Literature Search on Adaptive Radar Transmit Waveforms

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Adaptive Radar

In what follows, we present critical discussions of the literature that we have reviewed on adaptive radar. The discussion is presented under three headings:

- Controllable parameters for adaptive radar
- Physical aspects of radar transmission
- Detection, Tracking, and Classification

I. Controllable Parameters for Adaptive Radar

There are two major classes of adaptivity:

- **Adaptive-receive**: adaptive changes in the parameters and/or processing in the receiver in response to changes in the received signal

- **Adaptive-transmit**: adaptive changes in the transmitted signal based on feedback from the receiver in response to changes in the received signal

The class of adaptive transmit can be further divided into:

- **Transmit-select**: selection from among a set of predefined transmitted signal configurations

- **Transmit-create**: crafting of the transmitted signal in real-time

There can be overlap between transmit-select and transmit-create when the parameters of the transmit signal to be created are drawn from a finite set of possibilities due to hardware constraints.

There are two papers in the adaptive-transmit class. Wong (1998) was concerned with adaptively controlling the form of the radar ambiguity surface. He proposed a cost metric to be used in the optimization procedure for selecting the next pulse compression waveform based on the current received signal. He generated optimization procedures for two cases: phase-only modulation and frequency-only modulation. His application was battlefield surveillance. The applicability of ambiguity surface manipulation to the case of maritime surveillance requires further consideration. However, this paper presents a principled approach to the development of a suitable on-line parameter selection methodology.

The second paper, Davies and Hughes (2002) addressed the issue of PRF selection in an airborne medium PRF radar. In such a radar, there are ambiguities in range and Doppler that can only be resolved by processing returns taken at three or more different PRFs. Also, there are blind areas in both range and Doppler whose location are a function of the PRF. Through suitable selection of a set of (typically eight) PRFs, the range-Doppler area in which at least three PRFs are clear for each location can be maximized. This paper proposes the use of evolutionary computation algorithms (motivated by biological considerations) for on-line selection of the PRF set, chosen to maximize detection performance in the environment currently being encountered. Again there is identification of a clear performance metric to be maximized in real-time.

Most of the remaining papers are of the class adaptive-receive. Some were concerned with the use of dual-polarized returns to try to distinguish target and clutter echoes based on their polarimetric properties. The proposed polarization discontinuity detector of Park et al (1994) was based on the generalized likelihood ratio test principle, but worked only in Gaussian clutter. One point of note from Watts 2001 is his proposed probability of detection display. Using the currently chosen values of the parameters of the radar, one can estimate the sensitivity and/or performance capability of the radar as a function of range and azimuth. In this way, the operator develops some sense for the effects of on-line adaptation.

In terms of technology, McPherson et al (2001) reported on an IQ modulator that permits direct digital modulation of a W-band carrier signal, allowing arbitrary waveform generation. This would be a key element to a fully adaptive-transmit system. Leatherwood et al (2000) pointed out the effects of the signal distribution considerations in a phased-array radar. The differential signal delays in the feed network can increase the length of the impulse response of the antenna, potentially modifying the transit and receive signals.

II. Physical Aspects of Radar Transmission: Wavelets and Atomic Decomposition

Conventional radars employ linear frequency modulated chirp signals to detect targets over some range of transmitted frequencies. Unfortunately, for any target to be detected, classified or tracked, such generic waveforms do not make optimal use of the transmit bandwidth or energy in order to accomplish the prescribed radar mission.

Another issue of concern is that the target of interest may be experiencing some form of rotational motion. For example, in the tracking of a spaceborne target, its motion can be quite complex in comparison with airborne targets (e.g., aircraft) in that the target can tumble. Closer to the issue at hand, that of designing an adaptive radar for maritime surveillance, the challenge is to deal with small targets such as a small piece of ice (i.e., growler) or a human body floating in the water. In situations of this kind, the target motion van be quite complex due to the external forces exerted on the target by the continuous motion of the ocean waves.

In a pair of papers, Clark (2000) and Bonneau (2001), the use of wavelets is proposed for the design of the transmit waveforms. The wavelet transform provides an optimum basis for the time-frequency representation of stationary signals for fixed energy. Moreover, the wavelet transform provides additional dimensions that enable the individual scattering surfaces of the targets to be tracked in range as they progress during the radar's dwell time on the target. In particular, not only the linear motion of the target can be estimated but also the rotational motion of the target can be seen as a characteristic feature of the target. Hence, the use of wavelets may also provide a method for enhanced classification of radar targets.

The use of atomic decomposition, based on the idea of projection pursuit, provides a further generalization of the wavelet transform by adding several degrees of freedom to the design of the transmit waveform.

Few words of caution are however in order:

- In the papers cited here, no account is taken of the background clutter.

- Computational complexity may also be a practical factor when it comes to practical considerations.

In the context of the latter issue, it may be argued that with the ever-increasing improvements in computers and digital signal processing, computational complexity my not be a major issue of concern in the long run. However, the issue of clutter cannot be ignored. Indeed, the use of wavelets for radar transmission in an ocean environment mandates that we take sea clutter into account, hence a new research problem in itself.

III. Detection, Tracking, and Classification

The key motivation for adaptive radar is to improve one or more of the detection, classification and tracking (data processing) performances. Thus, it is critical to adapt the parameters of the radar with feedback from the detector, classifier or the tracker. **The sensor and the data processor cannot be considered as two independent entities and adaptation cannot be accomplished by considering fixed (static) scenarios.** For example, in a tracking system, the tracker's output in terms of state estimates, covariances or prediction errors need to be fed back into the adaptive radar.

Some of the performance metrics used in the literature are

1. Target detection probability
2. False alarm probability
3. Correct classification probability
4. Time for detection, classification and confirmation
5. Detection, classification range
6. Length of false tracks
7. Tracking accuracy
8. Track purity and track breakage
9. Performance limits (e.g., in terms of the lowest SNR for acceptable performance)
10. Radar energy
11. Radar revisit interval
12. Computational complexity

Adaptation of different radar parameters (e.g., waveform, frequency, polarization) will affect different performance metrics and it is important to quantify the effect in terms of one or more of the above performance metrics. Then, a suitable mechanism needs to be used to adapt the parameters of the radar at design time or in real-time.

From the literature, we have identified the following tools (or techniques) for performance evaluation combined with tracking, detection and classification.

1. Hybrid conditional averaging (HYCA)

This technique is useful in predicting the performance of a single model (e.g., Kalman filter) or multiple model (e.g., Interacting Multiple Model --- IMM) estimator. HYCA will be useful in selecting radar parameters **at design time** based on expected tracking performance.

2. Posterior Cramer-Rao lower bound (PCRLB)

This technique is useful in quantifying the limits of performance in uncertain (with false alarms and missed detections) dynamic environments and in adapting the radar parameters **in real-time**. For example, this will be valuable in accounting for the dynamics of the boat or the periscope the radar is trying to detect and track.

3. Kullback-Leibler information number

This is useful in quantifying classification performance. Waveforms can be designed or selected in real-time to maximize discrimination capability.

IV. Abstracts

Electronic versions of the abstracts of all the papers listed in the Bibliography are recorded in a compact disk (CD), a copy of which accompanies this Report.

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