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SmartMesh: A Smart Structure for Object Creation

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Abstract. We introduce the SmartMesh, a novel type of active structure capable of deforming actively its shape and thus being able to form objects. It is a new approach to find a solution to the difficulties that are encountered in the field of haptic interaction in virtual environments. The SmartMesh creates in real time the virtual objects as seen through head mounted displays at the according position in space. Thus, the virtual objects are not virtual anymore. The SmartMesh can be embedded into a table, into walls, ceilings and floors. The SmartMesh is actuated by a large number of linear actuators and its resolution depends on the amount of nodes and the length of the actuators.

1 Introduction

While the visual and auditory components in virtual environments have reached a quite satisfying quality, the haptic components are still in the fledgling stages. In fact, today's state of the art haptic interfaces show some constraints and disadvantages. This is due to several factors, which can be classified into two major categories: the human and the technical factors, such as the complexity of the human anatomy and its dexterity of the tactile sense or the inappropriate properties of the state of the art actuators for instance.

Basically, two types of haptic interfaces can be distinguished. The grounded devices and the portable ones [1]. The former types mostly consist of robot arms, which work in a reverse mode. They usually are grounded on a desk, a floor or a ceiling and haptic feedback is provided in the desired direction and strength. Other types of grounded devices are the pin array based ones for texture simulation. The portable devices mostly consist of exoskeletons that transfer mechanically the feedback force from its source to the desired location on the body. They are always grounded on the body itself.

Most of these devices were developed for dedicated tasks and fulfill their requirements quite well. However, for many tasks, haptic feedback to the whole palm, the whole hand or even to the whole body is needed. Unfortunately, this cannot be achieved with the existing haptic feedback devices.

The new approach here presented takes into account the above mentioned problems. The SmartMesh is an active structure, which simulates the object itself, its shape and also its physical and structural behavior. The surfaces and

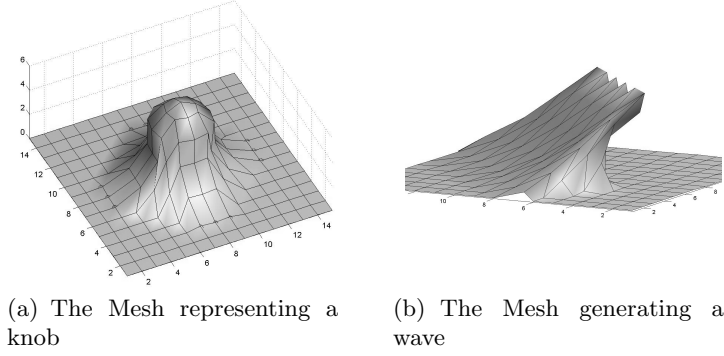


Fig. 1. The Mesh simulating different structures

structures created by the SmartMesh can be touched practically as real objects. In figure 1(a) the SmartMesh with 15×15 nodes represents a knob. Furthermore, the SmartMesh differs from devices based on needles by its ability to create overhanging surfaces as shown in figure 1(b). This augments by factors the amount of possible simulated objects. The SmartMesh can be integrated in several places, such as tables, walls, ceilings and floors. It is scalable, which means, that structures with a low number of nodes can be developed as well as such with a high resolution, thus with a high number of nodes.

2 The SmartMesh

The SmartMesh consists of two grids connected together forming a multi layer structure. These grids consist of nodes connected by linkages. By elongating these linkages, the shape of the whole structure can be altered in any dimension to form the surface of an object.

A particular node can be moved within the plane by changing the length of the adjoining linkages respectively. In order to move a particular node in the third dimension, a second grid is needed. The principle can be explained with a cross section through the structure as follows (see figure 2(a)):

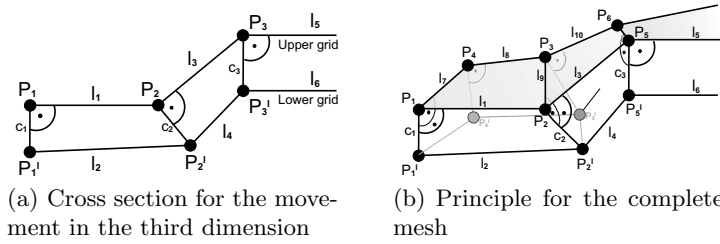


Fig. 2. Working principle of the mesh

Node P_1 of the upper grid is connected to the equivalent node P_1^l of the lower grid perpendicularly to the linkage l_1 . These perpendiculars c_n have a constant length. It is assumed now, that the nodes P_1 and P_1^l are grounded. By elongating or shortening the lower linkage l_2 , linkage l_3 is forced to move, thus rotating node P_3 around node P_2 . The length of linkage l_4 determines the position of P_3^l , thus the direction of l_5 . The same principle can be extended to the whole structure, by connecting all upper nodes to the equivalent lower nodes perpendicular to two of the linkages of the upper grid (see figure 2(b)). In this example c_1 would always be perpendicular to l_1 and l_7 .

Using this technique, the positioning of a node in the z-direction can be accomplished. However, this is not the only advantage. A second layer ensures also a better stability during manipulation, due to its better distribution of the forces on both grids. As a result, the torque on one single node will be smaller when a force is applied.

The whole structure of the prototype has two grids connected through perpendiculars and one grid has exactly n^2 nodes and $2n(n-1)$ linkages. Thus the overall structure consists of $4n(n-1)$ linkages, $2n^2$ nodes and n^2 perpendiculars. Nevertheless, the mesh is statically determinate (following the Kurzbach criterion).

The realized SmartMesh has 16 node-doubles (combination of the equivalent nodes of the upper and lower grid to one single node with six spherical and two revolute joints) and 48 linkages (see Figure 3). These linkages have a prismatic joint and show an elongation rate equal to 60%. The corner node-double, that connects its two linkages via revolute joints is grounded. Its size with completely retracted linkages is 480mm*480mm while in the maximum extension it measures 690mm*690mm. Thus an overall extension of 43.7% can be realized. It has a total weight of 2750g and it is already able to form many different surfaces, including also some overhanging ones. Figures 4 and 5 show some of these surfaces (in some cases two nodes were grounded).

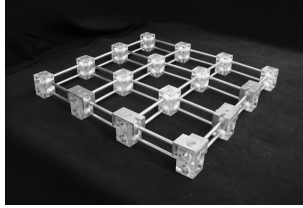


Fig. 3. Flat SmartMesh

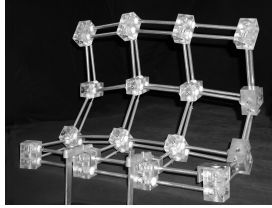


Fig. 4. A wave

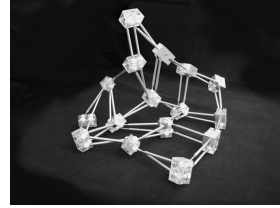


Fig. 5. A random structure

The SmartMesh can be applied in many fields and performs also several functions. So it may have only output or only input functionalities or it may include both of them. In the field of virtual reality its application is on the hand. It can generate objects, which can change their shape and which can be touched and grasped. Other possible applications may include novel types of

input devices for any kind of machines (CAD, game and aerospace industry etc.), rapid prototyping systems, applications for the molding and furniture industry or novel tools for art objects.

3 Problems and future work

Although the prototype shows many promising features, it still is in a very early development stage and it has not been actuated yet.

To keep the overall weight as low as possible, these actuators have to be small in size and weight. In addition, they have to show a good elongation rate (at least 60%). Smart materials seem to be more suited for such a kind of application, than any other state of the art actuator, mainly due to their high power density. In addition, they partly show other interesting characteristics, such as high frequency range, high expansion rates, a long durability, but also the capability to sense and measure their environment. Thus, studies are already being made on how to integrate shape memory alloys [2] or electro active polymers [3] into such a linkage.

Further, the nodes will be downsized and other materials, such as carbon fibers for instance, will be used to reduce their weight and to improve their mechanical properties. By scaling down their size also the accuracy of the whole system can be improved: the rotation around their own axes (with all its implications). In addition, slackness has to be eliminated as much as possible. The joints themselves can be improved to allow a bigger range of rotation. However, extensive studies are being done here as well to find better solutions for the joints, such as joints without mechanical parts.

The SmartMesh will be covered by a texture to hide and protect the complex mechanism. This texture has to be stretchable but also as stiff as possible.

Not only mechanical properties have to be improved. A concept for the quite complex control hardware has to be studied. It may be interesting for example, to have one node being responsible for its neighbors, integrating in it the actuation and sensory hardware. This would significantly reduce the connections to the controlling mainframe.

Much effort has also to be put into the system modelling. To form a structure it will then be necessary to have some kind of sequence of actuation of the linkages during the shape forming. This sequence has to be calculated in real time. Thus, powerful algorithm have to be studied.

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