A Novel Post Process Method For Smoothed Particle Hydrodynamics by Interpolation on Specified Slice Plane

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Abstract. The smoothed particle hydrodynamics (SPH) is widely used in numerical simulations as a kind of meshless method. The particles are used to represent object, which is a fully Lagrangian modeling scheme without the need to define a spatial mesh so it can simulate large deformation. The classic post process method cannot visualize the simulation results smoothly, so a novel post processing method is proposed in this paper. By developing a program, the coordinates and field variables of particles were collected to a file. Using the kernel function, the field variable on a specified slice plane was interpolated. By developing a program, the simulation results have been rendered smoothly. This method is illustrated by a penetration example in this paper.

1. Introduction
Smoothed particle hydrodynamics (SPH) uses a collection of points or so called particles to represent a given body[1]. SPH is a typical numerical method that is part of the larger family of meshless (or mesh-free) methods[2]. Smoothed particle hydrodynamics is a fully Lagrangian modeling scheme without the need to define a spatial mesh. For some fluid flow and structural problems involving large deformations and free surfaces, if continuum element is used in simulation, the element may be excessively distortion and causes termination. While smoothed particle hydrodynamics (SPH) as a mesh-free method has been widely used, in some post processors of business software the solving region is rendered as particles. Since nodal connectivity is not fixed, some disadvantages are shown such as field variables are discrete and geometry boundaries are obscure. It is difficult to visualize spatial distribution of variables in internal plane, which is more convenience in finite element method. While these information such as geometry shape, free surface, or spatial distribution are concerned by users or researchers who use SPH method[3]. So it is necessary to develop a post processing method to improve the visual effect for SPH method.

2. SPH discrete method
At its core, the method is not based on discrete particles (spheres) colliding with each other in compression or exhibiting cohesive-like behavior in tension. Rather, it is simply a clever discretization method of continuum partial differential equations. SPH uses an summing interpolation scheme to approximate a field variable at any point in a domain, by summing the weight contributions from neighboring particles, as in Eq.1. The weighting function is called kernel function W[1,2].

\[
\langle f(x) \rangle = \sum_{j} \frac{m_j}{\rho_j} f(W(|x - x_j|, h))
\]  (1)
Here, \( x \) is the coordinate of any point, \( j \) represents neighboring particles, \( m_j \) is the mass, \( \rho_j \) is the density, \( f_j \) is the field variable, \( x_j \) is the coordinates, \( h \) is the smooth length. An example kernel function is shown in Fig 1. The smoothing length \( h \), determines how many particles influence the interpolation for a particular point.

![Figure 1. The kernel function in SPH](image1)

The common kernel function is shown in Eq. 2 as a cubic spline as the interpolation polynomial

\[
W(r, h) = \frac{C}{h^n} \begin{cases} 
1 - \frac{3}{2}d^2 + \frac{3}{4}d^3 & \text{when } 0 \leq d \leq 1 \\
\frac{1}{4}(2-d)^3 & \text{when } 1 \leq d \leq 2 \\
0 & \text{elsewhere}
\end{cases}
\]  

(2)

Where \( d = r/h \) and \( r = |x - x_j| \), and \( C \) is the normalization factor,

\[
C = \left\{ \begin{array}{ll}
\frac{2}{3} & 1D \\
\frac{10}{7\pi} & 2D(\text{circular}) \\
\frac{1}{\pi} & 3D(\text{spherical})
\end{array} \right.
\]  

(3)

The shape of kernel function in Eq. 2 can be well illustrated in Fig 2.

![Figure 2. Shape of cubic spline kernel function](image2)

The visualization method for SPH can be concluded as following:
1) Gathering particles coordinates and field variables by user interface such as Python[4] script or other programming language
2) Saving the information as text or csv file[5]
3) Defining the slice plane or region which is concerned by the user
4) Finding all the neighboring particles of slice plane or region by smoothing length
5) Defining the destination mesh grid on slice plane
6) Calculation all the value of mesh grid by interpolation of selected particle in step 4
7) For any grid whose distance to selected particles in step 4 larger than given value, make it as boundary or exclude it

8) Visualizing the results by figure or image. A GUI based data extractor program developed by Python tkinter[6] is shown in Fig 3. The information such as particles coordinates, strain, stress and et al are saved as a csv file.

![GUI based data extractor program](image1)

Figure 3. The GUI based data extractor program developed by Python

3. SPH visualization example
Smoothed particle hydrodynamic analyses are effective for applications involving extreme deformation such as ballistics, impacts and et al. The established model for the projectile-target penetration problem is shown in fig 4. The target is split into two parts and bonded in the interface. The outer part may undergo small deformation, so is model by finite element method, while the inner part can be modeled by SPH and they were tied together. The deformed mesh of projectile and target is also shown in fig 5. As the limitation of current post processor function, the result shown in figure 5 is not rendered as a field directly.

![Mesh of rigid projectile penetration into target](image2)

Figure 4. Mesh of rigid projectile penetration into target

![Deformed mesh of projectile and target](image3)

Figure 5. Deformed mesh of projectile and target
By developing a program, fig 6 shows the SPH particle distribution of the target at center cross section region from simulation results, the shape of deformed target can be well rendered.

![Figure 6. Deformed of the target by developing program](image)

By the above method, the typical variable distributions of equivalent stress and plastic strain are rendered as fields, as shown in fig 7 and fig 8. The shape of target can be well visualized by this method. In this cross section, the maximum equivalent stress is about 1000MPa, the maximum equivalent strain is about 1.0 locating at shear zone. And the maximum equivalent stress and plastic strain coincides in the same area indicating that material undergoes large plastic deformation and strain concentration.

![Figure 7. Equivalent stress distribution of the target](image)
4. Conclusions
A novel post process method for smoothed particle hydrodynamics by interpolation on specified slice plane was proposed in this paper. By this method, field variables distributions of SPH region at a specified cross section can be obtained. The projectile penetrates target process with a given velocity was investigated by numerical methods. The deformed shape of SPH region were extracted and rendered by threshold based on smooth length and kernel function type. And the distributions of equivalent stress and plastic strain in a specified cross section was interpolated by kernel function. This method can also be used for other simulations in which smoothed particle hydrodynamics is employed.

References
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