

String Sculptures Editor in Virtual Environment

Martin Bezdeka*

Supervised by: Jiri Sochor†

Faculty of Informatics
Masaryk University
Brno / Czech Republic

Abstract

We present a new approach for editing string sculptures in virtual environments. The string sculptures consist of a set of rigid objects (hoops) connected by tightened strings. The main aim of the newly created environment is to enable the artists to design and interactively modify the string sculptures. This can be done by using features of virtual environment where users can manipulate objects by using their hands which control the whole scene as well as a set of tools. Moreover, virtual environment enables to arrange the final appearance of the sculpture in a more natural and straightforward way.

Our environment was integrated into the VRECKO system for virtual reality developed at the Human-Computer Interaction Laboratory at Faculty of Informatics, Masaryk University. This integration enhanced the whole manipulation and perception of the virtual environment by using various devices, such as OptiTrack system for capturing positions of objects in 3D space. In addition, our environment enables to finally test the stability of the designed sculpture by using the PhysX™ library[4] for physical simulation.

Keywords: string sculptures, virtual environment, OpenSceneGraph, PhysX, VRECKO, OptiTrack, physical simulation

1 Introduction

The expansion of modern technologies in the last decades introduced the virtual environment to a broader community of users. Moreover, these users currently come from diverse fields, such as medicine, flight industry, or art. In the latter case, game and movie industry and modern artists use these technologies to enhance their creativity process. One of the very interesting areas are string sculptures (see Figure 1). Generally they consist of two basic parts: rigid objects forming the skeleton of the whole sculpture and a set of strings tightened between the rigid objects. The greatest challenge of their construction is their design which has to follow the physical rules in order

to maintain the sculpture stability. Thus a tool for designing and testing the stability of string sculptures can serve for verifying the feasibility of sculptor's ideas.

We created a new environment for designing, modeling and testing the stability of string sculptures which uses the modern features and devices in virtual environments. The selection of virtual environment for this purpose is straightforward because its features enable users to create and manipulate objects in an almost natural way. Moreover, the new system integrates the simulation of physical forces which enables to verify the final stability of designed sculpture. If an artist discovers that the result will be unstable, the system will allow the sculpture to remake and retest.

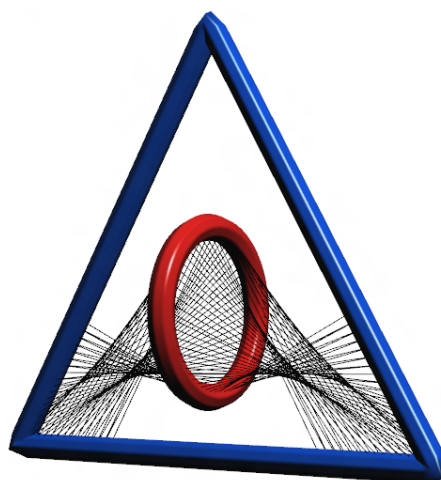


Figure 1: Example of 3D string sculpture.

Many thin strings with dense distribution can form visually appealing patterns which in connection with the rigid geometrical objects take the form of resulting sculpture. Press discusses in [5] the results of testing different types of stringing and evaluation of their visual appearance.

String sculptures are also interesting from the mathematical point of view. The basic idea is to maintain the stability of the whole sculpture by utilizing sets of strings only. Another restriction which the string sculptures must fulfill is that the rigid parts cannot collide. This restriction is called a tensegrity[2] and its principles will be described

*xbezdeka@fi.muni.cz

†sochor@fi.muni.cz

further.

When designing the string sculptures, it is complicated to assess the final visual appearance and integrity in advance. Our system offers to minimize this problem by introducing the virtual elements into the design process. The author is then able to visually compare the modeled sculpture with the initial ideas. Additionally, the sculptor can easily test the stability of designed interconnections. The three-dimensional environment allows users more deep view onto the object and in case of sculpturing this plays even more important role.

The environment serves as a very helpful tool in a process of designing string sculptures. Thanks to the intuitive user interface and involving many useful functions the system provides sculptors with vast amount of possibilities which would be very hard and expensive to achieve when modeling with real materials. Moreover, thanks to the possibility to create hand strokes of arbitrary shape and complexity, users can design sculptures of various shapes as well. This can consequently lead to designing, testing and constructing sculptures of much more complex shapes which would not be probably imaginable using traditional approach.

2 Background

Firstly, we concentrate on the related work corresponding to the field of our interest. Then we briefly describe the technical background of our solution along with the frameworks and devices utilized in the realization.

2.1 Related work

In the last decades many authors were interested in designing and realization of different kinds of string sculptures. However, their efforts led to construction of real statues and only few of them revealed the possibilities which can bring the computer science into this field. Some solutions revealed, such as the string_art application which is included in the Antiprism package ([1]). However, this application is designed only for two-dimensional environment.

This paper primarily concentrates on design of 3-dimensional sculptures mainly because of the nature of the environment in which they are designed - the virtual space. Of course, this environment does not limit the user when designing 2-dimensional sculptures. In such case simply the third dimension is not taken into account. Designing of 2D string sculptures (see Figure 2) is described for example in [3].

2.2 Virtual environments

Virtual environment enables to utilize new interaction techniques mainly via spatial input tracking and stereoscopic rendering. In order to utilize most of the already

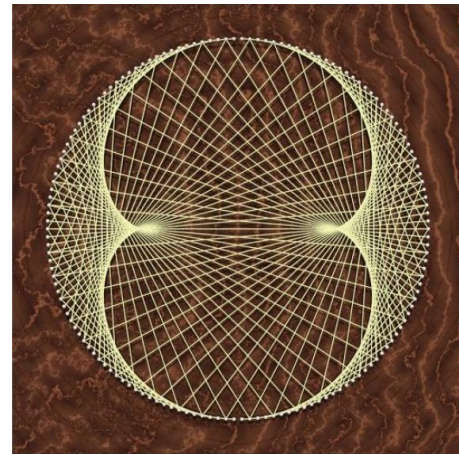


Figure 2: Example of 2D string sculpture[1].

implemented and tested features, our new environment was integrated into the VRECKO framework for virtual reality[7]. It was initially developed for rapid prototyping of applications in virtual environment. It is a high level programming framework using underlying toolkit and graphics library for low level tasks such as rendering 3D primitives, texturing, scene culling, etc. It supports several kinds of stereoscopic projection and it is able to process data from various input devices. Except for the traditional devices, such as mouse and keyboard, we can use OptiTrack system enabling to capture position of objects in space, 3D mouse, Nintendo[®] Wii[™] Remote and Microsoft[®] Kinect[™]. The whole system is modular and can be extended by plugins, such as the environment for string sculptures described in this article.

3 Generation of String Sculptures

This section contains the description of sweep surface generation which is utilized for construction of rigid parts of the sculptures. Then we describe the process of generation of string patterns and finally we mention the physical simulation which should verify the stability of the final sculpture.

3.1 Sweep surface generation

String sculptures consist of stringing and a set of rigid objects. In our case these objects can have a form of hoops of different shape. In order to create such objects, we need to create a general library for generating them. For this purpose we designed and implemented the SweepSurface library. One of the most important parts of this library contains the computation of rotation of profile curve when sweeping it around the main curve defining the general shape of the rigid object. It ensures the natural appearance of the result (see Figure 3). To ensure that the rotation of the strokes along their centerline is natural, we utilize a ro-

tation frame. It is defined by a set of "points" defined by three vectors - tangent t , normal r and binormal s (see Figure 4). These "points" are situated around the main curve.

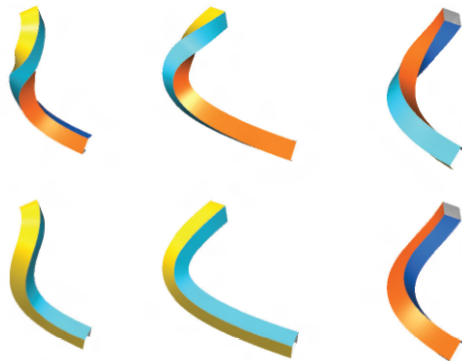


Figure 3: Left: Example of wrong (top row) and correct (bottom row) rotation around the curve (taken from [8]).

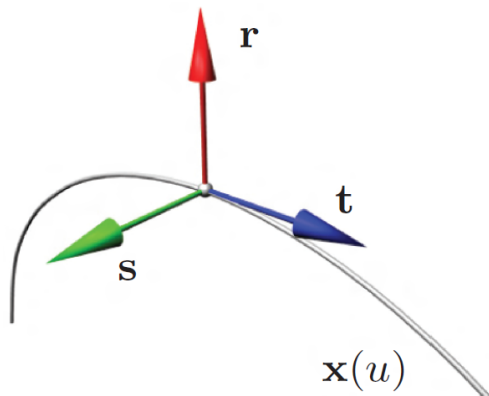


Figure 4: Definition of rotation frame (taken from [8]).

In our system, we utilized the Rotation Minimizing Frame (RMF) algorithm for computation of rotation frames. This algorithm ensures the minimal rotation of the sweep surface created around the main curve. Thanks to this property the algorithm is widely used in many areas of computer graphics. However, the RMF computation depends on the solution of a complex differential equation which does not have any analytical solution. This leads to various approximations in real implementations. In our case we decided to implement the discrete approximation which is described in [8]. This method is suitable in cases when the curve is constructed dynamically so we do not have the information about all its points at the beginning.

The SweepSurface library contains a set of predefined basic shapes, such as ellipse, rectangle or triangle. These shapes can be utilized as parts of some sculptures consisting of these shapes or can be used as reference objects for non-skilled users of the system. The library also allows the dynamic changes of curves in real time, such as modification of profile curve, interpolation, filleting etc.

3.2 Patterns generation

The appearance of the sculpture is determined by the chosen type of stringing. It depends on the ordering of the strings on the rigid object (hoop). Figure 5 shows the different approaches to ordering of strings between two rigid objects. The left part of the figure shows the basic bonding. Some patterns can be marked as reversible or self-reversible. Reversible patterns form tuples of patterns which are symmetric (see Figure 6), whereas self-reversible patterns are formed by only one symmetric pattern (Figure 7).

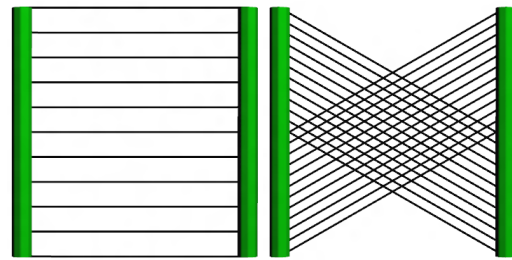


Figure 5: Different approaches to ordering of strings.

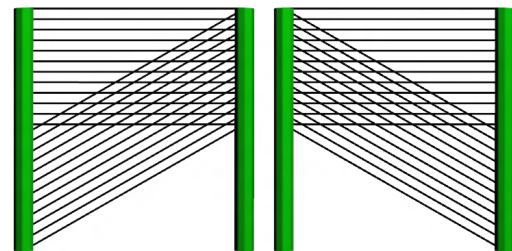


Figure 6: Examples of reversible patterns.

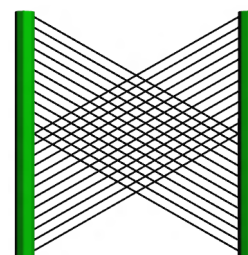


Figure 7: Example of a self-reversible patterns.

3.3 Physical simulation

Our environment enables to design also string sculptures which cannot exist in real world. It is because the environment does not possess any constraints to mutual position of the hoops, their interactions caused by gravitation and the ability to maintain the sculpture in its desired shape.

Press in [6] discusses the problem of tensegrity. According to [2], tensegrity is a structural principle based on utilization of single isolated components connected by net where the components cannot collide and are held in fixed position defined by tightened elements (usually strings or flexes).

In our case, the main task is to determine whether the stringing pattern is capable to hold the string sculpture in a desired position even after the hanging the sculpture and taking gravitation into account. In other words, we want to verify that the sculpture retains the fixed shape in real world conditions.

For such verification we utilized physical simulations taking into account the real environment. For the simulations we use the PhysX™ library[4] from NVIDIA®. The library integrates the simulation only for several basic shapes, such as sphere, box or cylinder, it is not applicable to more complex shapes. A possible solution for complex objects is to create an approximation of the object by combining the basic shapes, e.g. spheres (see Figure 8). The illustration of behavior of a string sculpture in physically simulated environment is shown in Figure 9.

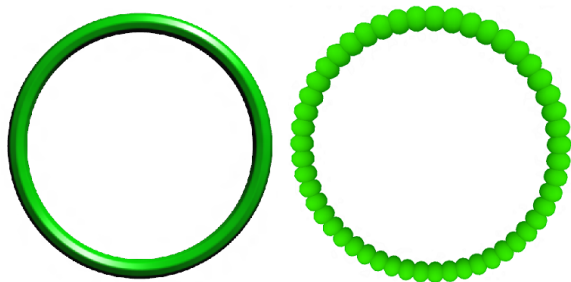


Figure 8: Approximation of an object using spheres in PhysX™.

4 Integration into the VRECKO Framework

The system for editing string sculptures was integrated into the VRECKO virtual reality framework. The long-term project VRECKO has been developed at the Human-Computer Interaction laboratory at the Faculty of Informatics at Masaryk University. It is basically an educational tool which serves as the basis allowing an easy extension with a new functionality implemented as plugins. It contains many features commonly used in standard virtual environments.

In this section we describe the main features of the VRECKO which are utilized for creating string sculptures. Combination of these features is then able to control all functions of sculpture editor.

As mentioned above, the VRECKO system integrates various input devices. The less common input devices which are used in our system, are listed below:

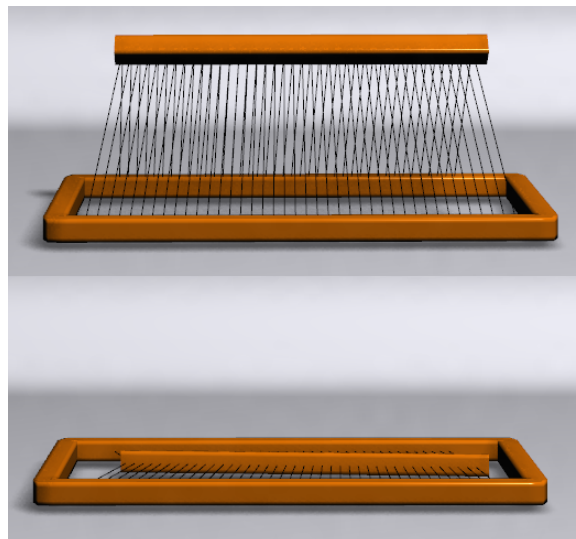


Figure 9: Example of using physical simulation to test sculpture.

- **OptiTrack** - system consisting of a set of infrared cameras covering the tracked space. These cameras are able to capture reflection markers placed e.g. on the user's body. Positions of these markers then serve for computation of position and orientation of corresponding points in virtual space.
- **WiiMote** - it is the wireless remote control created by Nintendo™. In the VRECKO system, the device is used in combination with the OptiTrack system. Markers are placed on two WiiMotes which the user holds in hands. Three markers are attached to each WiiMote. Their mutual position enables to determine the rotation of the WiiMote in hand. The positions and rotations are then mapped to "virtual hands" in virtual environment. For further interaction with the system, users can utilize buttons of WiiMote.

The equipment described above (namely the OptiTrack) is usually present only in specialized laboratories. As we did not intend to limit the number of potential users by using only a special equipment for virtual reality systems, we had also included traditional input devices. Our system enables also to control artistic work using mouse and keyboard. In VRECKO system, input devices are used in a unified way and the control of the scene using OptiTrack or mouse and keyboard can lead to very similar results.

In order to enhance the design of string sculptures, we implemented advanced editing tools which were integrated into the VRECKO system. Now we concentrate on the most important novel tools (see Figure 10).

- **Selector**. The most important tool serving for creation of so called sectors. Sector is defined as a part of a hoop where the stringing is subsequently created. This tool enables to create as well as further modify



Figure 10: Icons of tools designed for string sculptures in VRECKO system.

existing sectors. Context menu of each sector enables to edit the parameters of stringing. Example of this tool is depicted in Figure 11.

- **Paint.** This tool enables to create hoops and other objects of arbitrary shapes. This broadens the possibilities of the system because the number and shapes of predefined hoops are very limited. All objects created using this tool possess the same physical properties as the predefined hoops.
- **Tongs.** This tool serves for manipulation with the string sculpture in the virtual space. Using this tool users can change position and rotate with the sculpture or with its rigid parts. When combined with OptiTrack device, the manipulation is straightforward. The user has to grasp the sculpture or its hoop by pressing given button on WiiMote and by simple waving with hand holding the WiiMote the grasped object changes its position and orientation. When using mouse and keyboard instead of OptiTrack, the manipulation is more complicated. Changing the position in three-dimensional space cannot be reached using a traditional mouse so the keyboard arrows have to be utilized. However, this process is not suitable for fine corrections of position. To overcome this problem, we designed another tool - Rotation.
- **Rotation.** This tools serves for controlling of fine rotation of hoops in their local coordinate system. When this tool is activated, there appears the graphical representation of local coordinates near each hoop (see Figure 12). The Rotation tool has also its context menu and basically serves for rotation directed by a mouse.
- **Eraser.** Enables to delete selected hoops. When a hoop is deleted, all its sectors are also removed. Sectors of other hoops are automatically connected to the remaining hoops according to their order in which they were added into the scene.
- **Hook.** When the string sculpture is designed and modeled, we can verify its stability using physical simulation. Basically it simulates the gravitation so when the simulation is launched, the sculpture "falls" to the ground of the scene. However, our system enables to hitch up the sculpture by the Hook tool. Users can create, edit or remove an arbitrary number of hooks. When the user deletes a hoop, it causes removing of all its hooks.

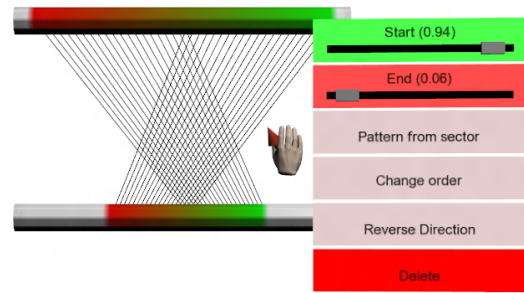


Figure 11: Selector tool.

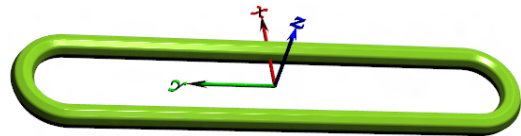


Figure 12: Activation of Rotation tool activates the displaying of local coordinate system for each hoop.

Figure 13 shows an example of a string sculpture created using our editor integrated into the VRECKO framework. In the bottom of the figure you can see the shadow casted by the sculpture so the user can immediately see the ground of the scene. Some other examples are depicted in Figure 14.

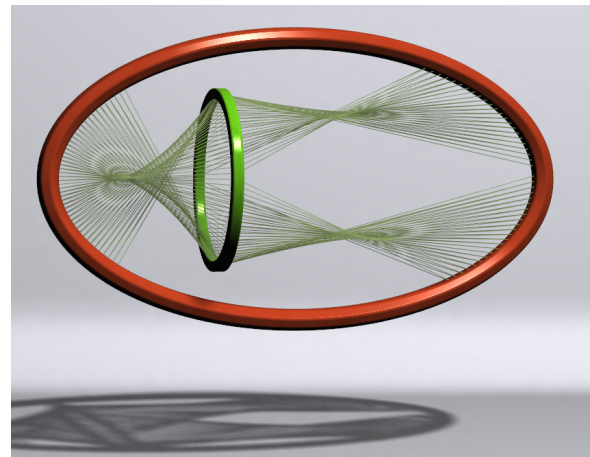


Figure 13: Example of a string sculpture in VRECKO framework.

5 Conclusion

In this paper we described newly created environment for designing string sculptures which offers new tools and possibilities to artists. It was integrated to the virtual environment providing users with several advanced features for exploration and manipulation with models. The resulting system enables to create basic shapes of hoops as well as freehand-made rigid objects. This enables users to

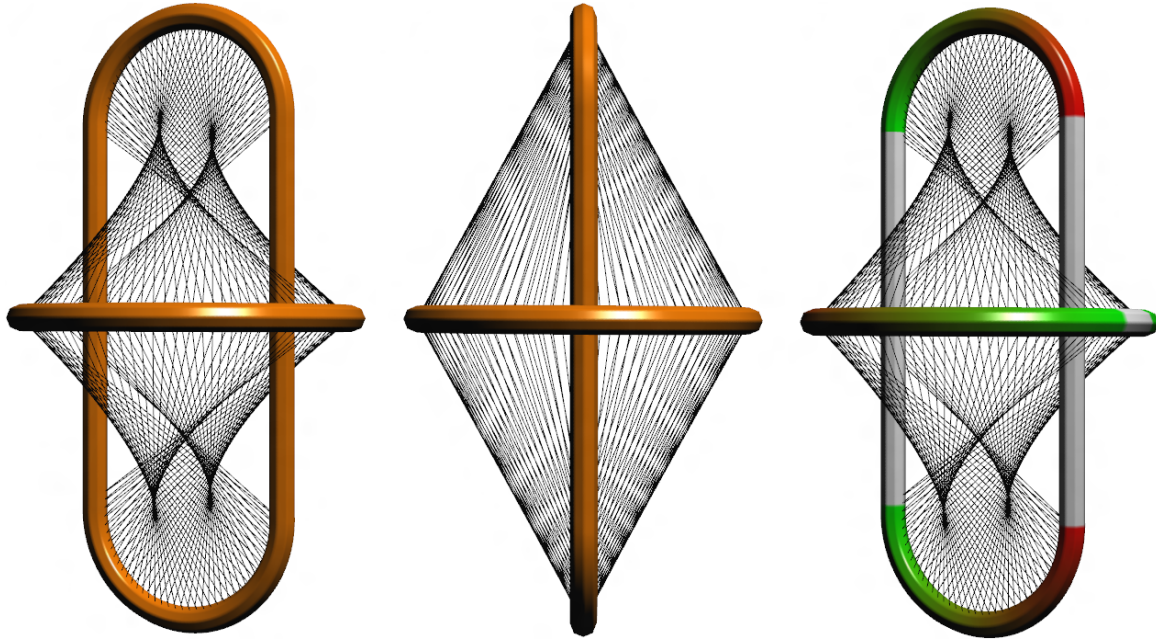


Figure 14: Examples of string sculptures created by our system. The right figure emphasizes the sectors on the hoops.

test the feasibility of sculptures consisting of a large set of geometric representation. The system also implements a set of basic stringing patterns and is prepared for appending more patterns. Thanks to the integration into the VRECKO framework, the resulting string sculptures can be loaded from or exported to various file formats, such as .3ds, .obj and others. Users are allowed to change visual parameters of sculptures, such as the color of hoops and stringing or the shape of hoops. The system also integrates the physical simulation which enables to verify the stability of a given model by simulating the real world conditions.

The second important part of the system is the Sweep-Surface library which is primarily used for generation of hoops. Its goal is to provide users with general tool for creating sweep surfaces of arbitrary shapes.

The system was primarily designed for artists but thanks to the integration of physical simulation it can also be utilized for teaching purposes or as a basis for simple logical games. In the future, the system can be enhanced with other features, such as designing more complex stringing patterns, advanced hanging of hoops simulating the movements of a rope or more precise simulations of string behavior.

References

- [1] Antiprism - Polyhedron Modelling Software. <http://www.antiprism.com>. [cit. 2012-02-04].
- [2] Valentín Gómez Jáuregui. *Tensegrity Structures and Their Application to Architecture*. Ediciones Universidad de Cantabria, 2010.
- [3] E.H. Lockwood. *Book of Curves. A Book of Curves*. Cambridge University Press, 2007.
- [4] NVIDIA. Rigid bodies. PhysX SDK documentation, 2008 [cit. 2012-02-04].
- [5] H. Press, David. String Sculpture. *HYPERSEEING*, Spring, 2009.
- [6] H. Press, David. String Sculpture – New Work. In Nat Friedman and Ergun Akleman, editors, *HYPERSEEING, The Proceedings of ISAMA*, 2010.
- [7] VRECKO Manual. <http://vrecko.cz>. [cit. 2012-02-04].
- [8] Wenping Wang, Bert Jüttler, Dayue Zheng, and Yang Liu. Computation of rotation minimizing frames. *ACM Trans. Graph.*, 27, March 2008.