RADAR WAVEFORM DESIGN USING GENETIC ALGORITHMS

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THESIS

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ABSTRACT

Optimum binary phase codes of length L are characterized by an autocorrelation function $R(\tau)$ with uniform sidelobes of level $1/L$ with respect to the main lobe. These optimum binary codes are called Barker codes. Binary phase codes that exhibit minimum peak sidelobes above $1/L$ are called suboptimum. A genetic algorithm (GA) is implemented to conduct the search for optimum and suboptimum binary codes of a given length L. In this approach, several different fitness functions are considered. These fitness functions are based on sidelobe level (SLL) and generalized entropy measures. To verify that these are reasonable fitness functions, they are first applied to sequence lengths for which optimum codes are known to exist. It is shown that if L is such that a Barker code exists, and S is a generalized entropy measure, then the Barker codes are the only ones that give the minimum value for S. It is also shown that the proposed binary phase code search is efficient for large vales of L.

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Chapter 1

INTRODUCTION

Active electromagnetic surveillance is the main purpose for radar, an acronym that stands for ***RA**dio **D**etection **A**nd **R**anging*. Although the first radar systems were designed for the sole purpose of detecting and ranging non-cooperative targets, modern radar systems now provide ground mapping, target recognition and imaging [WEH87]. The ability for a radar system to provide target recognition and imaging relies mostly on the type of transmitted signal. The search for an optimum radar signal is a complex process of global optimization on some objective function.

Solutions of global optimization problems that occur in large-scale engineering systems have been successfully found using simulated annealing [PER91]. This process relies on the use of a Markov chain for generating the next search point. Thus, this stochastic method for optimization produces a random walk through the search space. To avoid this random walk for the optimization of phase modulated signals a genetic algorithm is used instead. The genetic approach is also a stochastic method for optimization in which the search is directed by the use of probabilistic transition rules.

This paper presents the results of using a genetic algorithm (GA) to find optimum and suboptimum binary phase codes of length L. First, a brief description of radar principles including radar waveform design is given. The principles behind the genetic algorithm are presented as well as an analytical solution for the performance of a simple

genetic algorithm, followed by a performance analysis using a known objective function. Results are given on the convergence efficiency of the GA with respect to population size, number of generations, and crossover and mutation rates. Finally, a genetic algorithm is used for the search of optimum and suboptimum binary phase codes using different fitness functions for the optimization of both the autocorrelation and ambiguity surface.

Chapter 2

RADAR WAVEFORM DESIGN

2.1 Radar Equation

The basic radar range equation gives the range at which a target can be detected. It is expressed in terms of its radar parameters, the environment and target properties. The radar range equation, which is essential in the design of high resolution radar systems, is given by

$$P_r = \frac{P_t G^2 \lambda^2 \sigma L}{(4\pi)^3 R^4} \tag{2.1.1}$$

where P_r is the received power, P_t is the transmitted power, G is the antenna gain, λ is the wavelength of the transmitted signal, σ is the radar cross section of the illuminated target, L is the total system loss, and R is the distance from the target to the radar.

The ability for a radar to detect the received echo signal is determined by the receiver sensitivity:

$$S_r = kT_s\beta_n(S/N)_{in} \tag{2.1.2}$$

where $kT_s\beta_n$ is the noise power, k is Boltzmann's constant ($1.38\text{x}10^{-23}$ J/K), T_s is the receiving system noise temperature in degrees kelvin (K), β_n is the receiving system noise bandwidth, and $(S/N)_{in}$ is the input signal-to-noise power ratio required for detection. If the received power is greater than S_r, the target can be detected. Thus, the maximum detection range is

$$R_{\max} = \left[\frac{P_t G^2 \lambda^2 \sigma L}{(4\pi)^3 k T_s \beta_n (S/N)_{in}} \right]^{1/4} \tag{2.1.3}$$

A complete discussion on the radar range equation where clutter (environmental echoes), jamming, and other interference are considered is given by Nathanson [NAT69].

2.2 Range Resolution

Resolution is the ability to distinguish closely spaced targets. The distance between two targets in the slant-range, along the line of sight, is given by the time delay difference between both targets. To resolve these two targets, the time delay difference must be greater than the correlation width 1/β. Thus, resolution in the slant-range given by [WEH87] is

$$\Delta r_s = \frac{c}{2\beta} \tag{2.2.1}$$

where c is the propagation velocity and β is the bandwidth of the transmitted signal.

2.3 Doppler Resolution

Doppler is the frequency shift of the echoed signal coming from a moving target. This observed frequency shift of the incoming signal is directly proportional to the radial velocity of the target relative to the radar. The doppler shift for a continuous-wave (CW) signal as produced by a moving point scatterer is given by

$$\phi_d = \frac{2v_r}{c} f \tag{2.3.1}$$

where v_r is the radial velocity and f is the radar frequency. Doppler processing is carried out by coherent integration of the echo signal. This coherent integration can be achieved by use of the discrete Fourier transform (DFT). In order to resolve two moving targets, the doppler shift must be greater than the width of the frequency spectrum of the doppler-shifted signal. Thus, the doppler resolution given by [WEH87] is

$$\Delta\phi_d = \frac{1}{T} \tag{2.3.2}$$

where T is the integration time.

2.4 Radar Cross Section

The radar cross section (RCS) is defined as the effective echoing area of a target. It refers to the equivalent area on a sphere's surface at the target position that reflects the same radiation intensity as the target re-radiates toward the receiver [WEH87]. The radar cross section of a target is proportional to the far-field ratio of reflected to incident power density, that is

$$\sigma = \left[\frac{\textit{Power reflected back / unit solid angle}}{\textit{Incident power density} / 4\pi}\right] \tag{2.4.1}$$

The reflected energy of a given target is dependent upon many factors such as transmitted wavelength, the target's geometry, orientation, and reflectivity [NAT69]. Thus, these parameters determine the RCS of the given target.