Constraint Stabilization: A New Way to Correct Error in Multi-Rigid Body Simulation

Overview

Rigid body simulations with contact is widely used in different areas. For example, in Robotics, simulations are used in processes such as virtual prototyping, robot testing, model predictive control, and planning. These simulations are mostly implemented using a time-stepping scheme. In this scheme, the simulation finds out the changes that will happen to the bodies in the system at the current time frame and then integrates the changes to the current configuration to proceed to the next time step. One of the problems of this approach is that numerical error cumulates during the process, and bodies start to interpenetrate when the error is large enough.

Despite the fact that such interpenetration causes simulations to behave unrealistically, the time stepping approaches for rigid body simulations do not even attempt to prevent bodies from interpenetrating. Instead, algorithms are used to correct interpenetrations after they occur. The currently most used algorithm uses extra force to push the interpenetrating bodies apart. The strength of the force is dependent on how much the interpenetration is. The following diagrams shows an example of this approach. In *Diagram 1.1*, one of the bodies is lying on top of the other. In this case, a force F_x is

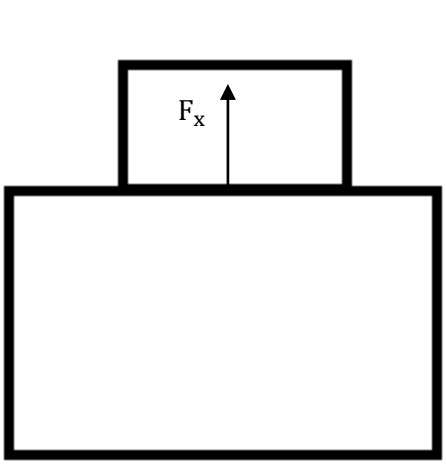

Diagram 1.1

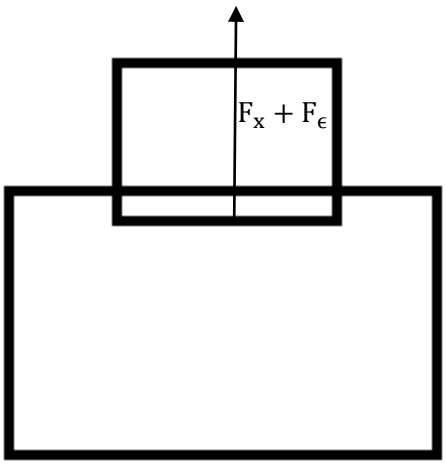

Diagram 1.2

applied to keep the two bodies separated. In Diagram *1.2*, the two bodies are interpenetrating, therefore an extra force F_ϵ is also applied to push away the two bodies. The main advantages of

this algorithm are its simplicity, time efficiency, and its ability to yield the proper result as the integration step size tends to zero; however, this algorithm also has several downsides. First, this algorithm has preset constants and therefore requires tuning while running, and there is no automatic way to do this tuning. Second, since forces are exerted on the bodies when they interpenetrate, we are allowing the simulation to be in an inadmissible configuration (bodies violating the assumption of rigidity) at some times. Due to the fact that bodies always tend to contact with each other in these simulations, the simulation will often be in an inadmissible configuration. Third, this algorithm will decrease the stability and accuracy of the system due to adding extra forces to the system.

Since these downsides can be greatly problematic to simulations, another interpenetration correction method addressing these downsides needs to be developed, and Constraint Stabilization is the algorithm that does that. In this method bodies are moved apart directly after every step. Although this method is slower than the currently most used one, it addresses all the three disadvantages mentioned in the previous paragraph. No tuning constant is involved in the process. The bodies are always in admissible configurations at the end of a step. The stability of the system is also less affected because less energy is added to the system.

Business Plan

Nowadays, rigid body simulations are used in various areas. Examples are, robot simulations in Robotics, virtual prototyping in Mechanical Engineering, physics engine in Game Development, etc. With such a wide application, simulator software has a large market; however, there is also a lot of competition in the market. Currently there exists a lot of different software for users to choose from. We believe that by incorporating our algorithm into a simulation software, the simulation software will then have a comparative advantage in the accuracy of contact simulations, and will be able to simulate a more complicated configuration. Companies and organization will then be more willing to choose the simulator that has this algorithm, which can bring tremendous profit; therefore, we believe the best way to market our product is to market the product towards the rigid body simulation software developers.

The main way we are going to promote our product is to do personal selling. After the algorithm is developed and tested for accuracy and robustness, we will be contacting the major simulator software development companies and organization and advertise our product. Although simulators are widely used, our algorithm only target a small group of people comparing to the

population. By promoting our software through personal selling, we can get the most effect out of the least cost.

The advantages of our product are very obvious. First of all, our product addresses the main outlying three issue of the currently most used algorithm. This will make our product unique in the market comparing to other outlying algorithms. Being unique in the market means that if any software developers wants to create a simulator that is more accurate and can simulate more complex configurations, they need to come to us and use the algorithm to solve the three issues. There will be minimum competition which leads to a potentially high benefit.

Second, our algorithm is an intellectual property instead of a physical product, the fund required by us after the algorithm is developed is very low. We won't need to maintain a production line to produce the product, or transport any product in order to sell it. These can all save us a lot of cost comparing to other project that has a final physical product. With a lower cost, we believe that our product will earn even higher potential profit.

Finally, the risk of the project is also really low. The only large risk is if the algorithm works or not; however, the first version of the implementation of this algorithm has already been developed and tested on simple 3D geometrical shapes. From the testing result, the algorithm has a satisfying performance during test. We are confident to say that for more complicated shape, the algorithm will also perform the same way while simulating more complex configurations.

For future development of our business, we plan to increase our product awareness first by using the algorithm we have. Once we have enough fund and awareness from selling our product, we will tackle on more existing challenges in the area of numerical computing. We believe doing this will put as always at the leading position in the technology field, and our product can then have a better credit to the potential customer.

In conclusion, we believe that due to the fact that our algorithm is unique in addressing the current issue of rigid body simulation. Our product will successfully bring us large amount of profit and awareness which will help us growing into a larger business trying to develop numerical software challenge solutions.

Social impact

As an algorithm, our product will have impact both short term and long term. In this section, both the short term and long term social impact of our algorithm will be discuss from different aspects. These aspects include, educational, social, and ethical aspects.

As a research project, Constraint Stabilization has great impact on the academic and educational field. In short term, running this project will provide more chance for researcher and student to practice their skill and enhance their knowledge. The project deals with numerical computational problem, which is known to be very hard; therefore, there will be a lot of chance for the participants of the project to learn something new and develop newer and more profound skill in the area of numerical computational software. We are planning to have university students with good skill as research assistant. Students can then have a taste of what it is really like to write numerical software. They can also learn much more content that will not be taught in the class. In long term, after the algorithm is developed, simulating complex bodies will become much easier. Many researchers can use simulator with this algorithm embedded to simulate more complex things more reliably. The academic research efficiency can then be improved drastically.

For social impact, this project will not have much in the short term. This is because Constraint Stabilization is for specific user group. Constraint Stabilization is also an automatic algorithm which works in the background, so it won't create job for people because no special technique is required to actually use this algorithm. On the other hand, this project will have a very big long term impact. When Constraint Stabilization is widely used, a lot of manufacturing and testing process can be much easier and the product produced is also going to be much more reliable. These products will then strongly affect people's daily lives. For example, research in robotics will be much easier since the simulator will provide a much more reliable testing result. Robots then will have a higher possibility to behave what they will do in simulations. After a few years of development, robots may be able to come into everyone's daily life. They will make our daily life much easier. For example, they can do simple household work for people and saving people a lot of time. They can also help take care of the elderly and the kids. Kids and elderly will then live in a more secure environment and a lot of accidents can be avoided.

Finally, we need to consider the ethical problem with Constraint Stabilization. As an algorithm, there is not much ethical issue if it is widely used; however, one must consider about the fact that this algorithm or the simulator with it may be used to perform unethical actions. In order to prevent this, we are only going to distribute the algorithm towards reliable organization and set limitations on the people who can get the software to organization developed.

In conclusion, Constraint Stabilization will have great positive effect both long term and short term on the education field and people's daily lives. We believe that when this product is developed people will have a much better life.