Radar Waveform Optimisation as a Many-Objective Application Benchmark

Evan J. Hughes

Department of Aerospace, Power and Sensors,
Cranfield University, Shrivenham, Swindon,
Wiltshire, England. SN6 8LA
e.j.hughes@cranfield.ac.uk

Abstract. This paper introduces a real, unmodified *Many-Objective* optimisation problem for use in optimisation algorithm benchmarking. The radar waveform design problem has 9 objectives and an integer decision space that can be scaled from 4 to 12 decision variables. Proprietary radar waveform design software has been encapsulated in a fast and portable form to facilitate research groups in studying high-order optimisation of real engineering problems.

1 Introduction

Real engineering problems are often characterised by many objectives. Pareto ranking has been exploited in recent years to develop a large number of excellent multi-objective optimisation algorithms which can solve bi-objective optimisation problems effectively and reliably, for example, NSGA-II [2]. However, it is known that Pareto ranking alone does not scale well to problems with large numbers of objectives (4+ typically cause problems) [9,5]. Currently, there are few algorithms that are designed specifically to tackle many-objective problems.

This paper describes a real, unmodified engineering problem and the software is provided to allow optimisation with many-objectives to be studied, and hopefully efficient optimisation algorithms developed.

The problem has 9 objectives, and from 4 to 12 integer decision variables, each in the range [500,1500] inclusive, giving 1001 alleles per decision variable. It is known that some of the objectives are not totally independent, and it is suspected that the Pareto set is concave in places, with regions of low density.

The problem is the design of a waveform for a *Pulsed Doppler Radar*, typical of many airborne fighter radar systems. The radar system is required to measure both range and velocity of targets. Unfortunately, with the very long ranges (100 nautical miles typical) and very high velocities (Mach 5 possible), with a simple waveform it is only possible to measure either: range unambiguously but ambiguous velocity; velocity unambiguously but with the range ambiguous; or with both range and velocity ambiguous. For example, if velocity is measured, then target range may only be known modulo by say 5 kilometres, i.e. a target at 108km would appear at 3km.

To allow full unambiguous measurements, a set of simple waveforms is transmitted, each subtly different from the last. The results of the multiple waveforms are then combined in order to resolve the ambiguities. The problem is how to choose the set of simple

S. Obayashi et al. (Eds.): EMO 2007, LNCS 4403, pp. 700–714, 2007.

waveforms. Previous work in this area has led to the development of an evolutionary algorithm capable of designing practical waveforms [1].

This radar waveform design problem is interesting in that in a practical radar system, an entire set of non-dominated solutions would need to be created prior to each mission. While the radar is active, it will choose a general location on the non-dominated surface, based on current radar operating conditions, then select a waveform randomly which is local to this chosen location. The random choice helps prevent 3rd-party interception of the waveform as it is changing constantly, yet the waveform is biased towards an optimal radar configuration. Thus the radar chooses its operating point on the non-dominated surface dynamically on-line, from a non-dominated set that is likely to remain fixed for each mission.

An initial analysis of the properties of the objective surface has been performed and a demonstration of the typical behaviour of two different optimisation algorithms, NSGA-II and MSOPS, on the function is presented.

Section 2 details the radar design problem and section 3 describes the format of the objective function software. Section 4 introduces initial results from analysing the non-dominated surface and section 5 describes the results of comparing the performance of two example optimisation algorithms. Finally section 6 concludes.

2 Radar Waveform Design

2.1 Introduction

Radar systems are categorised by the rate at which they transmit pulses of energy toward the target, called the Pulse Repetition Frequency, or *PRF* [10]. There are three broad categories: Low PRF with few pulses (20 typical) and big gaps between them (1 millisecond typical); High PRF with many pulses (thousands) and short gaps (few micro seconds); and Medium PRF where there are a moderate number of pulses (64 typical) and moderate gaps (100 μS typical).

Low PRF radar systems can measure range exactly, but velocity measurements are ambiguous for any velocities greater than the maximum unambiguous veloctiy V_{mu}, given in (1) where F_{prf} is the pulse repetition frequency in Hertz and λ is the wavelength of the transmitted pulses.

$$V_{\text{mu}} = \frac{F_{\text{prf}}\lambda}{2} \qquad (1)$$

The maximum unambiguous range of the radar is given by (2), where $c \approx 3 \times 10^8 \text{ms}^{-1}$ is the speed of propagation of the pulse.

$$R_{\text{mu}} = \frac{c}{2F_{\text{prf}}} \qquad (2)$$

A typical Low PRF radar may have a PRF of 1kHz, yielding a maximum unambiguous range of $R_{\text{mu}} = 150\text{km}$ and a maximum unambiguous velocity of $V_{\text{mu}} = 15\text{ms}^{-1}$, assuming a 10GHz transmission frequency ($\lambda = c/F_{\text{TX}}$, therefore $\lambda = 0.03\text{m}$).