Title:
The Issue of Virtual Reality in Industrial Design: a Discussion on Its Adoption and New Possible Approaches

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Introduction

The matter of Virtual Reality as a breakthrough technology in the design and engineering domains has recently become an interesting topic within the research community. In fact, in the current state, hardware and software tools have become widely available on the market, they are generally easily affordable and have reached a decent level of optimization to be integrated into the design development workflow. Despite this, when considering industrial design and the complex shape generation methods needed for everyday products as well as in the automotive/transportation fields, the industry seems quite reluctant to embrace these new possibilities, sticking with traditional approaches that are deemed as more reliable.

The reasons behind this mismatch are several. There are still some technological limitations that set more analog methods apart. For instance, we are still far from achieving a realistic feel of touch in Virtual Reality environments, though many efforts are also going in this direction [4]. The relevance of this aspect cannot be overlooked, given its importance in relation to some very common techniques such as physical clay modeling.

As a result, many different approaches that have taken advantage of Virtual Reality have been investigated at research level in the last decade, and while few have actually turned into commercial successes, each contributed to pave the way in the current direction. However, the novelty of such a breakthrough technology also meant that interaction systems and user experiences in general had to be rethought from the ground up compared to traditional desktop solutions, which in turn have reached a very established level of configurability in these regards. This aspect is enticing and yet critical at the same time: it is now possible to reimagine the user experience in ways that weren't even conceivable until a few years ago. On the other hand, Virtual Reality developers that are willing to invest their efforts in this domain have to face against the lack of well defined guidelines, protocols and assessment methods to properly understand the actual potential of such solutions.

Related Works

A debate on the issue mentioned above was already raised in [3], highlighting how difficult is to compare

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between each other the plethora of proposals that have arisen through the years at research level, and so how vital the definition of an established protocol to evaluate them would be. On that basis, the foundations for a new testing methodology were laid down, and a small sample of users that were involved in the process was still able to provide some interesting feedbacks about the most relevant criticalities of Virtual Reality in such contexts.

More specifically, a Virtual Reality sculpting system called Kodon VR was tested, resulting in mixed feedbacks by the users. On one hand, they praised the ability to quickly shape any elementary object with very natural interactions. But as the level of complexity increased, the whole experience turned out to be more and more frustrating, especially from the point of view of the more "untrained" ones, that felt unable to control fine details in an unbounded, yet physically empty 3D space. More positive feedbacks were gathered in relation to another Virtual Reality application for 3D sketching called Gravity Sketch. This methodology basically consists of a 3D, virtual transposition of the traditional 2D drawing activity, where non-material entities such as line strokes and surfaces can be generated in mid-air, making it less dependent on the sense of touch. While not being suited for more advanced operations across the design process (e.g. consistent definition of surface behaviours), it still proved its potential towards fast shape generation activities, where frequent reiterations are common, as an alternative to traditional 2D sketching.

In both cases, users enjoyed the sense of presence allowed by the immersive environment and the fact that natural gestures applied to shape generation activities were much more intuitive and involving to accomplish compared to the classic desktop user interfaces (UIs), where at least a basic level of knowledge of the commands is usually required [2].

A common downside though regarded the lack of dimensional references in the virtual environment, which is a problem that ultimately alters the sense of scale from the user's point of view.

Finally, when considering the ergonomic implications of Virtual Reality, the absence of a supportive area like a table or a board that are normally part of a traditional workstation setup for 2D sketching led to a decreased level of precision of the inputs and, conversely, an increased level of fatigue even after short sessions, because of the lack of a constraining surface where the user would normally lean on.

Architecure of the New Interaction System

The core idea that characterizes the approach that will be proposed hereby is related to the fact that we want to investigate the possibilities to bring the classic workstation layout inside a Virtual Reality environment, taking advantage of the benefits that the latter may ultimately imply in terms of immersiveness, while still being able to rely on the ergonomic principles of the traditional drawing activity.

Grounding on the considerations expressed in the previous paragraph and on the outcomes of other interesting proposals that have been reviewed in [3], and specifically [1], a hybrid 2D + 3D sketching solution is described. It must be noted that some solutions with similar approaches are already available on the market: Umake (https://www.umake.xyz/it/) is a 3D modeling software meant to be operated from a tablet through a digital pen. The effort to bring a similar modeling methodology in Virtual Reality though opens up to many other challenges that have to be tackled throughout the development stages. In our specific case, the workstation is set up as follows (Figure 1):

1. A pad is placed on the desk, in front of the user, and it works as a traditional planar surface to be operated through a digital pen. The user holds it and performs the drawing activity by means of his/her dominant hand. Its digital counterpart is a virtual drawing plane that is visible in semi-transparency in Virtual Reality, through the HMD device, and located in a fixed position in the Virtual Environment that from the user's point of view replicates the one of the actual pad.

2. An optical hand-tracking device (e.g. Leap Motion) is placed in a position where it's able to detect the non-dominant hand (i.e. on top or on the side).

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Fig. 1: Conceptual architecture of the workstation

3. When the non-dominant hand is detected by the hand tracking device, its orientation is replicated dynamically as the orientation of the whole scene relative to the virtual drawing plane; As the scene orientation is being progressively updated, the user is able to simultaneously produce strokes on the pad; through this feature it is possible to unlock the third dimension inside the virtual environment, making the generation of digital 3D shapes possible.

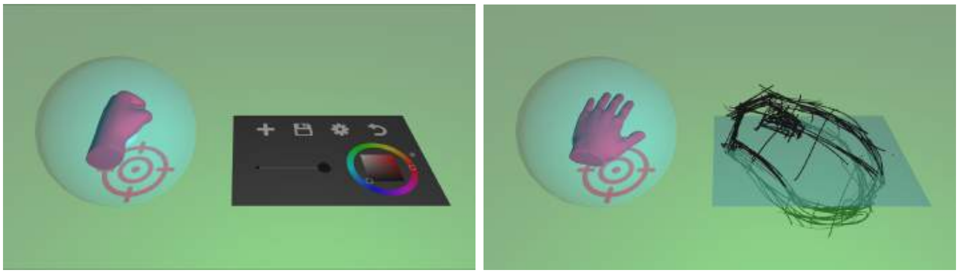
So far, the implementation has been carried out within a prototype VR application built in Unity 3D, in which the main features for shape generation and navigation inside the environment have been made available.

Development of the Application

In this section the main features that characterize the user experience are presented. Finally, a few considerations regarding the most urgent issues that still need to be addressed will be provided. Considering the prototype layout presented in figure 2, the hardware configuration is composed by a traditional Wacom tablet device located in front of the user and the included digital pen that are operated by the dominant hand, and a Leap Motion hand tracking system on the left side that is operated by the non-dominant hand.

The set of tasks that are assigned to the dominant hand are completely in line with any other traditional sketching application where the user is able to produce digital strokes. Specifically, it is possible to control a number of parameters such as line thickness and color from a dedicated menu available at any time.

However, the operations that are performed by the non-dominant hand are crucial to gain control over the tasks related to the scene manipulation. For this purpose, the hand tracking system works by associating a virtual 3D model of the hand joints to the acquired image of the user's hand that hovers above it. This operating principle allows to assign certain user defined gestures to specific actions. In particular, the system has been built to detect the position and the orientation of the palm joint when a prolonged pinch gesture is recognized. This triggers the re-positioning and the re-orientation of the whole scene in real time, while the dominant hand is still able to produce strokes at the level of the drawing



(a) (b)

Fig. 2: (a) Layout for the application: the left hand (non-dominant) fist gesture is detected by the Leap Motion to activate the menu, while the right hand (dominant) is operating on the tablet. (b) An example representing a conceptual design for a desktop mouse.

area, which stays fixed, enabling at this point the generation of 3D curves. When the pinch gesture is interrupted, the scene reorientation gets re-locked accordingly. At this point it is worth discussing what are the main problems that may eventually affect such a configuration. The most evident issue that needs to be tackled regards the ability for the user to coordinate the movements of both hands in a seamless way, while allowing him/her to achieve the expected results in terms of shape generation. This is a critical implementation issue, since by default the hand tracking device is able to detect the hand's movement with a very high level of sensitivity and accuracy, that at the same time is detrimental in our specific case where we strive to limit as much as possible the negative effects of hand tremor and micro-movements in general, since they'd generally result into irregular, broken lines as the user simultaneously tries to draw curves. A possible approach is the generation of a dedicated script that is able to filter certain inputs according to predefined threshold values that control both speed and sensitivity according to the user preferences.

Technically speaking, this solution has been laid out as follows: instead of a 1:1 connection between hand and scene, a dedicated control algorithm has been developed. It implements a velocity control rather that a position control; it means that, given the initial position and orientation of the hand, the more the hand deviates from it, the faster the plane is moving/rotating according to the coordinate system placed on the virtual plane.

The pinch gesture is recognized at t=0, either for position or orientation. At this point, a coefficient - that is always less then 1 - is multiplied at each frame to the transformation delta of the scene object from t=0 to t=1. This coefficient is set to be proportional to the delta itself, meaning that it progressively increases as the position of the palm joint is displaced further away while transitioning from t=0 to t=1, while it does the opposite if, in the context of the same gesture (i.e., the pinch is still active), it's reverted back to a position closer to the one at t=0. Moreover, the global position or orientation of the palm joint at t=0 is not taken into consideration, meaning that regardless of the original configuration of the user's hand, the only parameter that manages the manipulation is the transformation delta.

Future Developments

When a reasonable level of refinement will be achieved, it will be interesting as a consequent research work to test the proposed solution while also trying to tackle the issue of the inconsistency of the assessment methods to figure out the true potential of this kind of solutions. The idea of laying down an established protocol and making it suitable to evaluate against each other as many proposals as possible is a huge feat that was already proposed in [3], though we believe that starting to define its foundations is still necessary to better orient the efforts across the research community towards future developments in the field.

The first aspect that needs to be addressed is the matter of establishing more reliable metrics. Some of them are pretty easy to define as objective measures: time to accomplish a given set of tasks and the number of the operation that are required to achieve them are often taken into consideration to evaluate the user-friendliness of a given workflow. More subjective metrics so far have been mostly based on qualitative evaluations of the outputs or on the users' feedback themselves. This is a crucial issue, and more objective ways to evaluate the outputs can prove extremely beneficial for the research.

Conclusions

In summary, a brief overview about the currently most established systems for shape generations in Virtual Reality was provided based on literature analyses and available products on the market. Grounding on a critic review of the most advanced solutions, we found out that such system may potentially provide great improvements compared to traditional workflows, since they usually take advantage of the immersive user experiences that Virtual Reality is able to support. On the other hand, they pose some issues in terms of usability and ergonomics that need to be addressed, such as lower precision and increased level of physical stress compared to standard solutions.

Grounding on such considerations, we propose an hybrid 2D plus 3D virtual reality sketching system that is based on a similar configuration layout as a traditional desktop workstation, but thanks to the implementation of an hand tracking device, allows the user to navigate and reorient the virtual scene according to the movements of his/her non-dominant hand. Several refinements have to be carried out before validating the proposal, including a number of adjustments to the sensitivity of the system to the hand's micro-movements, which predictably turned out to be the most relevant problem.

Once this step will be achieved, a testing session can be set up, possibly improving on current procedures whose metrics and assessment methods cannot be considered sufficiently reliable. At that point, a more defined protocol to be applied also to other Virtual Reality systems in this domain could be implemented.

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