Title:
Visuo-Tactile System for 3D Digital Models Rendering

Authors:
Alessandro Mansutti, alessandro.mansutti@polimi.it, Politecnico di Milano
Mario Covarrubias Rodriguez, mario.covarrubias@polimi.it, Politecnico di Milano
Giandomenico Caruso, giandomenico.caruso@polimi.it, Politecnico di Milano
Monica Bordegoni, monica.bordegoni@polimi.it, Politecnico di Milano
Umberto Cugini, umberto.cugini@polimi.it, Politecnico di Milano

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Introduction:

The product design process is based on a sequence of phases where the concept of the shape of a product is typically developed through a 3D Computer Aided Design (CAD) model, and often also by means of a corresponding physical prototype. The digital CAD model allows designers to perform visual evaluation of the shape, while the physical model is used to better evaluate the aesthetic properties, such as symmetry, roundness, of the product by touching and interacting with it. If the new shape, either in its digital or physical form, does not satisfy the designer, it has to be modified. A modification of the digital model requires a new physical prototyping of the shape for further evaluation, often developed through a traditional manufacturing process of through modern rapid manufacturing techniques. Conversely, a modification of the physical prototype requires the consequent update of the digital model, which may require the use of reverse engineering. Design and evaluation activities are typically cyclical, i.e. repeated many times before reaching the optimal and desired shape. This reiteration leads to an increase of the time-to-market and also of the overall product development cost.

The aim of the research work described in this paper is to develop a novel system for the simultaneous visual and tactile rendering of product shapes, thus allowing product designers to both touch and see new shapes already during the creative initial conceptual phase of product development. The proposed system for visual and tactile shape rendering consists of a Tactile Display able to represent in the real environment the shape of the CAD model of a product. It allows designers to explore the rendered surface through a continuous touch of curves lying on the product shape. In order to physically represent these selected curves, a flexible surface is curved by means of servo-actuated modules controlling a physical deforming strip. The device is designed so as to be portable, low cost, modular and high performing in terms of types of shapes that can be represented. The developed Tactile Display has been integrated with an Augmented Reality visualization system, which allows rendering the visual shape on top of the tactile haptic strip. This allows a simultaneous representation of visual and tactile properties of a shape.

Main Idea:

The design process of products, mainly for what concerns the shape and the aesthetic properties of a product, can be divided into five main phases:

- *Concept ideation*: this is the preliminary phase, where the designer creates the concept of the product that is represented by hand drawing and sketches;

- *Shape modelling*: where the shape of the product is modelled and represented by using a CAD software tool, which allows obtaining a 3D digital model of the product;
- *Visual evaluation*: in this phase, the designer evaluates the shape and the aesthetic features of the 3D digital model. This phase is typically performed simultaneously with the shape-modelling phase;
- *Physical Prototyping*: in this phase, it is created a physical prototype starting from the CAD model of the shape. In this way, the designer can have a physical interaction with the model of the product;
- *Tactile evaluation*: thanks to the development of physical prototypes, the designers can experience a physical interaction with the models of their in-progress products. The information provided by the tactile evaluation cannot be obtained by the sole visual evaluation. This phase is fundamental for the designers, because it also allows them to evaluate how the shape of the future product will be perceived by the user.

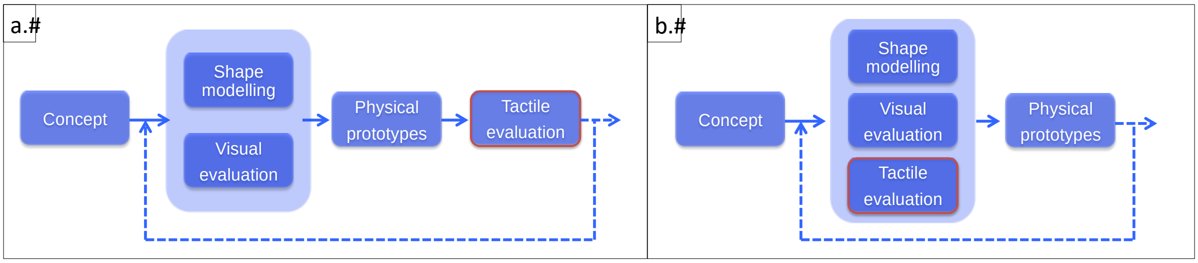

Fig. 1: Phases of Product Design Process: (a) Traditional approach, (b) New approach.

With respect to the traditional product design process of aesthetic shapes shown in Fig.1-a, the design approach presented in this paper proposes to anticipate the tactile evaluation phase, as shown in Fig. 1-b. In this way, the designer will be able to check the shape of the model and perform the tactile evaluation directly during the shape modelling together with the visual evaluation phase. By means of this new approach, it will be possible to decrease the number of physical prototypes needed, and therefore reducing the development time and costs.

System Specifications

In the last decades, several systems have been developed for tactile interaction with digital models and in general for Virtual Reality applications, such as the projects Feelex [5] and Sublimate [7]. All these devices allow rendering a portion of a surface, and are based on a matrix of moving pins, which could be perceived by the user during the tactile evaluation. Moreover, the curvature radii that these devices can render are not appropriate for the evaluation of the typical shapes of products in the industrial design domain.

It has been observed [1] that designers slide their hands along a trajectory, while exploring a surface. Starting from this observation, the authors have developed the SATIN system [2][3], which includes a device capable to render a curve that allows users to perform a continuous free-hand shape evaluation. However, the system has some drawbacks such as the high value of curvature radii that can be rendered, the dimensions of the whole system and the implementations costs. In order to overcome these limits, the authors have developed a new system that has the following features:

- *Modularity:* to be customized according to the needs of the designers*;*
- *Portability*: to provide flexibility and usability in the everyday working life;
- *Low-cost*: to be affordable for a large number of design studios or for single designers;
- *High performance:* to overcome the limits of the previously developed solutions.

System architecture and working principle

In order to obtain a system that allows designers to perform a tactile and visual evaluation of the digital models of the products they are designing, we have developed a Tactile Display integrated with an Augmented Reality visualization system. The Tactile Display working principle is based on the attitude of the designers, who typically explore the shape of products along trajectories as it usually happens when they use flexible curvilinear strip. Considering a generic shape, in order to obtain a continuous trajectory similar to the one that would be explored by a user touching the corresponding shape, we have intersected the 3D shape with a cutting plane obtaining, in general, a 3D curve. This curve can be physically represented by the centreline of a flexible strip, which has to be bended and twisted in order to approximate the trajectory to render.

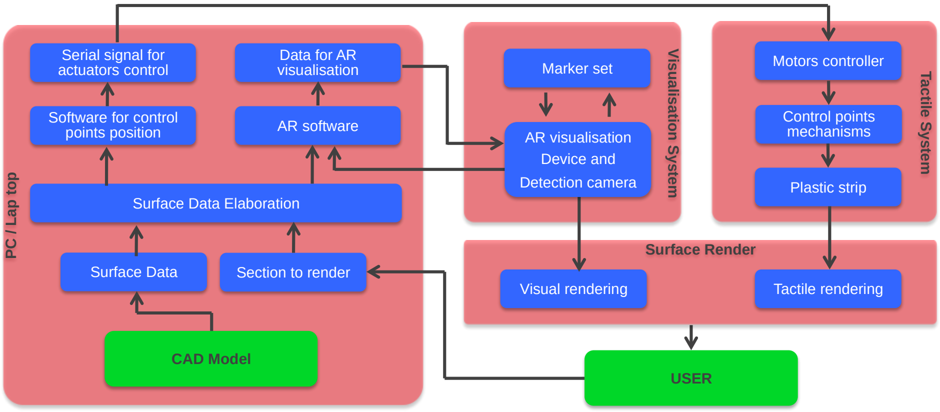

Fig. 2: System working principle.

As shown in Fig. **2**, the data provided by the CAD model can be processed so as to control the Tactile Display and to obtain the information needed for the visual rendering. The user can select the cutting plane, and the system computes the 3D curve obtained by the intersection of this plane with the surface of the CAD model. Then, in order to control the elastic deformation of the strip, a variable number of control points are identified on this curve. This control points and the deformation of the strip are managed by a modular system, which will be described in the following section.

Tactile Display

To control the elastic deformation of the strip, so as to physically represent the curve that has to be rendered, the authors have developed an interface based on modules (Fig. 3-a) with absolute actuation system. It is possible to control the behaviour of the strip by controlling the position and the rotation of those sectors of the strip where the modules are connected. The modules are replicated and placed in the space alternately. This characteristic avoids collisions between two adjoined modules, thus decreasing the minimum distance needed between them, which is the resolution of the system. Each module is equipped with 5 degrees of freedom. Three degrees are needed to position the control point in space, and two are needed for the rotations, which allow handling the torsion of the strip and the local tangency of the trajectory to the control point. This is a novel feature in the architecture of haptic interfaces. In fact, currently there are not similar devices able to control the local curvature. The positioning of the control point on the transversal plane is provided by the planar articulated system, which is obtained by actuating the element *Arm1* and *Arm2.* The third displacement needed to place the control point in a specific position is provided by a translational system obtained thanks to a rack-pinion system. As regards the rotation in charge of controlling the torsion, the upper end of the element *Arm2* is equipped with a tilting system, which allows the rotation needed. It is controlled by the twisting servo by means of a four bar linkage. Inside the tilting system, there is the frame that hosts the tangency servomotor. This servo controls the rotation of the contact element between the module and the strip. It is equipped with two miniaturised bearings, which allow the sector to slide on the strip. This feature allows us to dynamically change the distance between the control points. In this manner, it is possible to place each control sector in a specific point by selecting the best position for each trajectory. On the upper side of the contact element there are two ultra-thin plates, which have the aim to guide the tangency of the strip in the correct direction. The position of the bearings is adjustable in order to allow us to use strips of different thickness.

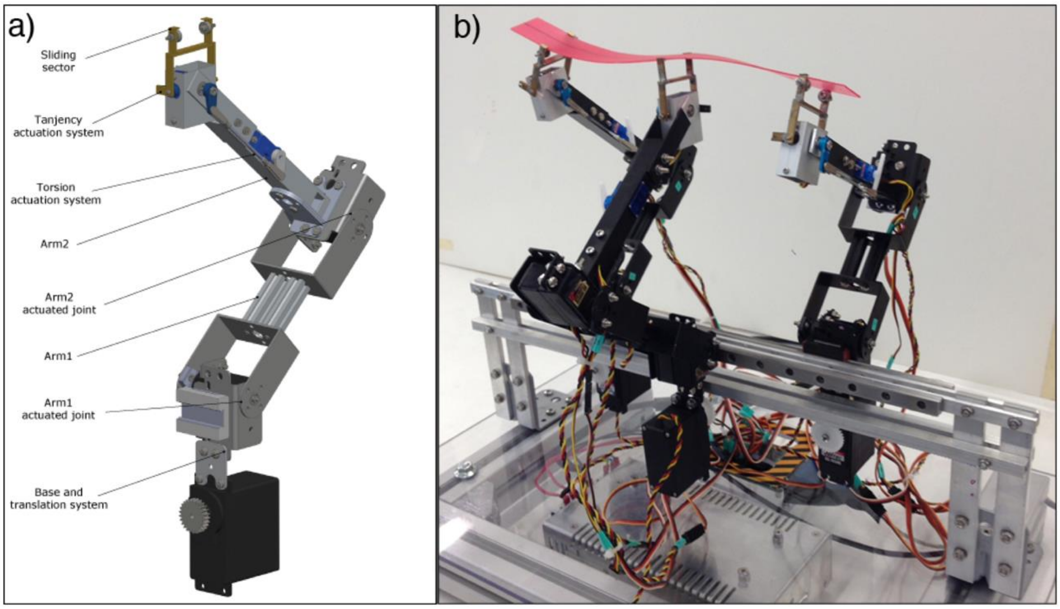

Fig. 3: The tactile display: (a) Architecture of the module, (b) Tactile display with 3 modules.

The developed tactile display is able to render trajectories with minimum curvature radius of 30 mm. This value allows the users to render a large range of smooth surfaces. The minimum number of modules needed to control the strip is 3, but there is not a maximum number of modules, since this value depends on the length of the longitudinal rail, which can be selected according to the kind of surfaces to render. The obtained device presents small dimensions, which satisfies the portability requirement. Regarding the implementation costs it is difficult to make an accurate estimation. The components needed to develop the prototype have required less than 1.000 Euros. Therefore, it is possible to assume that the proposed solution is less expensive than similar devices developed in research Labs.

Augmented Reality Visualization System

Augmented Reality (AR) visualization technologies have demonstrated to be effective in the development of applications for design review [6][8], since it allows evaluating 3D virtual models in a real context. This feature makes more realistic and engaging the interaction of users with virtual models. Several devices can be used to provide AR visualization but surely the use of AR Head Mounted Display or glasses represents the most suitable solution for our system. The benefits of this visualization solution have been proved in several research works [9], and the authors themselves have developed and tested a specific visualization system for design review [4].

In the context of this research, a commercial AR visualization device has been used. The device provides the users with stereoscopic AR visualization (Fig. 4-a). Cameras mounted on the device have been used to track the point of view of the user. In this way, the user constantly visualizes the 3D model coherently with the tactile display (Fig 4-b). The software application, which manages the AR visualization, has been developed by using osgART [10], which is an open-source AR library, in order to maintain the low-cost feature, as required by the specifications of the system.

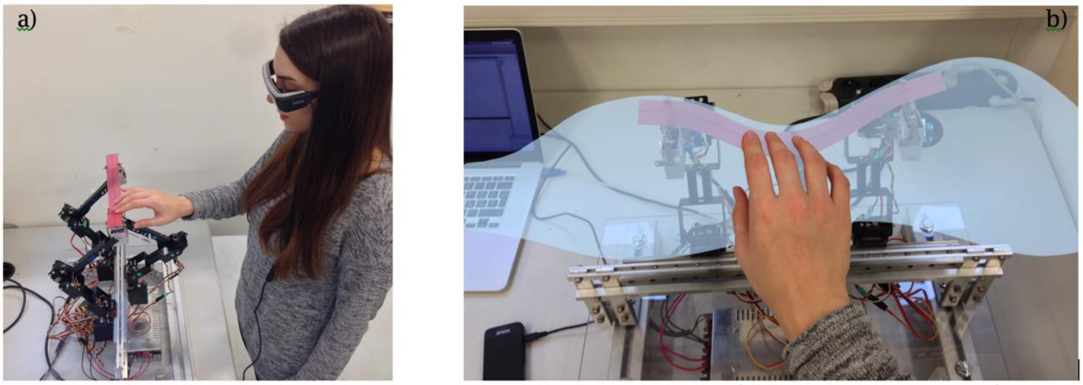

Fig. 4: Augmented Reality visualization system: (a) External point of view, (b) User point of view.

Conclusions:

The aim of this research work has been to design and develop a novel tactile display integrated with an Augmented Reality visualization system. The aim of this device is to allow designers to perform tactile evaluation of the CAD models of the products they are developing directly during the shape-modelling phase. In this way, the designer will be able to change the shape of the model according to the tactile evaluation before the creation of the physical prototype. This feature would benefit the design process, since the number of prototypes to develop for testing the product concept would decrease, thus reducing, consequently, both cost and the overall time of the product development process.

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