have been completed and your patience, understanding and helping hand have help me through every issue that has arisen. I would also like to thank both the panel and those friends and family who have been there so provide not only sound advice and support, but encouragement and belief in my ability to complete the task.
VII. References

Text:


Images:
