The inverse scattering problems are usually treated by the traditional deterministic methods which are founded on a functional minimization via some gradient-type scheme. The major drawback of these types of deterministic methods is that the final reconstructed image is highly dependent on the initial trial guess.[15] In general, they tend to get trapped in local minima when the initial trial solution is far from the exact one. Thus, some population-based stochastic methods, such as genetic algorithm,[5,16,17] differential evolution,[18,19] particle swarm optimization (PSO),[14,20–22] are proposed to search the global extreme of the inverse problems to overcome the drawback of the deterministic methods. Concerning the shape reconstruction of conducting scatterers, the asynchronous particle swarm optimization (APSO) has been investigated whereas the APSO has been utilized in the reconstruction of a two-dimensional metallic cylinder.[22] In this case, the reported results indicate that the APSO is a reliable tool for inverse scattering applications. To the best of our knowledge, there is still no investigation using the APSO to reconstruct the electromagnetic imaging of a perfectly conducting cylinder with arbitrary shape in free space under time domain.

There are two main advantages for cubic-spline expansion as follows: i. For a complicated shape, the number of unknowns for expanding the shape function by cubic-spline expansion is less than that by Fourier series expansion. ii. The exact center of the object is insensitive for cubic-spline expansion unlike for Fourier series expansion. If there is some displacement for the exact center of the object, the number of unknowns for expanding the shape function by Fourier series expansion will increase greatly. On the other hand, the number of unknowns does not vary for cubic-spline expansion.

In this paper, the computational methods combining the finite difference time domain (FDTD) method[23] and the PSO algorithm with an asynchronous updating scheme is presented. The forward problem is solved by the FDTD method, for which the subgridding technique[24] is implemented to closely describe the fine structure of the cylinder. The shape of the scatterer is parameterized by closed cubic spline expansion. The inverse problem is formulated into an optimization one and then the global searching scheme APSO is used to search the parameter space. In Sec. 2, the subgridding FDTD method for the forward scattering are presented. In Secs. 3 and 4, the inverse problem and the numerical results of the proposed inverse problem are given, respectively. Finally, in Sec. 5 some conclusions are drawn for the proposed time domain inverse scattering.

2 Forward Problem

Let us consider a two-dimensional metallic cylinder in a free space as shown in Fig. 1. The cylinder is parallel to the z axis, while the cross section of the cylinder is arbitrary. The object is illuminated by a Gaussian pulse line source located at the points denoted by Tx and reflected waves are recorded at those points denoted by Rx. The computational domain is discretized by Yee cells.[24] It should be mentioned that the computational domain is surrounded by the optimized perfect matching layers (PML) absorber[25] to reduce the reflection from the environment-PML interface.

The direct scattering problem is to calculate the scattered electric fields while the shape and location of the scatterer are given. The shape function $F(\theta)$ of the scatterer is described by the trigonometric series in the direct scattering problem

$$F(\theta) = \sum_{n=0}^{N/2} B_n \cos(n\theta) + \sum_{n=1}^{N/2} C_n \sin(n\theta), \tag{1}$$

where Bn and Cn are real coefficients to expand the shape function.

In order to closely describe the shape of the cylinder for both the forward and inverse scattering procedure, the subgridding technique is implemented in the FDTD code; the details are presented in the following.