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Deformation Exploration in Mass Spring Model using Euler and Verlet Integration Methods

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Abstract: The paper assigns the firm technique that has been designed for the mesh based simulation by using the concept of mass spring model. The general mass spring model has been utilized in a lot of applications for instance, fashion designing, merging virtual booth and in the basics of cloth simulations, consecutively in order to develop effectual surgical training through virtual environments. Though, virtual simulators necessitate meeting both requirements that are, dynamic to be real time and high realistic. While dissimilar forces have applied on the particles they generate several differential equations. In order to, solve these equations, different kinds of integration methods have been used to get the best results. Here in this paper, it shows the procedure of generating a mesh based simulation using euler and verlet integrations method. Verlet method executes vigorous compared to Euler integration method on the basis of deformation error.

Keywords: VR, Mass Spring Model, Verlet integration, Mass Spring Methods.

I. INTRODUCTION

The improvement [1] of geometric, mathematical and computational model has allowed the studies and the development of surgeries termed as minimally invasive (MIS), used in the surgical practical doctors training. The probable methods of working among the models and also allows the interactions of the medicine as well the areas of mathematics, engineering, physics and computation, among others. In addition, creating these sciences contributes further indicative through the improvement of the methods of analysis, planning of surgeries and the development of new equipments, turn out to be practical surgical every time with less unkind and harmless for the patients. While the key model of mass-spring provides a competent simulation of the medical anatomical structures, though the purpose of the values of damping is capable of being a hard task, where the unpredictability of the system depends on these values, being that a lot of times a change in the topology might cause uncertainty in the system.Deformable models [1] are broadly used for surgery simulation. It works by using a mass-spring that is reasonably simple in its conception, through a structure Matrix type, every vertex of one tetrahedral has been allocated a part of the total mass in addition to each vertex connects towards an adjacent through a structure mass – spring - damper in Parallel. One of the probable elucidations of this system has been termed in fiction as being the one that uses the method of explicit Euler solution. The equation directs dynamics of each vertex appears from the laws of Newton and Hooke, where the anxiety is in function of the mass is proportional the acceleration along with the force proceeding from the spring is proportional that it is constant as well the losses normally has been credited to the glutinous erosion that is proportional to the speed of mass. When the structure of tetrahedron makes to use in a cube, existence of all its connected vertices has only three possible dimensions, which has the side of the cube, diagonal line of the face and the internal diagonal line. In contrast, nor always the structure of tetrahedron poises for a cube, this allows to the element if adjust more effortlessly in the form of an additional complex structure. This amendment [2] makes that the initial dimensions that have to store in a matrix combined little extra density of the calculation and initiating a higher addiction of the mesh and as a result increase in the error of simulation. The simulation of virtual surgery of the larynx, embroils more that the simple deed in addition to reaction of soft tissues to the appliances, existing an interaction compact structure that has been used towards the construct of a one-dimensional glottal model. Here, in this work it is designed to improve the studies in the direction to mass spring in three-dimensional framework. It is the major factor in simulator’s perceived realism and also faces the close analysis from the experts working in the field. Soft tissue is able to simulate through a trickle of methods. In this, research emphases on the mass-spring model, where a body is modelled a set of point’s masses interconnected by several elastic springs that follow common physical laws. The concept behind this model, is fairly direct as well the algorithm has been required to simulate the model in general it does not require any complex operations. In practice however, a common serial applications are far from being quick enough due to high number of masses and the springs required for accurate and the precise simulated models. The vital problem of the virtual surgery systems along with the high perceived realism is requires the performance of simulations. The model that recycled in the simulation have to be an extraordinary resolution, so there by the user can clearly differentiate visual and haptic features can be performed in the operations as defined in a medical training situation. In other end, the simulation has to run at a quick enough rates in order to allow a smooth interaction through the haptic devices.

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II. RELATED WORK

The mass-spring methods [1] have motivated the choice of adjusted model, added satisfactory for the simulation. This technique moves on in the direction towards more efficient in relation to the not elastic conditions of soft tissues. The major objective of study in mass-spring methods is to focus the choice of the adjusted model more suitable meant for the simulation in three dimensions. Tri dimensional model simulation of the vocal fold reacted to the expectations. Here, in this paper it has been established that the simulations of vocal folds using the structural mesh methods utilizes very similar to actual observations.

In recent times a [2], novel mass-spring model algorithm consider towards exactly simulate soft human organ tissue, both through visual (graphic) and also haptic perception (touch). The algorithm is executed as a parallel mass spring model. This requisite was set to let for smooth and consistent haptic (and visual) interaction by the user, where two known soft tissue data sets are accessible to test this requirement, the renderer and haptic devices in a multi-threaded environment.

During [3] on soft tissues surgery simulation, Simulating an intellectual simulation platform intended for surgery of vein mass-spring gets the vital roles. This platform is able to afford good human-computer interface as well control a few simple motions. Without size every point has its own quality. All the points are scattered equally and it is just the point mathematically as well. Here, in this model, the agreed two points are connected to one spring in addition to one point be able to join with the multiple springs. The springs is linear and also assessment to Hooke's law. Mass-spring contains twist spring, structure spring along with tension spring. Twisting spring possessions to the springs between diagonal vertices can prevent the tissues twisting in abnormal. Structure spring is able to fix the whole tissue through attaching the nodes that is adjacent. Every two points connects with tension spring with the intention of helping to fold away smoothly. Accelerated velocity of a few mass-points can be computed, as a result, the application fields are extremely wide.

Here in, hybrid model [4] improves the facility of modelling temporal deformable behaviour to the standard Boundary Element Method (BEM).Simulating deformable objects uses BEM has the solved Boundary Value Problem (BVP) which is an not related to the variable of time. The deformation behaviour of seamless linear elastic material anchored in current boundary displacement as well as the traction conditions of object is reduced. Related to time together with viscous or damping effect it cannot model non-linear deformation behaviour. By integrated BEM into a dynamic deformable model driven to solve the problem through mass-spring an extra model and pure boundary value turns up. Physical accurate global deformations have been calculated by the BEM. Pre-processing stage and runtime computation stage are the two stages. Including both the surface meshes and the discrete points this model represented in a hybrid method; through the point-based simulation framework it is simple to pair the model.

Elastically deformable models [5] have been used in a variety of cloth objects; it is available to be used in super elastic method that has been delivered string stiffness. Here it has been showed that when absorption of high stresses occurs in a tiny region of the surface the local deformation turns to be unrealistic compared to real deformations of textiles. It is an elastic model the merely solution towards decreasing these deformations has been so far to increase the stiffness of the deformed springs, however, here it is showed that it radically increases the cost of algorithm. As a result a new method to adapt this model to the predominantly stiff properties has been inspired from the dynamic inverse procedures.

The uses of 3D image-based [6] surgery planning systems have additional as well further recognized in this field. Here in a surgery planning system to predict soft tissue changes it presents a tetrahedral soft tissue model that can be used due to the skeletal hangs. Moreover, it consists of mass point connected through springs in this model. Because of external changes it directly calculates the deformation of the model. User take advantages of the fact that generally deformations are local and it has been compared with the results through pre-computed reference models in order to, achieve fast calculations, and to prove the model's accuracy. In addition, the dynamic behaviour of these models besides forces considering at mass points is simulated.

The current The current improvements in the fields for example, a living tissues of modelling bio-mechanics, technologies of haptic, capacity of computational and practicality of graphics necessary to create the conditions of to develop the concrete training surgical using the environmental virtual. In computation and workload intended for a simulator surgery the main computational assignment is that of simulation deformation of the structures anatomical. A novel approach has to be used in surgery virtual. Specifically newness appears in two forms; a mass-spring model with highly realistic and a technique based GPU. It also analysis that provides an almost serial implementation over speedup and CPU based parallel execution over speedup.

III. MASS-SPRING MODEL

The basic of algorithm in questions are easy to understand. A model of mass - spring consists;

A set of mass points Mi

i = [0, *N*]

whereas *N* represents the number masses in total.

This has interrelated among the springs *Sij* connecting any two arbitrary mass points *Mi and Mj* .

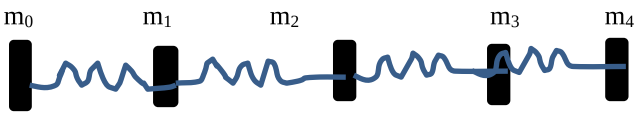

Figure1. One-dimensional case of a mass-spring system

Figure 1 The simple one-dimensional case it represents the mass-spring model as specified in this particular case contains masses *M*0, *M*1, *M*2, *M*3, *M*4 and the springs *S*01,*S*12, *S*23, *S*34. Now, here the model of mass-spring, force has been applied on masses connected and summed in accordance to second law of motion of Newton's.

$$m_i a_i = \sum_{j \in S_i} \vec{F}_{ij} \qquad (1)$$

where S_i the set of connected masses for m_i, a_i is the acceleration of *mi*, and F_{ij} is exerted the force by connecting the spring with the two masses m_i and m_j can be obtained from the law of Hooke's:

$$\vec{F}_{ij} = K_{ij}(l_{ij} - l^0_{ij}) \frac{l_{ij}}{|l_{ij}|} \quad (2)$$

Whereas k_{ij} is stiffness of the spring, l_{ij} is current length of the spring or else the distance among masses m_i and m_j, and l^0_{ij} is spring rest length in equilibrium. In order to, obtain a set of useful results; equation 1 is numerically integrated using Verlet integration. Here in this integration is one of many numerical methods that to integrate equations of motion of Newton's and also commonly inured to calculate the masses of trajectories.

1.1 Initialization of Model:-

The mesh models are not in uniform in soft tissue simulation. Here it is assigned, that the parameters in MSM are based on the different structures of tetrahedral models.

A. Masses of Point:-

Assuming amongst vertices the mass of a tetrahedron is evenly divided. The mass m_i masses of point i is estimated the same as m_i

$$m_i = \sum_{\forall j \in T_i} \frac{1}{4} \rho V_j \quad (3)$$

T_i set of tetrahedron that contains point i, V_j. The tissue density is the preliminary volume of tetrahedron j and ρ.

B. Stiffness of spring

Certain stress-strain relationships of soft tissues are provided by Parameterization of the spring stiffness. In formula, it was recognized to calculate the stiffness of spring intended for regular tetrahedron by single length spring based on an isotropic material of elastic through Young's modulus of E., It has been calculated an equivalent edge length for irregular tetrahedral formulation. It from the volume for every tetrahedron element t, i.e.

$$l_t = \left(V_t \frac{12}{\sqrt{12}}\right)^{1/3}$$

Here it is computed in body spring of stiffness from

$$K_{(i,j)} = \sum_{t \in T_{(i,j)}} \frac{\sqrt[3]{2}}{25} l_t E \quad (4)$$

Whereas T(i;j) is the set of tetrahedrons contains the edge(i; j). The liver and gallbladder are E = 3:5 kpa and E = 1:5 kPa, taken respectively for the experiments from the Young's modulus. In contrast, it has been used springs that are stiff as repulsive springs due to their function in order to prevent collision. In the simulation, it is merely given the repulsive springs for stiffness as the largest spring is computed.

C. Spring Damping

The best behavioural consistency for the different and combined resolution is the formula given to calculate the damping constantly and to make sure to give the best out of it. Connecting of the spring point mass m_i and m_j by the rest length l_0, using the following formula to compute damping constant

$$d_{(i,j)} = \frac{2\sqrt{k_{(i,j)}(m_i + m_j)}}{l_0} \quad (5)$$

1.2 integration of Verlet:-

To integrate Newton's equations of motion the numerical method has been integrated to use in Verlet Integration. In molecular dynamics simulations and also in computer graphics this integration of Verlet is frequently used to calculate the trajectories of particles. Integrator of Verlet endows with an excellent numerical stability and also other properties in physical systems that are significant. For instance, in the simple Euler method, the time reversibility and also preservation of the simplistic form on phase space, at no foremost along the additional computational cost over.

Time integration algorithm used to have constructed as a Verlet scheme following the Trotter expansion

$$e^{A+B} = \lim_{p \to \infty} (e^{A/2p} e^{B/p} e^{A/2p})^p \quad (6)$$

where e^{A+B} to be an operator by making the *P* steps of "size" 1/*P*. *A* and *B* symbolise the two quantities that is advancing the state of system that influences mutually and require simultaneously updated". The equation is approximate if *P* is finite. The system are positions *q* and *v* velocities (for each mass point defined), as well the time in system advances (specifically from 0 to *t*) with steps *dt* in MSM simulation, above mentioned are the two qualities that characterise.

By the following algorithm the Eq. (1) can be translated:

1. 0.5*dt* by Advance positions; ($q \mathrel{+}= v \cdot 0.5dt$)
2. *F* is the compute forces
3. *dt*; ($v \mathrel{+}= F/m \cdot dt$) is Advance velocities
4. 0.5*dt*, is the advance positions

this is called as a Verlet integration scheme of *position*. To simulate the time evolution of a mass spring system it can be used. Since the entire force in the system comes from the springs or gravity it does not account for collisions. Consequently, algorithm to be extended requires for collision handling.

1.3 Implicit Euler:-

Implicit Euler method states that solution to: x = f (t; x) can be found by using:

$$X_{k+1} = X_k + hf(t_{k+1}, x_{k+1}) \quad (7)$$

Where h is the time step.

Equation on top cannot be solved directly because there is x_{k+1} both in Left and right side of the equation. Hence, it requires to be changed to:

$$g(X_{k+1}) = X_{k+1} - X_k - f(t_{k+1}, x_{k+1}) = 0 \quad (8)$$

Since the above equation is now in form of: g (x_{k+1}) = 0, thus, here it can be used Newton-Raphson to solve g (x_{k+1}) and acquire x_{k+1} as the result

1.4 The Mass Spring System on position based

Assuming MSM used a set of point masses N and a set of mass less spring's ϵ. Any point of mass $x_i \in N$, i = 1; : : : ; n, then there is a mass $m_i \in R$ and there will be a force acting on the point $f_i \in R^3$.

The force fi is computed because of its neighbours and its spring connections, together with the external forces. All the point masses in the geometric state are simply $x \in R^{3n}$ and $f \in R^{3n}$. This can be described by Newton's Law of motion in relations among the acceleration and the force that can be as follows

$$M_x = f \qquad (9)$$

whereas M is 3n x3n mass matrix in diagonal.

The second derivative of the position is x and it is with respect to the time. The algorithm that is recommended in this work has been mentioned below

1. i is initialize x_i, v_i and m_i for all vertices
2. loop
3. do position-based attachment
4. for all vertices i do $p_i \leftarrow x_i+v_i\Delta t+f_i\Delta t^2/m_i$
5. for all vertices i do $v_i \leftarrow (p_i-x_i)/\Delta t$
6. loop Constraint Iterations times
7. project Constraints ($C_{stretch}$, $C_{compress}$, $C_{direction}$)
8. end loop
9. for all vertices i do $x_i \leftarrow p_i$
10. end loop

IV. EXPERIMENTAL RESULT AND ANALYSIS

The performance of this implementation has been carried out and evaluated by a machine through Intel core running at GHz of 2.66 and Ram of 8 GB running in Windows 10.

2.1. Recital Metric

(a) The **computational time (iteration)** has taken for the algorithm. This is based on the complexity of technique and also it relates towards the number of times forces the system to derive from the system state by using the mechanics laws.

(b) The **time step** of an iteration that signifies the time discretization has been essential towards reaching a specified accuracy if not stability of numerical for the method given.

(c) **Deformation error** is defined through the challenge might be very small however; forces affect the original shape of an object. The displacement of an object mass regains previous position in a particular time interval.

2.2 Performance Analysis:

The following figure 2 shows the effect of the force that has been applied on a square mesh. Figure 2 (a) shows the initial mesh. Here it is to fix the mesh along the left boundary; deform the points in all other region by external forces. Figure 2 (b) & 2 (c) shows the effect of force applied middle & left corner of deformation.

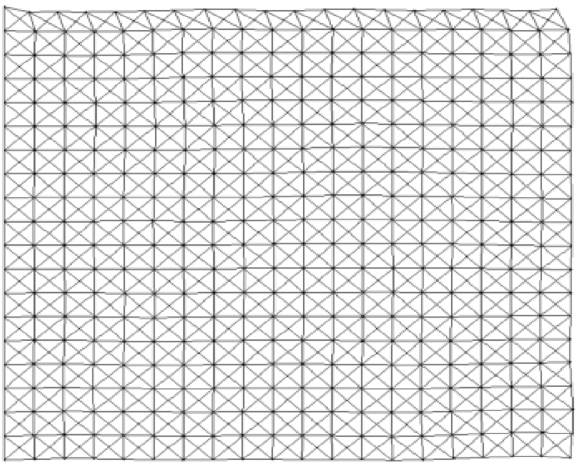

Figure2 :(a) Initial mesh

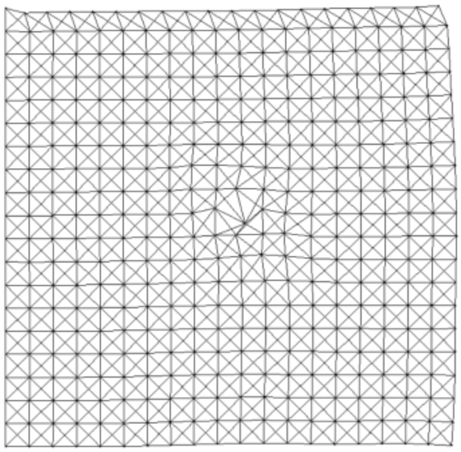

Figure (b) Middle mesh

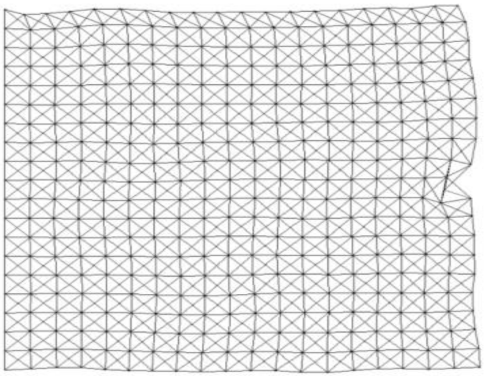

Figure (c) left corner

The following table; 2.2.1 contains the computation time time for Euler and verlet method with different number of points. Computation time analysis graph has shown below in Figure 3.

Table 2.2.1 computation time in seconds

Number of Points	Computation Time(Sec)	
	Euler	Verlet
200	0.5	0.3
500	1.7	1.2
1000	2.78	2
2000	3.14	2.67
4000	3.96	3.12

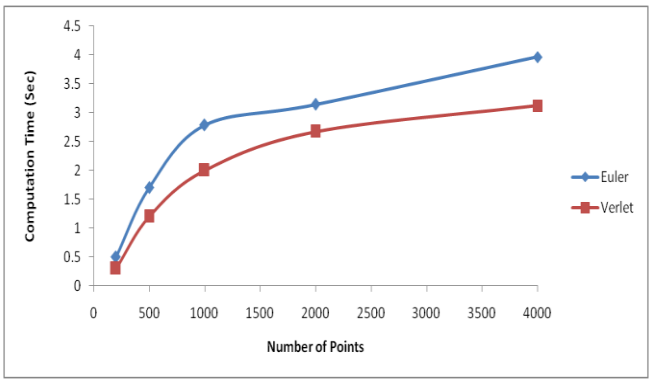

Figure 3: comparison of computation time and number of points

The above graph clearly shows that the computation time analysis for Euler and verlet methods, the average computation time of verlet method is less than the Euler method with 1.628730833 seconds.
The following table 2.2.2 shows the time step analysis of explicit Euler, Implicit Euler and verlet method.

Table 2.2.2: Represent the time step analysis method

Method	time step [ms]	comp. time [ms]
expl. Euler	0.5	9.3
impl. Euler	49.0	172.0
Verlet	11.5	8.5

The following table 2.2.3 shows the analysis of the deformation error that occurs in different forces that are applied in Euler and verlet method. Its corresponding graph has been shown below in figure 4

Table: 2.2.3 Represent the analysis of deformation error

	Deformation Error(mm)	
Force(N/m)	Euler	Verlet
0	0	0
2	1.583356	1.298453
4	3.248017	1.972952
6	4.183456	2.7839
8	9.492629	6.93582
10	12.423452	8.1674

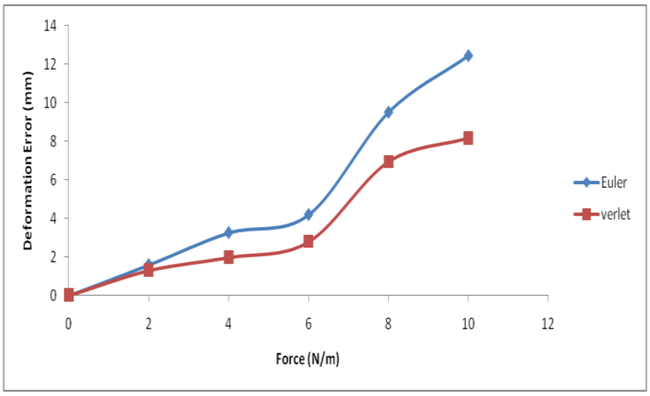

Figure 4: Analysis of Deformation error when force applied.

The above graph clearly states that the average deformation error of verlet method is less than Euler method with 0.558mm.
From the analysis it finds that Verlet method is to some extent better than Euler method. it's mainly due to the velocity is derived from the current position and also previous position (and time step) instead of calculating based on the acceleration, making it harder for the velocity and the position to get out of sync (since the velocity is not stored)
The Euler algorithm:
x' = x + v *dt
v' = v + a *dt
The Verlet algorithm:

x' = 2*x – xOld + a * dt^2
xOld = x

In Euler algorithm, it is mostly due to the error of floating points, the x and v can move out of sync since they are separately stored. Numerical instability and, in cases, a breakdown of the system can be caused. Due to the verlet integration estimates the velocity as the change in velocity in the last frame, there are no synchronization issues, and the algorithms never turn out to be unstable.

V. CONCLUSION

In this paper it has been mentioned that Euler integration and verlet integration method for mass spring System, where the complex computation that has been required. Euler method is having the large interval of the model. Verlet integration formulation is with the number of points in a square mesh for simulating the deformation of soft body organs. Generally, when it is applied an internal force between the points of the mesh by connecting them with the repulsive springs the deformation process depends on the applied force. By the analysis it is found that the verlet method incorporated the points on the length of springs to preserve geometry properties of the mesh body during the deformation. With the help of performance analysis verlet method is more suitable for objects in mass spring system. The performance of the proposed model has been well demonstrated.

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