

Achieving real-time pulse-to-pulse PRI prediction

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Abstract:

Radar deception with the use of Digital RF Memories (DRFMs) is quite common in today's Electronic Countermeasures (ECM) systems. Those ECM systems can deceive radars with the production of false targets, which can be positioned over the full Pulse Repetition Period (PRI). This allows the systems to create up-range and down-range false targets and to implement the range gate pull in and range gate pull out techniques. However, without PRI Prediction only down-range targets can be produced for non-constant PRI modulated patterns. Thus, with many radars in the Asia-Pacific environment employing PRI patterns modulated in a staggered, dwell-shift, sliding and wobulated fashion it is important to have a PRI Prediction capability to produce leading targets for greater ECM effectiveness. This paper covers the development of a PRI Predictor that can successfully predict in real-time on a pulse-to-pulse basis upcoming PRI's patterns that are constant, staggered, dwell-shift, ramping or even wobulated. The PRI Predictor, with an internal programmable false target generator for up-range and down-range targets, is meant to easily interface with a DRFM and control the read and write signals. Results will show the benefits of the incorporation of a PRI Predictor in a DRFM-based ECM system. This PRI Predictor has been designed by MC Countermeasures Inc. and is currently incorporated in the EWTS training system. Applications include EW Training (e.g. EWTS, CATS, etc) as well as operational requirements.

1. Introduction:

This paper starts by giving background information of radars and current ECM. Then, it continues by presenting what is PRI Prediction and how it can be used for effective ECM. This is followed by how PRI Prediction is accomplished and it presents results achieved thus far.

1.1 Radar Background:

Before proceeding to PRI prediction lets glance at the evolution and current state of radars and radar jamming. The table below presents radar types, based on pulse repetition frequency (PRF) and their respective modes of operation and characteristics. This is followed by a short discussion of radar jamming, using either noise or deception, and how PRI prediction fits in.

Type	PRF	Characteristics
Pulsed Doppler Illuminator	Up to 500 KHz	<ul style="list-style-type: none"> • Constant PRI (Coherent) • Approximately 50% DC • Semi-active illumination for missile seeker
High PRF Pulsed Doppler	75 to 250 KHz	<ul style="list-style-type: none"> • Constant and Dwell-Shift PRI (Coherent) • Tracking in Doppler • Gating in range
Medium PRF Pulsed Doppler	15 to 75 KHz	<ul style="list-style-type: none"> • Tracking in Doppler and range, both ambiguous • Needs staggered PRI to extend unambiguous range • Staggered PRI also helps moving target indicator (MTI) filter, only requires few stagger levels
Low PRF Pulsed Doppler	5 to 15 KHz	<ul style="list-style-type: none"> • Often non-track mode (acquisition) • Coherent MTI for clutter rejection • Range measurement, Doppler and MTI filtering • Staggered PRI tailored to suit MTI filtering
Low PRF Radars	100 Hz – 5 KHz	<ul style="list-style-type: none"> • Older non-coherent acquisition and track radars • Long range search • Many are pulse-to-pulse Radar Frequency (RF) agile • Complex PRI stagger patterns

Table 1.1.1: Radar Characteristics

1.2 Current ECM Employed:

For older non-coherent radars, since they are susceptible to noise jamming, there is no need for any PRI Prediction capability. These radars have a wide instantaneous bandwidth due to a few MHz receiver, thus it's easy to get high levels of noise into the radar's front end to mask out target returns, independently of range. Thus, radar deception is not needed since the radar return is lost in the noise.

With the introduction of burst-to-burst RF agile radars and coherent radar processing with narrow bandwidth Doppler filters, only a few 100 Hz, noise jammers were rendered largely ineffective. To counteract, jammers made use of fast tuning oscillators to attempt to mask the target return using noise in the proper RF band, however with tuning accuracy limited to a few MHz, the noise spreads out over a wide bandwidth. In consequence the noise signal in the radar's bandwidth is approximately 40 db down (1 Mhz / 100 Hz) and the radar can acquire the target. As a result the jamming is ineffective.

Henceforth, since noise jamming did not seem a practical option for these types of radars, radar deception was introduced where the idea is to create false targets and mislead the radar. The first try at deception was using analog delay lines to capture the radar pulse in a delay line and output it shortly after in order to implement the range gate pull out technique (RGPO) where the jammer hoped the MTI filter would follow the false target moving away. Analog delay lines can produce down-range false targets using a very limited range, 10 μ s maximum; afterward they experience significant signal loss and the technique is ineffective.



In order to produce up-range as well as down-range false targets over the full PRI, digital radar frequency memories (DRFM's) were developed to capture and store each radar pulse. Thus, we are now able to recreate the radar pulse, as false targets, anywhere with respect to the platform return (up-range and down-range). However, only down-range false targets are possible when the PRI is agile pulse-to-pulse since the fixed delayed DRFM reads are triggered by the radar pulse. Since, producing up-range false targets for non-constant PRI patterns is essential for better radar deception this creates the need for PRI prediction in order to determine the time of arrival for the next pulse and vary the read delay on a pulse-to-pulse basis. Thus, with PRI prediction capability a radar jamming system can now create up-range false targets and implement the range gate pull in technique (RGPI) for most PRI modulation types.

1.3 PRI Prediction:

Incorporating PRI Prediction capability in a DRFM based ECM system will improve greatly its effectiveness. First, the prediction of PRI's allows for better radar deception with the production of up-range false targets, which is the primary goal of PRI prediction. Second, PRI prediction will permit the jamming system to produce coherent false targets for periods of receiver blanking or signal fades (scanning radars) since the radar pattern is known. Third, with PRI prediction combined with pulse sorting capability a jamming system will have improved DRFM read and write control to store valid radar data and produce coherent false targets.

However, achieving real PRI prediction is not a simple undertaking. It requires real-time pulse-to-pulse analysis, acquisition and tracking of patterns with minimal information, which is often corrupt (missing pulses and containing spurious pulses). Additionally, a good PRI prediction must be able to acquire and monitor various PRI modulation types and keep track of patterns through signal fades and receiver blanking. Moreover, this system is required to have a simple interface and be of a small-form to facilitate the incorporation into DRFM based jammers.

MC-CM addressed this PRI Prediction need and created its line of PRI Predictor systems to solve the pulse-to-pulse agile PRI prediction dilemma. These systems can rapidly acquire and track with great accuracy a variety of modern radar pulse train modulation types, which include constant, dwell-shift, linear-sliding (ramping), staggered or wobulated (sinusoidal) modulations. In addition, once the pattern is acquired it can keep track through signal fades and filter spurious pulses. Furthermore, the MC-CM PRI Predictor can easily be incorporated in a DRFM based radar jamming system.

Based on limited pulse train history the PRI Predictor determines the upcoming PRI value and thus the time of arrival (TOA) of the next radar pulse. From that knowledge targets can be created at a programmable delay ahead of the arrival time thus creating a leading false target.

Staggered PRI Pulse Train - Down Range Target (no Prediction)

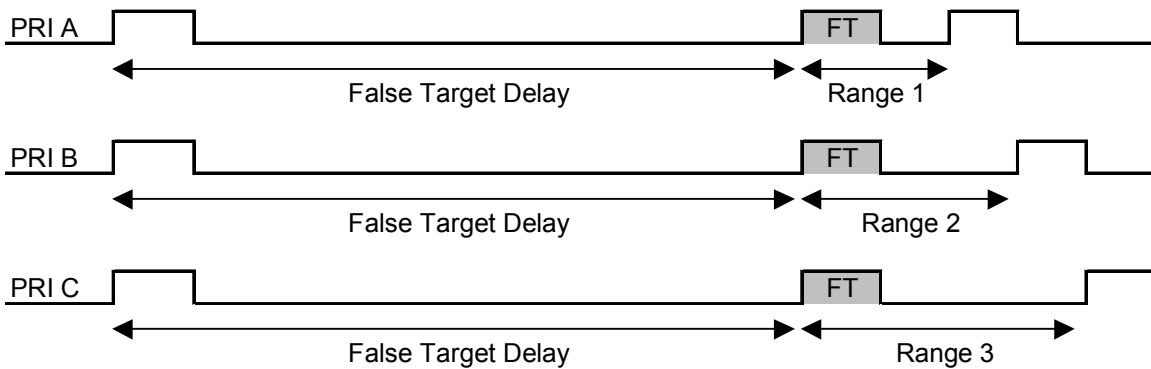


Figure 1.3.1: Without PRI prediction only down-range targets are possible.

Staggered PRI Pulse Train - Up Range Target with Prediction

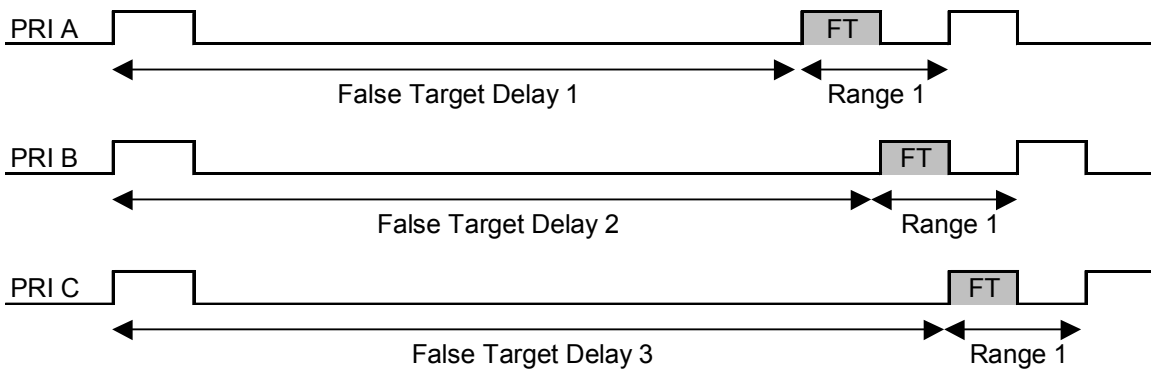


Figure 1.3.2: With PRI prediction up-range targets are now possible.

2. PRI Predictor Development:

The PRI Predictor system is the result of a number of years of intense research in the PRI prediction and Electronic Countermeasures (ECM) fields. MC-CM studied a wide variety of possibilities to achieve PRI prediction from predictive filters, for example Kalman and Optimal filters, knowledge based or data based systems and algorithms, artificial neural networks (ANN), computer architectures and various technologies such as FPGA's. MC-CM is consistently on the lookout for new technologies, algorithms and knowledge to improve the PRI Predictor and the results achieved thus far.

2.1 System Goals:

As the knowledge and development progressed a list of primary goals for the PRI Predictor system was established:

- Track various PRI patterns modulations:
 - ✓ Constant
 - ✓ Dwell-shifts
 - ✓ Staggered (2 to 192 positions)
 - ✓ Linear-sliding (Ramping)
 - ✓ Wobulated (Sinusoidal)
- Use only real-time data, with no a priori knowledge of pattern modulation type
- Analyze and predict PRI's on pulse-to-pulse basis
- Cover a PRI range which can be less than 2 us to greater than 15 ms
- Predict PRI's with great accuracy for minimal false target jitter
- Have minimal sensitivity to noise and spurious pulses.
- Include the capability to keep track through a series of missing pulses
- Build in a target strobe generator for up-range and down-range targets with multiple targets capability
- Build in the capability for future pulse filtering in order to isolate a single radar pulse train in a multiple radar pulse train environment.
- Construct the system small enough to fit in a pod radar jamming system

2.2 Implementation:

In order to meet the listed goals MC-CM started the development of an algorithmic approach. Using theories and knowledge acquired with the study of filters, ANN and knowledge-based identification methods we developed some custom proprietary software to solve the PRI prediction problems encountered. One of the main challenges encountered in the realization of accurate and flexible PRI prediction on a pulse-to-pulse basis is the speed of the incoming PRI data. This creates a need for fast and simple algorithms.

Using divide and conquer principles we developed a series of algorithms each trying to acquire and track a different type of PRI pattern. Not unlike an ANN with adaptive learning and feed back network these prediction algorithms trained themselves to recognize patterns, with actual PRI values measured in real-time, learn their characteristics and predict the upcoming PRI's.

$$PRI_{n+1} = \sum_{k=m}^{n-1} W_k \times PRI_k$$

Formula 2.2.1: Prediction Scheme

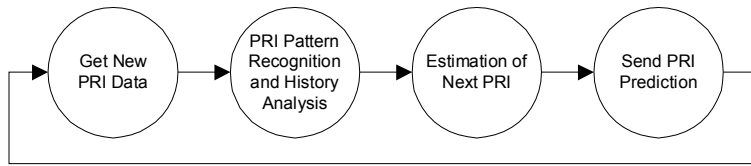


Figure 2.2.1: Algorithm Flow Chart

As shown in formula 2.2.1 the algorithms use PRI history to produce predictions for the upcoming PRI. In Figure 2.2.1 a flow chart shows that each PRI is retrieved and used to produce the next prediction all on pulse-to-pulse basis. Each algorithm analyzes the same PRI data, but run different prediction schemes and review only their own prediction history to monitor their performance. These various algorithms run in parallel which creates a need for an arbitrator to select a prediction from all the ones supplied. The PRI prediction software uses the Multiple Instructions Single Data (MISD) model, shown in figure 2.2.2 below, to run the various algorithms in parallel.

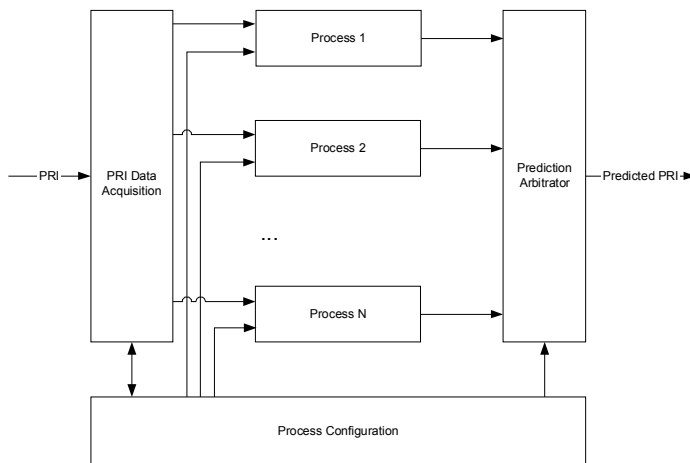


Figure 2.2.2: PRI Prediction Core Structure

Given that the system has a series of processes estimating the next PRI value, a prediction arbitrator is needed to choose which of the N predictions is most likely to be correct. The arbitrator uses a weighted probability function based on past accuracy and current state of the process to choose a prediction among the N available. This arbitrator must adapt quickly (pulse-to-pulse) in order to deal with the ever-changing state of the pulse train input and state of the various prediction processes.

The process configuration controls variables such as history length that the different processes will store and monitor. Shorter history monitoring can make acquisition and pattern lock faster, but it can result in false acquisition. The history length needed is very much PRI pattern dependent.

Once the PRI pattern is acquired and pattern tracking begins, meaning high prediction accuracy, the algorithms can keep tracking through periods of missing pulses and produce properly positioned target strobes during that time by keeping correct timing. The system basically assumes the prediction was right when the pulse does not occur in the expected time and keeps tracking the current pattern as if the pulse was present. Due to measurement and calculation errors tracking through periods of missing data can only be done for a certain time to keep the technique and targets coherent. The ability to keep track through loss of signal is vital for systems where the receiver is blanked occasionally and for deceiving scanning radars. Of course, the PRI Predictor will perform better if it has actual data to base its predictions, hence receiver blanking should be minimized to improve PRI prediction.

As well, when tracking, the PRI Predictor is capable of filtering out some spurious pulses caused by interfering radar pulse trains and keep proper track of the current PRI pattern. This is done using time gating principles to eliminate pulses that arrive earlier than expected. Ignoring spurious pulses is important for PRI prediction since the PRI pattern can quickly lose its coherence and prediction accuracy can be affected. Also, by letting the Predictor control the DRFM writes, as well as the reads, the spurious pulses are not written in the memory to overwrite the current valid information and the deception technique will improve considerably since only valid RF data is stored and read out.

Below, in figure 2.2.3 is a block diagram of the MC-CM Predictor system. With the incorporation of the Prediction and Technique generator the PRI Predictor can produce multiple up-range and down-range false target strobes (up to 200) that are synchronized with the detected video signal. In addition, using radar frequency (RF) tag data the predictor can perform RF de-interleaving of the detected video pulse to isolate a single pulse train and produce a target and write command for that pulse train only.

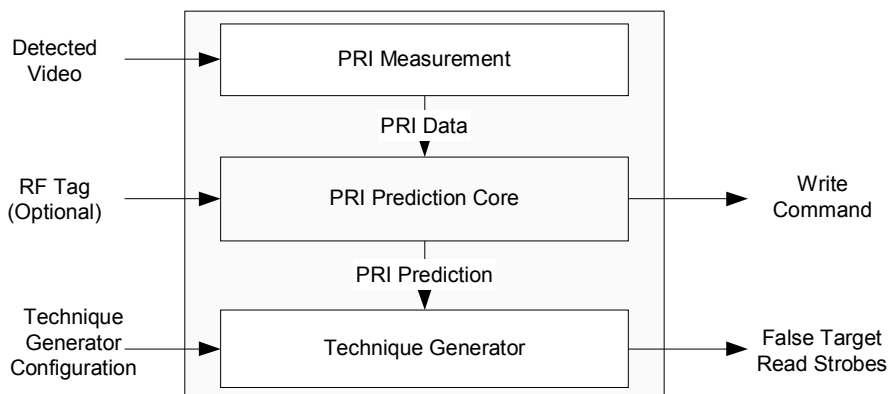


Figure 2.2.3: MC-CM PRI Predictor block diagram

2.3 Results Achieved:

Pattern acquisition processing can vary depending on the PRI pattern modulation type. Table 2.3.1 and figure 2.3.1 below present the results achieved so far for various pattern modulation types in reference to minimum PRI, false target position range and prediction accuracy. For most modulation types the system’s adaptive processes will start production of correct predictions after only a few pulses. For example, some longer staggered PRI patterns are predicted with greater than 75% accuracy after only a few PRI values, yielding very effective deception even before a full pattern frame is seen.

PRI Pattern Modulation Type	Minimum PRI in pattern (us)	False Target Position Range	Predicting at greater than 95 % after approximately
Constant	2	- PRI to PRI	3 PRI
Dwell-Shift	2	- PRI to PRI	3 PRI
Linear-Sliding (Ramp)	2	- PRI to PRI	6 PRI
Staggered (4 positions)	7	- PRI to PRI	7 PRI
Staggered (16 positions)	12	- PRI to PRI	19 PRI
Staggered (32 positions)	20	- PRI to PRI	35 PRI
Staggered (64 positions)	35	- PRI to PRI	67 PRI
Staggered (128 positions)	64	- PRI to PRI	131 PRI
Staggered (192 positions)	100	- PRI to PRI	195 PRI
Wobulated (Sinusoidal)	75	- (PRI + 50 us) to PRI	Pattern Dependant Typically 100 –150 PRI

Table 2.3.1: Modulation Type Typical Performance

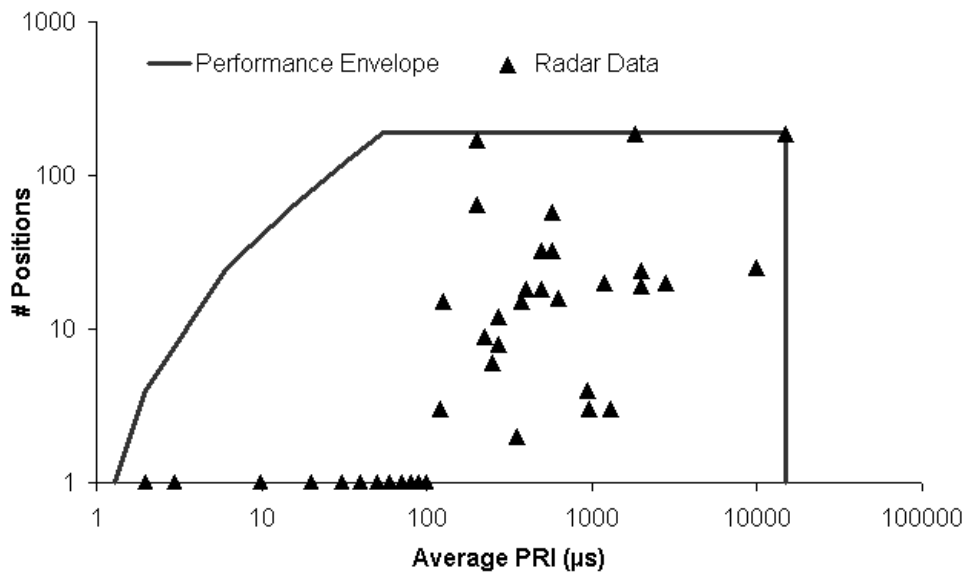


Figure 2.3.1: PRI Predictor Performance Envelope



For wobulated PRI patterns the number of pulses before achieving prediction accuracy greater than 95 % will vary on the number of PRI per sine cycles and the phase of the pattern. The PRI Predictor can acquire and track sine patterns that have at least a mean PRI of 75 us, at most a deviation of +/- 50 % from mean PRI and as little as 4 PRI's per sine cycle.

3. Conclusion:

To conclude, this paper has shown that using an algorithmic approach MC-CM was able to achieve easy and accurate PRI prediction on a pulse-to-pulse basis. Furthermore, this paper has illustrated some benefits of PRI prediction in an ECM system: target production over the full PRI range, improved pulse data storing and production of targets through signal fades and receiver blanking.

The next challenge is combining PRI Prediction with RF pulse sorting. In a real environment a radar jamming system can receive a pulse train containing multiple radar signals interleaved. In order to perform PRI Prediction the multiple pulse trains must be de-interleaved to isolate a signal threat to be tracked by the PRI Predictor.

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