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Ghost neighborhood method for handling Peridynamic boundary effect

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Peridynamic is a nonlocal continuum theory which is proposed at first by Silling [1] in 1998. In his pioneering work, Silling uses the integro-differential equations to replace the partial differential equations in classical continuum theory by introducing the model of long-range force between material points over finite distances in a body. This creative modification makes Peridynamic can deals with the continuous media, the discontinuous defects (such as crack, dislocation) and particles in a single theoretical frame work. After this modification, the motion equations of a body can be written as

$$\rho\ddot{\mathbf{u}}(\mathbf{x}_A,t)=\int_{\mathrm{H}}\mathbf{f}(\mathbf{u}(\mathbf{x}_B,t)-\mathbf{u}(\mathbf{x}_A,t),\mathbf{x}_B-\mathbf{x}_A)dV_B+b(\mathbf{x}_A,t) \quad (1)$$

Where $\mathbf{u}$ is the displacement vector field, $\mathbf{f}$ is the long-range force (per unit volume squared) between material point A and B. This interaction will be called a bond. $\mathbf{H}$ will denote the spherical neighborhood of A in $\mathbf{R}$ with radius δ. This neighborhood means a subset of all points exerting on point A in the entire body $\mathbf{R}$. (Fig.1) [2].

Fig.1.Each point A in the body interacts directly with points in the sphere H through bonds

In peridynamic theory, horizon determines the amount of material points that exert on one material point. In addition, we usually assume that the bond force depends only on the bond stretch rate [2] [3], in other words, all bond force are equal under a uniform deformation. Then for one material point *A* which is inside the body and enough far away from the boundary, the horizon is totally inside the body(Fig.1(a)), and the distribution of material points exerting on this is symmetrical, so the forces exerting on point *A* are balanced. However, if we choose a material point *C* near the boundary, whose horizon is partially inside the body(Fig.1(b)), the distribution of material points inside horizon is not symmetrical, so the forces will not be balanced. This result is obviously unreasonable [4]. This unreasonable phenomenon was called the boundary effect.

In this paper, our work will focus on the handling of peridynamic boundary effect with a "ghost neighborhood" method. Firstly, we will expound the boundary effect and its causes. Then a correction of bond force density is made which makes the resultant force density independent of horizons to make the resultant independent of horizon sizes. Because, the ghost neighborhood method is based on this independence. Thirdly, the ghost neighborhood method is advanced. The core idea of this method is to create a ghost neighborhood for a point nearby the boundary (the distance of the point and the boundary is shorter than the horizon size) to complete its neighborhood. The deformation of ghost neighborhood can be computed from those in real part, by doing this, the resultant force density for this point can be obtained from both real part and ghost part of its neighborhood. The theoretical basis is the independence of the resultant force density and horizon size. (As shown in Fig2). This independence makes these two different horizon size (size δ_a make a complete neighborhood while size δ_b b not) of point A give a same result of the resultant force density. Then the ghost neighborhood method can be thought right for the result computed with a complete neighborhood is thought right. Finally, the ghost neighborhood method is verified in both theoretical and numerical.

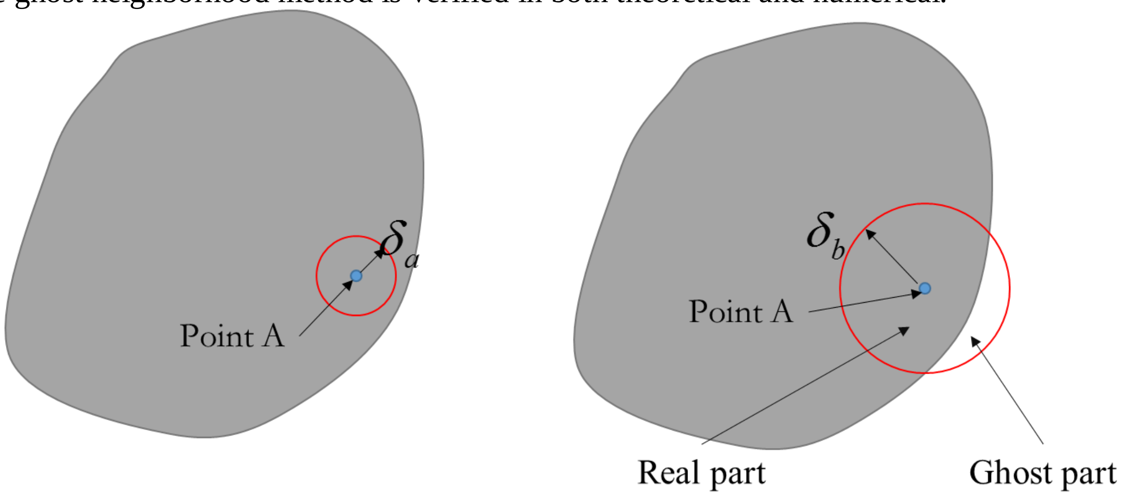

Fig.2. Horizon size δ_a make point A have a complete neighborhood while size δ_b not. For the second case a ghost part of neighborhood to complete its neighborhood.

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