§33. Particle Swarm Optimization for Reconstruction of Penumbral Images

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Penumbral imaging [1], one of coded aperture imaging technique, is used for imaging objects that emit high-energy photons; such objects arise, for example, in nuclear medicine, x-ray astronomy, and laser fusion studies. For these high-energy photons, classical imaging techniques (e.g., lenses) are not applicable.

Penumbral imaging is a technique which uses the fact that spatial information can be recovered from the shadow or penumbra that an unknown source casts through a simple large circular aperture. Since such an aperture can be ''drilled'' through a substrate of almost any thickness, the technique can be easily applied to highly penetrating radiation such as neutrons and γ rays. To date, the penumbral imaging technique has been successfully applied to image high-energy x rays, protons, and neutrons in laser fusion experiments.

Since the penumbral image is a convolution of source image with aperture function, the source image can be obtained by deconvolution. Usually a Wiener filter is used for deconvolution. The limitation of penumbral imaging is that the straightforward deconvolution is very sensitive to noise contained in the penumbral image. The reconstruction of penumbral images can be viewed as an optimization problem by optimizing its cost function. Though conventional optimization methods such as the gradient decent method can be used for penumbral image reconstruction, these methods need good initial values for estimation in order to avoid the local minimum. In our previous works, we proposed several heuristic reconstruction methods based on simulated annealing (SA) and genetic algorithms (GA), which are global optimization techniques. We have shown that heuristic global optimization methods are robust reconstruction methods even for noisy penumbral images. Recently, a new global optimization technique named as particle swarm optimization (PSO) has been proposed, which is a stochastic, population-based evolutionary computer algorithm as well as GA. Compared with GA, PSO is an extremely simple algorithm that seems to be more effective for optimizing a wide range of functions. In this paper, we apply PSO to penumbral image reconstruction problems and show that PSO is also effective for reconstruction of penumbral images [2].

Particle Swarm Optimization (PSO) is a new method of optimization which exploits some characteristic of biologic evolution[3]. Assume an extent diffuse population existing, called a swarm. The individuals, now termed as particle that can be viewed as a point in search space and it tent to cluster at position where minimum are identified. Therefore, particle swarm optimization base on making each particle evaluate itself by compare with previous experience and his neighbors for obtaining the best result.
Particle Swarm Optimization can be represented by

$$\begin{cases} \mathbf{v}_i^{t+1} = w^t \mathbf{v}_i^t + c_1 \cdot rand \cdot \left[\mathbf{p\_best}_i - \mathbf{x}_i^t\right] + c_2 \cdot rand \cdot \left[\mathbf{g\_best} - \mathbf{x}_i^t\right] \\ w^{t+1} = w^t + dw; \qquad dw = (w_{\min} - w_{\max})/T \\ \mathbf{x}_i^{t+1} = \mathbf{x}_i^t + \mathbf{v}_i^{t+1} \end{cases} \tag{1}$$

At iteration t, $\mathbf{x}_i$ is the i th particle that moves by a velocity vector $\mathbf{v}_i$, $\mathbf{p\_best}_i$ is the personal best of $\mathbf{x}_i$ and **g_best** is the global best among all particles. w is the weight (the initial weight is 0.4 and w_{min}=0.4, w_{max}=0.98), c_1 and c_2 are acceleration constants (c_1=c_2=2.0), and *rand* is a uniformly distributed random number among 0 to 1.

In PSO based penumbral image reconstructions, the particle **x** is the object parameters to be estimated and the *p-best* and *g-best* are determined based on its cost function (the mean square error between the obtained penumbral image P and the penumbral image $\widehat{P}$ of the estimated image $\widehat{O}$).

To validate the capability of the proposed method, we carried out computer simulations. Fig 1(a) is a phantom with two hot cores, shifted from the center and surrounded by cold plasma. The image size is 31×31 and aperture size is 19×19. The penumbral image is shown in Fig.1(b). Poison noise is added to the penumbral image, which is shown in Fig.1(c). SN ratio at the center is about 10. In our experiments, the noisy penumbral image is used for reconstruction. In order to make a comparison, we use both our proposed PSO based method and conventional Wiener filer for reconstruction.

Both reconstructions by our proposed PSO based method and conventional Wiener filter are shown in Fig.2 for comparison. It can be seen that conventional Wiener filter based method is not very robust to the noise, while our proposed method is very robust to the noise.

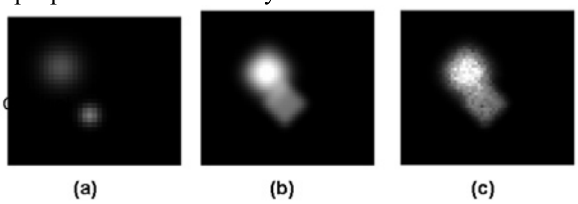

Fig.1 (a) Phantom, (b) its penumbral image without nose, (c) the penumbral image with Poison noise

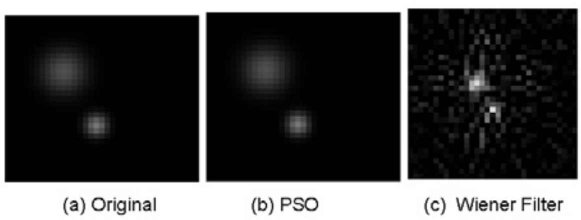

Fig.2 Comparison of reconstruction by our proposed PSO and the conventional Wiener filter

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[3] J.Kennedy and R.C.Eberhart, *Proc. IEEE Int. Conf. Neural Networks*, Vol. 4, pp.1942-1948 (1995).