

Sensor Network Management Through Fitness Function Design In Multi-Objective Optimization

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Abstract - Multi-objective optimization can support sensor network management by taking advantage of the many degrees of freedom available in controlling the sensors. Fitness function design is the key to increasing efficient use of the sensors complete a successful mission. This paper discusses applying fitness functions to model performance parameter decisions. Performance constraints can be introduced preventing solutions with fatal performance flaws from being considered as well as decreasing run-time. Also, the system's tolerance to missing performance goals may be increased or decreased by taking advantage of the weights in goal programming equations. The swarm can be designed to reduce run-time for real-time applications as well as improving the system's performance mismatches in key areas through the introduction of limits and performance weights in the fitness function.

Key words: process refinement, sensor management, particle swarm optimization, fitness, multi-objective optimization

I. INTRODUCTION

This paper describes the design of a multi-objective optimization or fitness equation that can be used to manage the sensor network[6, 7, 8, 13]. Data fusion has been an active area of research for some time and is used in this paper to increase the quality of information while, simultaneously, decrease the amount of data [1, 2, 3, 4]. The primary hurdle in applying fusion technology to wireless sensor networks is designing an efficient, and real-time algorithm capable of managing the sensors and transferring ALL critical information content to the optimal output locations. In this paper, a simple sensor network demonstrates a new management concept through multi-objective fitness equations that are scalable to larger systems and trade off performance improvements with complexity and speed. The paper discusses the process refinement research area, a description of the binary sensor network fusion problem, and then demonstrates some key fitness function design concepts. The paper concludes with some simulation results based on the example system, and ideas for further research.

Process refinement system (PRS) or sensor network management system (SNMS) must operate satisfactorily despite many real-time and practical issues encountered such as: [20][21]

1. the highly dynamic environmental noise and obstacles,

2. finite resources,
3. Sensors with limited capability,
4. Sensor failures,
5. Interference and spoofing.

A. Example Sensor Network Problem

Trade-offs in system resources can be made by evaluating the errors generated. More resources consumed will support more accurate results, generally. The two error types of interest are missing an event that should be detected, probability of miss, and declaring that an event occurred when it didn't, probability of false alarm. When using a set of distributed sensors, the sensors first individually detect, either correctly or incorrectly, a phenomena as a signal in noise and then send their decisions to a central processing center for fusion into a global decision. Optimizing the global decision based on the decisions sent from each sensor is an NP complete problem.

Optimization involves controlling two areas: the individual sensor thresholds and the global decision based on the individual sensor decisions. The thresholds and global fusion rule are chosen to minimize the total Bayesian risk or

$$R = \sum_{i=0}^1 \sum_{j=0}^1 C_{ij} P_j P(\text{Decide } H_i / H_j \text{ present}) \quad (1)$$

where C is the global cost of the decision and P_j is the probability of the j th event happens, and $P()$ is the global probability of deciding this hypothesis.

II. MULTI OBJECTIVE OPTIMIZATION OF SENSOR NETWORKS

In system design and management, the golden rule of never over-designing the system guides the designers. The rule originates from the idea that extra resources are always required in some form when the system performance exceeds the need; this increased cost is unnecessary so should be avoided even if it is not apparent initially where the cost occurs in the system. Of course, the system designer does not wish to under-design the system either. This concept is the basis behind balancing the performance requirements during operation.

A modified goal programming fitness equation intuitively works well for sensor management. The desired performance is the goal and normalizes or

$$Z(\vec{x}^*) = \min \left[\sum_{i=1}^N w_i \left| \frac{f_i(\vec{x}^*) - y_i}{y_i} \right|^r \right]^{\frac{1}{r}}, 1 \leq r \leq \infty \quad (2)$$

where r is an arbitrary parameter, $f(x)$ is the performance function for the region of space, x . The weights, w_i , reflect the importance of that objective in determining the total solution's fitness. The resulting set of solutions for a fitness equation is the Pareto front as illustrated in Figure 1. The value of r determines which solutions are selected within the Pareto front. Evolutionary algorithms addressing NP complete search problems include genetic algorithms (GA), particle swarm optimization algorithms (PSOs), neural networks (NNs), and ant systems. The paper will use various PSO and a new non-dominated PSO designed by the authors.

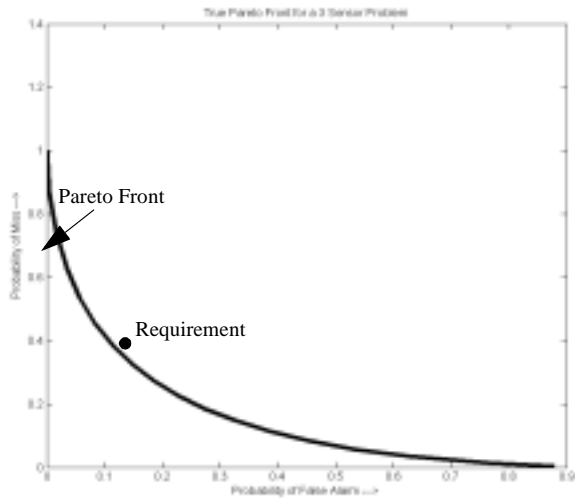


Fig. 1. An Example Pareto Front (ROC) For a 3 Sensor Suite

III. RESULTS AND CONCLUSIONS

The objective of this paper is to gain an understanding of how changes in the fitness function impacts the final solution and system operation. The search functions used are either the PSO or the new non-dominant PSO. The fitness functions are varieties of the weighted goal programming function in (2).

In the final Pareto surfaces shown in Figure 3, there are varying numbers of sensors in each suite and the curves contain discontinuities, which correspond to changes in the decision fusion rule. For larger networks having more rules to choose from, the Pareto surface is more jagged indicating more switching between rules. In comparing the resulting ROC curves for homogeneous sensor suites consisting of two to five sensors, we see the ROC moving towards the diagonal in the center of Figure 3. This diagonal represents lower values for both F_{AR} (False Acceptance Rate) and F_{RR} (False Rejection Rate) or better results.

The modified goal programming approach bases its particle speed on the current solution's distance from desired performance. This difference is normalized by the required value, raised to a power and weighted based on importance in (2). The sensitivity of the system to mismatches in performance is maintained by the power and weight. In (2), r controls the range of solution points available. The higher powers focus on the extremely wavy sections of the middle of the Pareto curve with the lower values covering the gently curving sections near the Pareto's edges. In Figure 4, the two resulting curves are plotted as ROCs with a connected curve for an r value of 1 and points marked for r of 6. In the expanded view, it is apparent that the r for 6 does not lie exactly on the linear curve indicating perhaps some concavity of the curve near the center. It is apparent that, as the power increases, the points focus onto the center regions where there is more switching between functions occurring and new curves are formed. It is apparent that designing the fitness function impacts the solutions found.

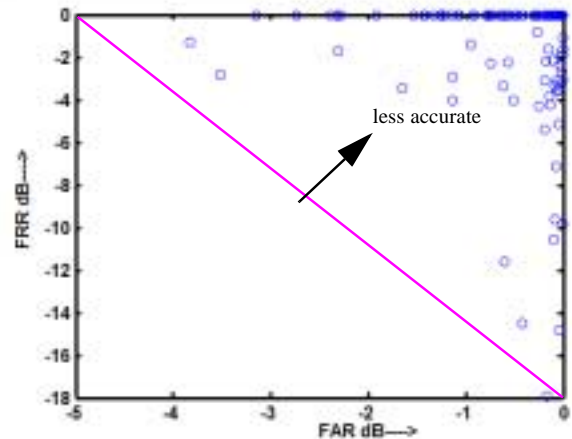


Fig. 2. F_{RR} and F_{AR} Performance Points for Initial Solution Locations

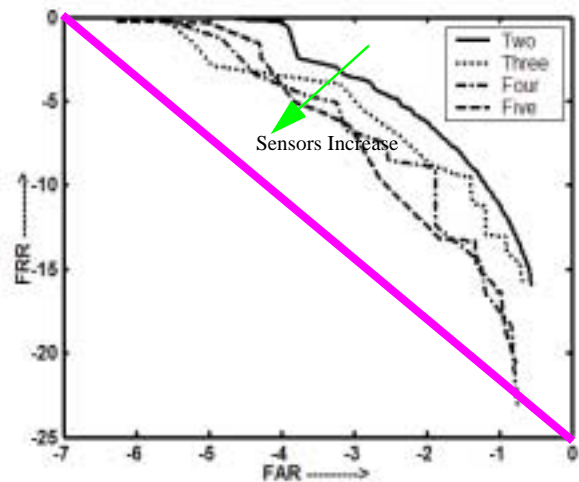
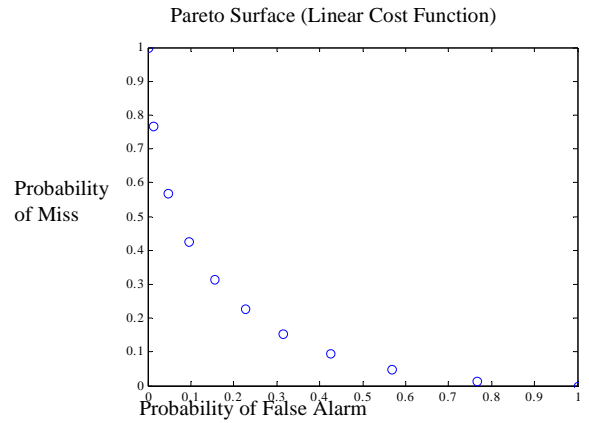
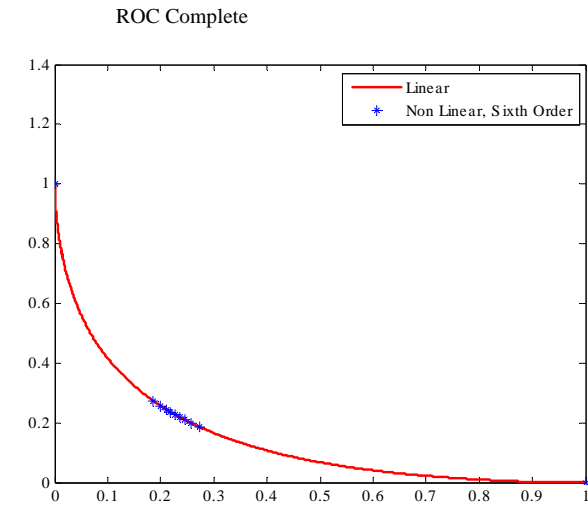
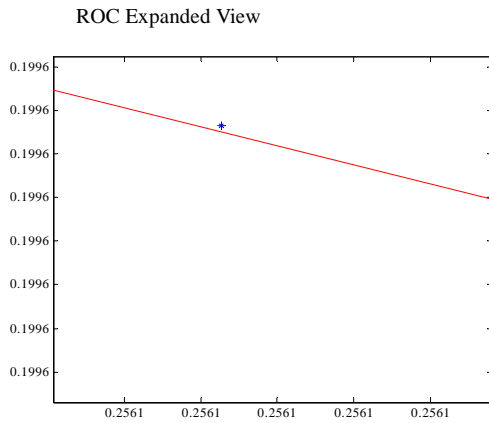


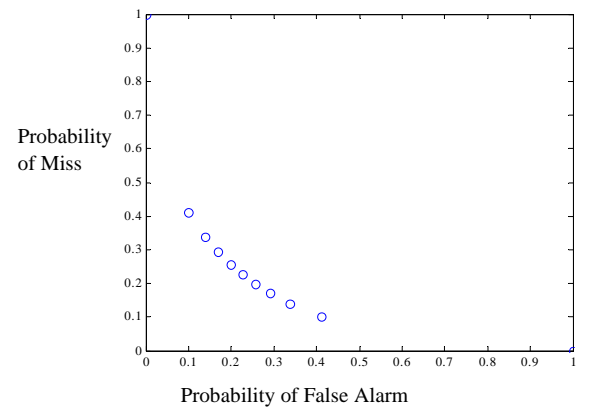
Fig. 3. Performance Curves for Sensor Suites with Uniform Accuracy



(a) Linear Fitness Function



Pareto Surface (Squared Cost Function)



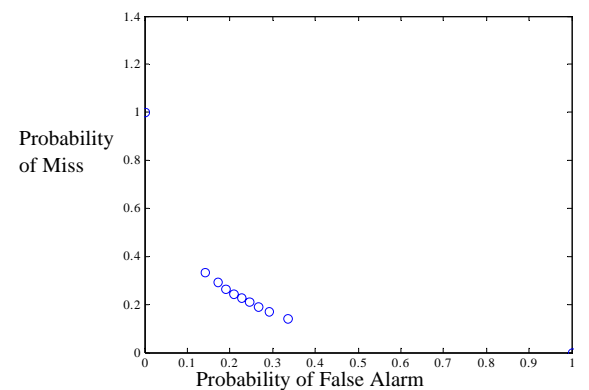
(b) Squared Fitness Function

Fig. 4. ROC with Solution Points Corresponding to Linear and Sixth Order Fitness Functions (a) full plot (b) expanded plot

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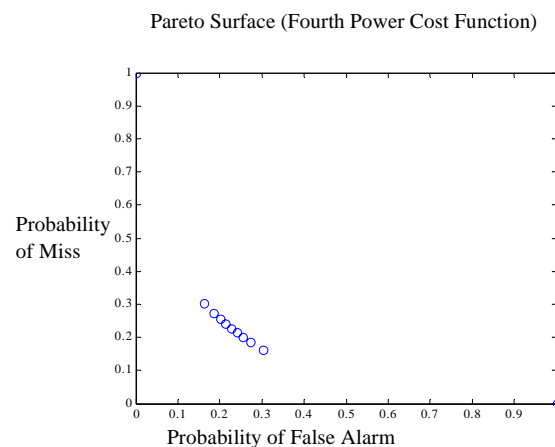
Pareto Surface (Cubed Cost Function)



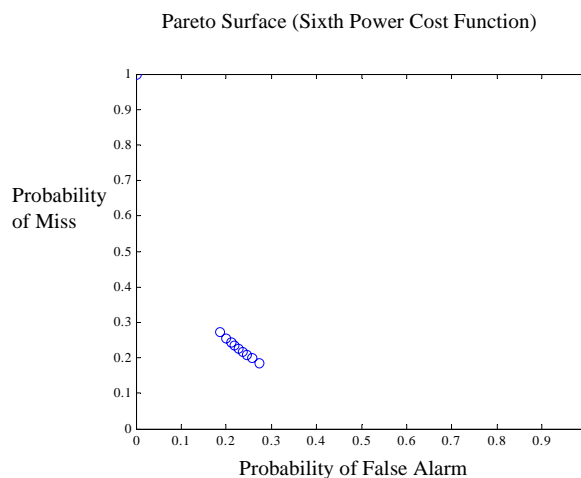
(c) Cubed Fitness Function

Fig. 5. ROC with Solution Point Performance for Various Fitness Function

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(d) Fourth Power Fitness Function



(e) Sixth Power Fitness Function

Fig. 5. (cont) ROC with Solution Point Performance for Various Fitness Function

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