Title:

Shape Modelling in Immersive Systems

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Introduction:

The recent advances in Virtual Reality (VR) systems paved the way for their increased use in several industries. Indeed, the availability of low cost VR tools and the new means to acquire and print 3D shapes increased the number of possible applications and the type of users that can make use of these technologies. Currently, only experts can use CAD software to create and modify 3D shapes. This poses a big barrier to entry to end users, as the over-complicated applications are hard to understand for even simple modifications. With the development of appropriate shape interaction and manipulation techniques, the inclusion of end users in the design and customization of products becomes a possibility.

Additionally, it is also important to consider collaborative approaches that can be applied to these scenarios. This is especially important when considering that producers and consumers will be able to interact in novel ways. For instance, it can become possible for consumers to modify an object present in a 3D object library and send the renewed design to a 3D printing company that will finalize and bring it to reality.

To allow a full integration of any potential customer in these scenarios, it is important to provide very natural shape modelling capabilities, and immersive VR may offer suitable environment to achieve this goal. To understand the state of play and in particular, which are the open issues and the main challenges to face, this paper provides a survey of research works addressing shape interaction and modelling in immersive VR environments. Moreover, our research objectives in this perspective and current achievements are briefly introduced.

To provide a meaningful classification of the relevant works available in literature, we selected three key characteristics that we think have considerable implications and importance for the future of immersive shape modelling and its effective usage in working context.

The first considered characteristic is the input method used for interacting with 3D shapes. This pertains to which manner the users will interact with the system, where controllers, physical metaphors or gestures are usually employed. The second considered aspect regards the types of manipulations allowed on 3D shapes. Here we make distinction between assembly and visualization tasks and shape modification operations, which ultimately are the goal of our study. Lastly, we focus on the shape representation adopted in the reviewed approaches, as the representation has a considerable impact on the operations available. The objective is in particular to highlight the ease of integration with modelling and production systems.

State of the Art:

Next, we highlight some of the works that, in our opinion, have driven the advance of immersive modelling. The considered works are analyzed and categorized according to the three above mentioned key aspects: input method, type of provided shape manipulation capabilities and adopted shape representation.

Input Method

The earliest approaches used a tablet with a pen device [13], or just a tracked stylus [17] to interact with the virtual environment. As an alternative to this paradigm, several works have used data gloves as their input devices. The use of flex sensors for individual fingers of the users' hands has been largely considered since it allows hand movements and gestures, that can be tracked, analyzed and interpreted as specific applications commands [1, 4, 6, 7, 10]. This hardware allows the capture of all of the users' fingers independently, consenting a high level of accuracy when performing gestures. However, these gloves are usually plugged into desktop computers, making the interaction space much smaller. Another approach is using a tracked controller with dedicated buttons. These two approaches have been combined in [2], pairing a wand device capable of six degrees of freedom for direct manipulation with a data glove. Controllers from the gaming industry have also been used in research, for instance, the WiiMote or the FlyStick [5, 11]. However, some are not adequate due to their ergonomy, and by not resembling classical drawing devices (e.g. pencil). More recently, color and depth sensing cameras have been used to try to achieve the same level of precision as tracked devices, but with inexpensive technologies. Two different setups, both including Kinect sensor for hand tracking, have been tested [3, 12, 14]. A similar solution has also been achieved, by substituting the Kinect sensors with PlayStation Eye cameras [16]. This last approach was limited to scenarios where the users' hands can be distinguished from the background, in order to segment them. The Kinect is the superior alternative, as the depth sensor can segment background from foreground data. The use of small markers in the users' hand for motion capture has also been tested [8, 9]. A more recent alternative to such sensors is the leap motion [4]. This device only tracks hands and arm motions, but its accuracy is superior to those mentioned above. Voice commands were also addressed in [1] and [2] with a limited vocabulary.

Summarizing, the data glove was the most common interaction device used. It is easy to use, ergonomic, but since it requires data cables to transfer data to the system, is impractical for applications that require large areas of movement or fully immersive approaches. Controllers are an extension of a desktop mouse, by providing the buttons and its pointing capabilities. The precision is very device dependent, with the state-of-the-art devices providing millimetric precision. The increased accuracy when tracking controllers makes them the best non-natural interface solution. The Kinect sensor offers full-body tracking, making it a robust solution when more than hand tracking is required. Multiple Kinects can be used simultaneously in order to resolve occlusion conflicts and increase the tracking area. Even though the sensor can only recognize open and close hand gestures, it is not robust enough to correctly track finger movements. The leap motion on the other hand, developed specifically for hand tracking, provides a much higher level of precision. There are still occlusion issues while using this hardware, as the fingers of one hand can prevent the sensor from seeing behind them. It works especially well when paired with a head-mounted display, as the user usually performs the actions in front of the sensor.

Types of operations on the Shape

Immersive assembly and modelling systems are capable of providing different and more engaging information into the parts that compose an object due to the nature of their visualization. The visualization method chosen has a considerable influence on how users perceive and interact with the objects. Looking at the existing tools for shape manipulation in immersive environments, we can distinguish works that focus on object assembling [3, 4, 6, 7, 13, 14, 15, 16] and works that tackle object modelling and deformation [1, 2, 5, 9, 10, 11, 12, 17]. These are fundamentally different operations to take into consideration to develop a complete modelling environment.

In the assembling area, scaling translation and rotation are the key operations to support. The systems described in [6] and [7] feature constrained motions of a certain object along an axis, and can provide both one-hand and two-hand assembly of parts. Despite all the aiding features, the use of virtual reality causes a lot of physical strain on the user, making this approach not suited for large assemblies or long task sessions. For these reasons, most works in previous research utilized CAVE-like environments, some with the addition of 3D glasses, since they require less body movements from the user. Another limit is the absence of physical perception of the parts. To overcome this, in [13] by using a tablet to aid in the visualization of the assembly, users were able to see inside all the parts that are in their selection. Objects and parts of assemblies were created that could be positioned and rotated to arrive at a final assembly. For the visualization and transformation of a completed assembly, users can utilize rotate, pan and zoom gestures with a Leap Motion sensor [4] or by using different types of depth [3, 14], color cameras [16] or by the aid of hand markers [8]. The differences between traditional desktop 3D modelling systems and the multimodal immersive systems for part creation and assembly are highlighted in [15].

In immersive modelling, a feature-based approach is adopted in [1] to build objects. [2] reports a system that thoroughly integrates VR and CAD software using gloves, where one of the goals was to resolve the poor accuracy of free-hand gesture interactions in the modelling operations. Another approach is the combination of gestures and menus [1, 5, 9]. Gestures are used to resize, orientate and transform geometry, while the menu provides access to the modelling capabilities. FreeDrawer [17] is a similar system, where surfaces are created by drawing and filling in between curves. A modelling system is presented in [12] for the modification of objects with symmetries through skeletal bending, sectional deformation and sectional scaling schemes. Deformations like Twist, Bend, Swell, Taper and Stretch, directed by the users' gestures have been made available in [11]. One of the main advantages of the tool was that by storing the modifications in a deformation curve, it is possible to see previous steps or later modifications. Surface modelling and modifications by transforming surface control points are proposed in [10, 18]. In [10] the resulting curves can be twisted and swirled in order to arrive at a "sweep surface". While Mindesk [18] provides a virtual reality interface to Rhino thus allowing precise shape definition and modification.

Shape sculpturing together with primitive combination and push and pull operations are the main capabilities provided by commercial applications, such as Oculus Medium [19] and MakeVR [20], which use specific hardware paired with their own controllers to provide complete shape modelling capabilities in immersive environments. Even though these approaches are moving in the right direction, they still require the use of controllers and menus, limiting their usefulness for non-experts.

Shape Representation

When working within a virtual environment, 3D shapes have to be represented differently than when using traditional CAD software. Previous works have answered this problem by connecting the virtual environment to a CAD application, and making the changes that occur in one of the applications immediately appear in the other [1, 13, 10, 2, 5]. Systems that can provide this type of integration are inherently superior to those that require manual integration. Even with the advances these works have shown, there are still problems when integrating a virtual environment for CAD applications, mostly notably the difficulty in creating an appropriate interface. The works that focus on novel integrated approaches to address this issue only offer a very restricted number of modelling actions by using controllers [18, 20].

In the other cases, depending on the type of operations offered, different geometric representation have been adopted. Mesh representation is a de facto standard in VR applications as it allows fast visualization and rendering. However, modelling capabilities are somehow limited in purely mesh environment, allowing less high-level controlled modifications, e.g. through parameters or leading curves, and this is a big limitation in particular when the specification of the model requires several parameters with mutual constrained relationships. The work addressing only assembly tasks [3, 4, 6, 7, 14, 15, 16] represent objects through meshes in VR which are generally directly translated from and connected to the CAD system [13]. While the works aimed at shape modifications adopt different shape representations. Some works propose ad-hoc shape representation (like generalized cylinders [12], or NURBS/splines [10, 17] or voxel-based [3]) which best fit the supported operation. Meshes are used for shape modification in [8, 19, 9].

Our approach:

Although natural interfaces are not suited for the totality of applications, the ability to control an application without resorting to any device is very compelling. In future, we expect an even bigger increase in interest in more natural approaches for shape manipulation driven by both hand/body motions and speech interfaces. The ambition of our research is to achieve a natural interface for shape modelling, allowing non-expert users to easily modify shapes. In our opinion, a natural interface should use as less as possible technical medium or pre-defined languages for the interaction with the 3D model. Low cost equipment should be used.

With this objective in mind, we conducted a user study to understand how humans would act to perform specific modelling tasks, if there is a consistency of motions/gestures among different users and if these gestures could be directly translated to a virtual environment. In this study we utilized HTC Vive for the VR rendering, leap motion for the hand movement recognition and virtual hand avatars. We applied the Wizard of Oz method, where users were merely performing the operations but not directly influencing the objects themselves. The actual modification on the object was performed by the interviewer in response to the user actions, to provide the feeling of an operating system. The guidelines we gave to users, in simple terms, stated that they should perform the modifications in the most natural way. This could be achieved by using hand motions, gestures or speech. The evaluation was comprised of five tasks, with a focus on the manipulation of objects or the modification of their shapes. We found that the strategy used by the majority of participants remained consistent and that the hand motions reflected physically plausible movements. We also observed that speech interaction was rarely used throughout the experiment. The results are encouraging on the consistency and thus on the possibility of their translation.

Conclusions:

In this paper, we briefly reviewed the current works in the immersive shape modelling and assembly areas, highlighting benefits and limits. The new hand and body tracking hardware, that have become available in the recent years, has allowed the exploration of new interaction techniques. The trend started with data gloves, which then moved into programmable controllers, and is arriving at a more natural scope with the depth and color sensors. These improvements are paving the way for the creation of more natural interfaces, which will enable the use of these technologies by non-experts in the 3D shape modelling area. Moreover, we introduced a study that we have carried out to advance the understanding of hand and voice interaction for 3D shape modifications in immersive environments.

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