Chapter 10
Applications in Noisy and Dynamic Environments

This chapter discusses the workings of PSO in two research fields with special importance in real-world applications, namely noisy and dynamic environments. Noise simulation schemes are presented and experimental results on benchmark problems are reported. In addition, we present the application of PSO on a simulated real world problem, namely the particle identification by light scattering. Moreover, a hybrid scheme that incorporates PSO in particle filtering methods to estimate system states online is analyzed, and representative experimental results are reported. Finally, the combination of noisy and continuously changing environments is shortly discussed, providing illustrative graphical representations of performance for different PSO variants. The text focuses on providing the basic concepts and problem formulations, and suggesting experimental settings reported in literature, rather than on the bibliographical presentation of the (prohibitively extensive) literature.

OPTIMIZATION IN THE PRESENCE OF NOISE

In many real-world applications, function evaluations are either the outcome of complex simulation procedures or come directly from measurement equipment. In such cases, the obtained values are almost surely contaminated by noise, which is induced by accumulated computational errors or equipment measurement tolerances. Noise limits the usefulness of classical gradient-based algorithms, rendering function and gradient values misleading for the algorithm. Thus, there is an increasing need for robust algorithms, capable of addressing noise and providing satisfactory solutions with the least possible computational burden.

A classical optimization algorithm for solving noisy problems is the nonlinear simplex method of Nelder and Mead (1965), presented for PSO initialization purposes in Chapter Three of the book at hand.

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Its simplex update scheme, which considers only relative differences among search points instead of their actual values, allows it to work with imprecise functions. Thus, possible inaccuracies in measurement have a less critical effect on its operation than for algorithms that require precise values. Torczon (1991) further improved this scheme by incorporating a more sophisticated approach that works equally well in noiseless problems. Of course, evolutionary and swarm intelligence algorithms could not be ignored in noisy problems. The use of populations and their inherent tolerance of imprecise information renders them a very appealing alternative.

Arnold (2001) investigated several optimization methods in the presence of noise. Specifically, he considered the following algorithms:

1. Direct pattern search of Hooke and Jeeves (1961)
2. Nonlinear simplex method of Nelder and Mead (1965)
3. Multidirectional search algorithm of Torczon (1991)
4. Implicit filtering algorithm of Gilmore and Kelley (1995)
5. Simultaneous perturbation stochastic approximation algorithm of Spall (1992)
6. Evolutionary gradient search algorithm of Salomon (1998). Evolution strategy with cumulative mutation strength adaptation of Hansen and Ostermeier (2001)

The behavior of these algorithms was studied on a simple multi-dimensional sphere model under Gaussian additive noise. The obtained results suggested the existence of a threshold on noise strength that, if surpassed, leads to the unreliable convergence of any algorithm, often resulting in search stagnation. In addition, the following remarks were reported:

1. The algorithm of Hooke and Jeeves declined rapidly in noisy problems even for small dimensions.
2. The nonlinear simplex method failed even on the sphere model, unless dimension was kept low, while it got easily stuck in suboptimal points.
3. The algorithm of Torczon alleviated stagnation but diverged for high noise levels.
4. The implicit filtering approach approximated the gradient, thus exhibiting poor performance especially in highly noisy cases.
5. Similar behavior was observed for the simultaneous perturbation stochastic approximation method, although it appeared to be more sensitive even for small dimensions, as well as for the evolutionary gradient search approach.
6. The evolution strategy with cumulative mutation strength adaptation of Hansen and Ostermeier was shown to be the most robust algorithm with respect to the effects of noise.

The adequacy of evolutionary algorithms in noisy problems was also verified and analyzed in other works (see Arnold, 2002; Beyer, 2000; Beyer *et al.*, 2004; Darwen & Pollack, 1999; Eskandari & Geiger, 2009). PSO was also studied in the presence of noise. The first study of Parsopoulos and Vrahatis (2001) was followed by more sophisticated approaches for different PSO variants (Bartz-Beilstein *et al.*, 2007; Han & He, 2007; Janson & Middendorf, 2006; Pan *et al.*, 2006; Parsopoulos & Vrahatis, 2002a, 200b), suggesting the ability of PSO to tackle noisy problems.

In most studies, additive Gaussian noise was used to simulate noise in nature. However, multiplicative noise is also an interesting alternative, perhaps closer to reality, since it considers noise strength

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