Improvements in the Estimation of a Radar Platform's Location when Multiple Antennas are used

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Abstract: This paper aims to give a general guide to how a Radar platform's position can be improved by appropriate processing. It describes how it not always possible to measure the received power simultaneously by antennas used in a Monopulse angle calculation. A way in which the simultaneous power can be estimated is proposed, and the practical implementation of such a scheme within a typical Radar system is explained.

1 Introduction.

A platform's position can be estimated by comparing the amplitude received by antennas located at different positions [1]. The amplitudes compared need to be measured simultaneously in order to determine an accurate Angle of Arrival (AOA). The accuracy of this estimate is essential if a platform is to be successfully tracked. Problems arise when the amplitudes associated with each antenna – which are used in an estimate – were not received at the same time. In such cases, further processing is required to adjust the values of the amplitudes detected. This is so they will approximate the values that would have been received, if they had been measured simultaneously.

2 The Estimation of AOA.

The Radar receiver implemented contains numerous separate antennas to provide spherical coverage. The AOA of an emitter is determined by calculating the relative powers of the pulses received by these antennas. However, only a fraction of these antennas are active at any one moment. When one set is active, the pulses are said to have been detected in an 'A dwell' (A) and when the other set is active, the pulses are said to have been detected in a 'B dwell' (B). Here, a 'dwell' is the name given to the time during which the receiver is sensitive to a particular range of RF emissions, and A or B denote the antenna set in operation. Therefore, when pulse trains are received they will be detected in either an A only, a B only, or in both sets of dwells (A+B).

When generated pulse trains are either A or B, the AOA can only be estimated using the simultaneous amplitudes from a fraction of the antennas. However, coincident signal power measurements from all antennas are preferred, as they will yield a more accurate AOA value than that derived using the subset of antennas. If the pulse trains are A+B, then simultaneous measurements from all antennas are not available, as antenna set A will never receive at the same time as antenna set B. This is because the downconvertors can only access a fraction of the receiver channels at one time. This was done to save on the complexity, weight and cost of the hardware required to access all of the antennas.

When an A-B transition point has been detected, the distribution of power can be estimated using the data received before and after the transition time, which will have been collected in different dwells. Traditionally, this power estimation has involved taking a simple average of the magnitudes of the pulses on either side of the transition. However, the different sets of antennas may have different gain characteristics, so this is not always the most sensible method. Also, the distribution of the magnitudes may not be constant on either side of the transition, so it would be incorrect to assume that it is flat and that an average will suffice.

As many radar platforms are mobile, the received power from them is not likely to be constant. Additionally, in an environment where multipath affects are common, the likelihood of the received amplitude being constant over time is even more unlikely. For example, see Figure 1 below which shows the typical distribution of power arriving around an A-B transition. This clearly shows that the predicted power based on a simple average would result in the power at the transition being underestimated. It also shows the improvement gained by using a quadratic approximation to the distribution of pulse magnitudes.

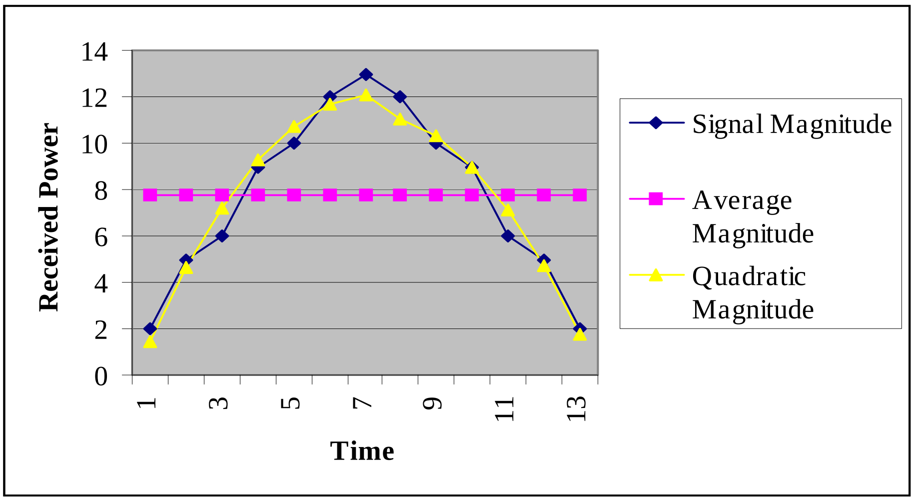

Figure 1

3 Pulse Data.

A typical Radar Electronic Support Measures (ESM) system is shown in Figure 2. It shows how the amount of radar pulse data is reduced as it flows through the system. This is in order to make it possible to process the large quantity of information received. This data reduction - or filtering - is essential as computational power is limited and much of the received data will be redundant.

The radar receiver detects RF emissions, which are parameterised by the Video Parameter Measurement (VPM) module. The VPM then sends the pulse information in the form of Video Parameter Reports (VPRs) to the Deinterleavers. The VPRs sent to the Deinterleavers are then sorted so that pulses with similar attributes are grouped together. These attributes are summarised in an Intercept Report, which is sent to the Active Emitter File (AEF) module. This module is responsible for linking RF emitters to RF platforms, tracking platforms, and updating the parameters of the emitters and platforms in its local store. The AEF then sends a summary of the emitter and platform information to the display, which will inform the radar operator of the current situation.

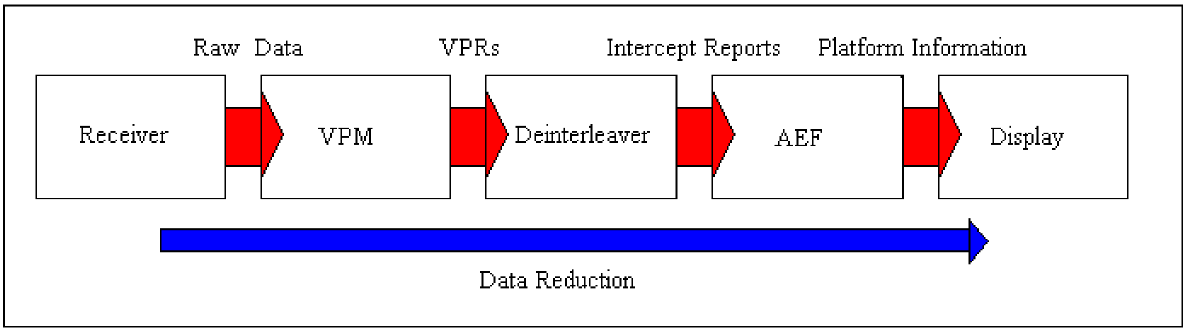

Figure 2

Any algorithm incorporated into the system which concerns the improvement of the instantaneous AOA should therefore be placed in the Deinterleaver module, as it requires parameterisation of the pulse trains to have taken place. The calculated AOA can then be sent to the AEF, and used to update and track any of the platforms known.

4 The Curve Fitting algorithm.

The AOA is estimated in the Deinterleavers using the power received in each radar channel. Due to the large amount of processing required – there are typically thousands of pulses that need to be parameterised over a few seconds – it is essential to minimise the complexity of any algorithms used.

The information contained in the VPRs can be used to estimate the power of a received signal at a particular time. The distribution of the magnitudes is often not linear and should therefore be represented by a polynomial. In order to minimise the number of measurements required to obtain an accurate representation of the data, and to contain the computation complexity of the algorithm, a quadratic distribution is assumed either side of the transition between A and B pulses i.e.

$$\mathbf{y(t) = c_1.t^2 + c_2.t + c_3} \quad – (1)$$

Where, y(t) is the estimated magnitude received by an antenna at a time, t, and c_1, c_2 an c_3 are constants derived from the pulse data. The values of c_1, c_2 and c_3 can be determined by manipulating the determinants of various combinations of the stored time dependant amplitudes. Once these constants have been derived, the amplitude can be calculated at any given time. The magnitude at the time of the transition between using antenna set A and antenna set B is typically used, as the data around this point was used to estimate the quadratic equation. This means that any estimates of amplitudes around this time are more likely to be accurate.

Clearly, the curve-fitting algorithm will be more complicated than the application of a simple averaging technique. Therefore, several checks are performed on the incoming stream of pulses to decide whether it is essential to apply a curve fit. Some of the checks performed are described in the following sub-sections.

Flatness

If the distribution is too flat, there is no benefit gained from applying the curve-fitting technique, as it would be a waste of processing power. In such cases the averaging technique is used. Flatness if tested by calculating the standard deviation of the set of samples used. If this deviation is sufficiently small, then the distribution is considered to be flat.

Local Minima

If a local minimum is located either side of the A-B transition, then the distribution is not considered to be quadratic. Here, a minimum is said to exist if there is a sufficient change in the gradient e.g. from having a positive value to having a negative value. If this minimum occurs close to the transition point on either side, then the distribution is considered to have a local minimum, and the curve-fitting technique is not performed.

An example of some distributions that contain the properties described above is shown below in Figure 3.

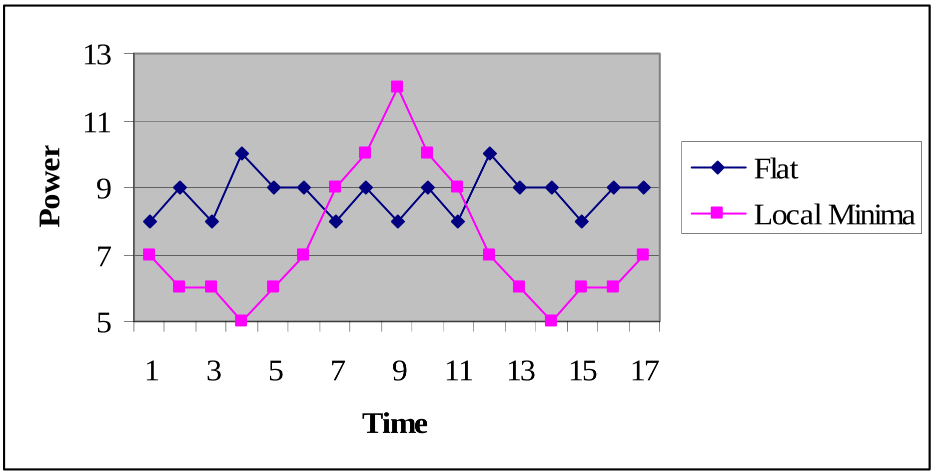

Figure 3

5 Verification.

The algorithm was originally written using Microsoft Excel. This had to be rewritten in ADA and incorporated into the software which is to be formally delivered. To validate the results, test pulse data used in the spreadsheet was applied to a simulation of the real system. The results were then compared to check that the algorithm had been transferred successfully.

6 Conclusions.

The AOA of a platform can be derived from a comparison of the signal powers received simultaneously by several antennas located at different positions. The distribution of the power received from typical radar over time is not always linear and can be represented as a polynomial. In cases where the simultaneous measurement of the received power is not possible, this polynomial can be determined providing that enough samples are recorded. To simplify the processing, a quadratic distribution can be assumed, and an estimation of the received power at a particular time can be derived for each antenna. This improves the accuracy of AOA compared to that which would result when a simple averaging technique is used. Further improvements can result by testing the validity of the quadratic assumption prior to its application.

Acknowledgments.

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References.

[1] Course Notes, ‘Radar Systems’. Prof. H. Griffiths (UCL).