Evaluating Consumer Interaction Interfaces for 3D Sketching in Virtual Reality

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Abstract. Since its introduction, 3D mid-air sketching in immersive Virtual Reality (VR) proved to be a very powerful tool for many creative applications. However, common VR sketching suites rely on the standard hand controllers bundled with home VR systems, which are non-optimal for this kind of tasks. To deal with this issue, some research works proposed to use dedicated pen-shaped interfaces tracked with external motion-capture systems. Regrettably, these solutions are generally rather expensive, cumbersome and unsuitable for many potential end-users. Hence, lots of challenges regarding interfaces for 3D sketching in VR still exist. In this paper, a newly proposed sketching-oriented input device (namely, a VR stylus) compatible with the tracking technology of a consumer-grade VR system is compared with a standard hand controller from the same system. In particular, the paper reports the results of a user study whose aim was to evaluate, in both objective and subjective terms, aspects like, among others, sketching accuracy, ease of use, efficiency, comfort, control and naturalness.

Keywords: Virtual Reality · Human-computer interaction · 3D sketching · VR stylus

1 Introduction

Thanks to the recent developments in the consumer market, Virtual Reality (VR) technology is increasingly widening its areas of application. One of the most prominent fields in which VR can have a huge impact is the creation of digital contents. Tasks such as painting [17], modelling [4], sculpting [18], and animation [12] greatly benefit from the possibility for the user to visualize and interact with the actual workpiece in an immersive virtual environment [2].

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In particular, sketching, which is a fast and intuitive method for communicating and conceptualizing ideas by hand drawing [14], is a basic requirement for many of the above tasks. According to [9], sketches are quick, inexpensive, disposable and plentiful. They have a clear vocabulary offering minimal detail: thus, they are open to different interpretations, which make them capable to suggest new solutions to a given problem, rather than just confirm existing ones.

Although sketching is generally considered a 2D activity, many sketch-based interfaces for creating 3D contents have been proposed already [4,5,20,26]. Usually designed for 3D modeling tasks, these solutions generate the final 3D sketch by combining multiple 2D sketches iteratively drawn by the user from different point of views inside the 3D environment. However, as reported in [14], this approach can be an obstacle for inexperienced users. To overcome this limitation, sketching can be easily moved from 2D to mid-air 3D by exploiting an external 6-DOF tracking technology [13]. However, the visualization of the output of a 6-DOF interface on a classical 2D display can be a source of inaccuracies due to the lack of depth perception. This latter issue can be solved by exploiting an immersive technology, like VR. Some commercial sketching tools targeting a broad creative audience, such as TiltBrush [17] and PaintLab VR [24], are specifically designed for being used in VR. Recent years have also seen the emergence of commercial software applications aimed at business users enabling both sketching and some modelling activities in VR, e.g., Gravity Sketch [18], flyingshapes° [16], Alias CreateVR [3]. The user, wearing a Head-Mounted Display (HMD), visualizes (and moves within) a virtual environment that serves as a 3D canvas. Sketches can be drawn by using one of the two 6-DOF hand controllers (or both) typically bundled with the VR system. This approach appears to be fast and highly intuitive, but it is characterized by a low level of accuracy, stability and control over what is being drawn [32].

To deal with the lack of accuracy and control introduced by the adoption of VR, works in the literature investigated the contribution of various forms of guidance (visual or physical [2,32]) that can be provided to the user while sketching in order to mitigate the said issues. Although these works showed that any kind of guidance can reduce the inaccuracy penalty introduced by the mid-air sketching in VR, most of them relied on complex, poorly feasible and non-generalizable approaches which are not representative of the typical usage of the previously mentioned commercial VR sketching tools. In [2], for instance, the user input for sketching is not captured by the VR system itself, but is managed through an external (and expensive) tracking system. The sketching is then performed by handling a tracked physical prop resembling a pen, which is also visualized in VR. Since the pen is a passive device, the drawing input is obtained by pressing a button on a VR controller held in the non-dominant hand. Although the work addressed the problem of mitigating inaccuracies by means of various forms of guidance, the selected configuration still appeared to suffer from some inaccuracies, because the reference systems may not always remain properly aligned, as well as because having the input button on a hand different than the drawing one may introduce unwanted stokes in case of imperfect coordination between the two hands [2]. In [32], the hand controller of a home VR system is directly used as input device, solving the issue of having a second tracking system, but in a way that cannot be considered as natural, efficient or ergonomic; this is due to the fact that the sketch is generated from the tail of the controller, which is held in an unconventional way.

As evidence, all the commercial VR sketching tools support the hand controllers as per any other interactive VR application. The user holds the controller the way it was designed, and he or she uses the trigger button to generate the sketches from the controller's tip. This approach minimizes the need for additional hardware, but it does not solve the problem of non-optimal performance of the standard hand controllers for sketching. Thus, it is not surprising that, recently, a new type of pen-shaped hand controller named VR Ink [28] appeared on the market. This device can be seamlessly integrated with the tracking technology of common VR systems and replace standard VR controllers, promising to be very accurate and ergonomic without requiring external expensive tracking systems.

The aim of this work is to investigate the possible contribution brought to the considered domain by devices like the one above. Thus, a user study was carried out, by following an experimental protocol mainly based on the approach adopted in [2] for the objective measurements, and in [32] for the subjective part. The evaluation compared the VR Ink device with a standard VR controller on a set of sketching tasks under a number of representative conditions, considering a large set of aspects including accuracy, usability, enjoyability, ease of use, efficiency, comfort, control and naturalness.

2 Related Work

Numerous works investigated the advantages of 3D over traditional 2D sketching [4,5,22,26]. However most of them focused on the use of 2D sketching interfaces for generating the 3D sketches, whose output was visualized on classical 2D displays. This being an obstacle for inexperienced users [13], literature moved towards the use of externally tracked 6-DOF sketching interfaces (i.e. pens and styluses) that allow user to directly draw mid-air in 3D.

For instance, the authors of [21] conducted a study, involving expert designers, aimed to compare traditional 2D and mid-air 3D sketching performed in an immersive Cave Automatic Virtual Environment (CAVE). Both the user and the input device (a pen) were tracked by an Ascension MotionStar magnetic tracking system. Although no quantitative measures were collected, results of the qualitative evaluation showed a high interest and a positive attitude of the focus group, indicating the existence of possible benefits coming from the adoption of 3D sketching in the design process.

In [2], the factors affecting human ability to freely sketch in 3D within an immersive VR environment were investigated. The study was preceded by a preliminary observational activity. This activity involved five expert designers who participated in a design session using a popular VR sketching tool. Designers appreciated the freedom of mid-air 3D sketching, but they also observed that more precision and control are often required for obtaining meaningful results. Then, a first experiment was aimed to compare traditional non-VR sketching on a physical surface to sketching performed in VR, with and without a physical surface. A second experiment studied how much the presence of visual guidance in VR could mitigate the loss of accuracy caused by VR itself. Both experiments used a passive 6-DOF pen tracked by an OptiTrack motion capture system (which also tracked the physical surface, when available), whereas the drawing input was triggered by pressing a button on a regular hand controller held with the other hand. Results showed that the presence/lack of a physical surface, the position/orientation/shape of the drawing surface, the size of the stroke and the presence/absence of a visual guidance are all factors affecting the drawing performance. Physical surface increased the accuracy by 20% if compared to unguided mid-air drawing, whereas a virtual representation of the surface could increase it by 15%. Moreover, in applications where the shape to be drawn is known in advance, showing it could boost accuracy even more. Regarding physical guidance, sketching on a virtual surface was 50% worse than sketching on its real counterpart in terms of accuracy, whereas maintaining the physical surface aligned with the virtual one worsened it only by 20%. Although the work provides a useful quantitative analysis of the multiple factors affecting accuracy of 3D sketching in VR, the uncommon input metaphor (triggering the sketching with a hand different than the one holding the pen) and the expensive additional hardware are not exactly representative of the common usage scenarios for VR sketching. Researchers have also explored the usage of a stylus form factor in VR [27,29]. However, these studies were limited to point-and-click and scroll tasks, and did not consider sketching.

An alternative approach presented in [23] exploited a hand-held mobile Augmented Reality (AR) device for drawing and visualizing 3D sketches. The work addressed issues of mobile AR sketching compared with VR-based alternatives, such as the lack of a stereo visualization, the narrow field of view, and the coupling of 2D and 3D input. The result of the pilot study showed that the use of various expedients used in the work like relative drawing, various forms of snapping, and planar/curved surface proxies can mitigate the mentioned issues. The robustness of the solution was showed to be highly dependent on the inside-out motion tracking algorithm available on the device, which is often unstable and influenced by environmental factors. Although this solution may be acceptable when the cost of a VR system is not acceptable, the huge difference in performance (especially in terms of tracking accuracy) showed that VR is actually way more suitable than AR for 3D sketching.

In [1], a hybrid sketching system is proposed, combining mid-air 3D drawing with 2D surface drawing to create 3D designs in AR. In this case, the AR device is a Microsoft HoloLens HMD, which guarantees a more precise inside-out tracking with respect to mobile AR devices. The system combines the use of a 6-DOF passive pen (tracked via a Vicon motion capture system) and a Microsoft Surface Book tablet. Drawing input is triggered through a standard mouse magnetically tightened on the back of the tablet. Authors performed an evaluation which showed that the solution is useful, effective and able to support a variety of design tasks. Nevertheless, the proposed system suffers from many limitations characterizing the previously cited works, in particular the cost of the hardware setup and the decoupling between the drawing hand and the button used to trigger the sketching.

Finally, the combination of 2D and 3D input while using a 6-DOF pen (again tracked with a OptiTrack system) in VR were investigated in [15]. The presented VR sketching tool takes advantage of a 6-DOF tracked pen for mid-air 3D interaction, complemented by a 6-DOF tracked tablet to support 2D surface-based sketching. A user study explored all the possible combinations of the input devices (pen, tablet, and pen plus tablet), for both the 2D and 3D input dimensions, showing that the 2D and 3D sketching metaphors were each suitable for different tasks. Moreover, authors argued that the current VR input devices (the standard hand controllers) are not optimized for sketching in immersive environments; hence, the inclusion of traditional devices (like a pen) could bring benefits and opportunities to the end-user.

Starting from these considerations, the current work focuses on the evaluation of the performance of a sketching-oriented VR stylus directly compatible with the tracking technology (LightHouse 1.0 [19]) of a well-known consumer-level VR kit, which is compared with the standard hand controller bundled with the kit. The tasks selected for the experimental protocol, as well as the objective and subjective metrics used in the evaluation, were derived from existing literature, and will be discussed in detail in the following section.

3 Methodology

As previously mentioned, the experimental protocol developed for the testing activity was for the most part inspired to the first experiment presented in [2]. The aim was to investigate the impact of physical guidance on the stroke accuracy, by comparing mid-air drawing of planar curves (which play a fundamental role in 3D design processes [2]) with drawing the same curves on physical flat surfaces. Three configurations were explored, *traditional*, in which the users had to draw planar curves on a physical surface without being in VR, *VR*, in which they wore a VR HMD and drawn directly mid-air in a 3D space, and *hybrid*, in which drawing was performed on a physical surface aligned with its digital representation in the virtual environment. The VR system used for the evaluation was the HTC Vive.

In our case, the main comparison is related to the sketching device; hence, only two of the above configurations, namely *VR* and *hybrid*, were considered (hereafter referred to as *modalities*). The same VR system was used. The software adopted for the experimental activity was developed starting from the VR tool presented in [12] as a Blender 2.79 [30] add-on. This tool was previously used in other research works like, e.g., [10,11], and [25].

The two main configurations, *controller* and *pen*, will be referred to as *interfaces* for sake of clarity. With the *controller* interface, the study participants

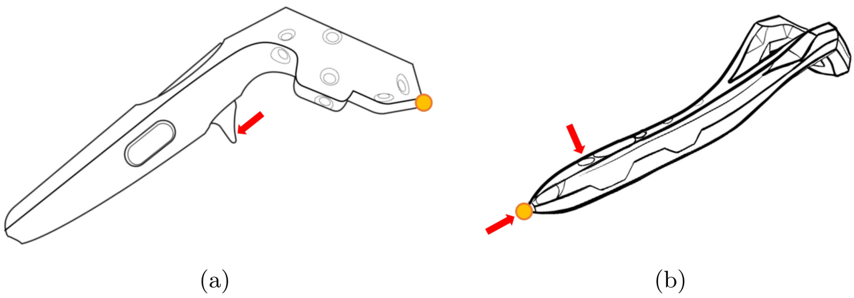


Fig. 1. The yellow points indicate where the stroke is generated from with a) *controller* and b) *pen*. The buttons used to initiate the sketching are indicated with a red arrow (for the *pen*, pressing the tip on a physical surface acts as a trigger too). (Color figure online)

performed the tasks by using the controller bundled with the HTC Vive and acted on its trigger to start sketching. The controller generates the sketch from its tip (Fig. 1a), so that it can be placed on physical surfaces to draw on them. With the *pen* interface, the Vive controller is replaced by a VR Ink stylus, which is tracked by the LightHouse system already used for the HTC Vive system. The pen has an analog, force-sensitive control on its tip which automatically triggers the drawing when pressed on a surface (Fig. 1b). Moreover, in case of mid-air sketching, a further force-sensitive control on the stylus's side can be operated with the index finger. Other inputs (grip and touch-pad, present in both the controller and the pen) were not used.

The experiment was designed as a $2 \times 2 \times 3 \times 3 \times 3$ within-subjects study, with *interface* (*controller*, *pen*), *modality* (*hybrid*, *VR*), *drawing plane orientation* (*horizontal*, *vertical*, *sideways*), *stroke shape* (*horizontal line*, *vertical line*, *circle*) and *stroke size* (*small 10 cm*, *medium 30 cm*, *large 60 cm*) as independent variables. *Horizontal line*, *vertical line* (in the following referred to as *u-line* and *v-line*) and *circular* shapes are illustrated in Fig. 2a, whereas the three *drawing plane orientations* and the two *modalities* are illustrated in Fig. 3.

Similarly to [2], a Latin square order was used, except for the shape dimension that was randomized; for each shape, three set of trials were performed (each one being a random permutation of the stroke sizes), resulting in a total of 324 strokes per participant. In case of sampled points more than 20 cm farther from the target, the trial was rejected and the participant asked to repeat it. The *horizontal* drawing plane was placed at 0.75m from the floor, whereas the other orientations were chosen so that the center of the stroke was at 1. 5m.

Regarding the experimental procedure and the data preparation steps, most of indications and precautions reported in [2] were implemented and followed. Participants were shown both the target stroke and its starting point until they started drawing, and were told to draw circles in clockwise direction, horizontal lines from left to right or far to near, and vertical lines from top to bottom. They were also asked to draw as quickly and accurately as possible. In the

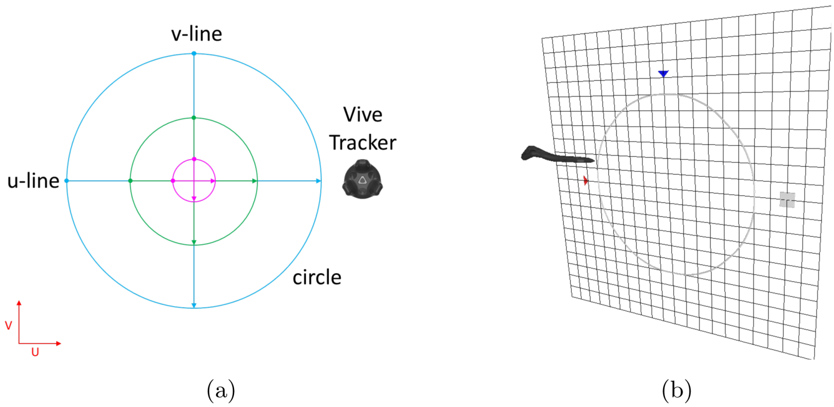


Fig. 2. Representations of a) the three *stroke shapes* (light blue 60 cm, green 30 cm, magenta 10 cm), and b) the grid provided as visual guidance during the experiment. (Color figure online)

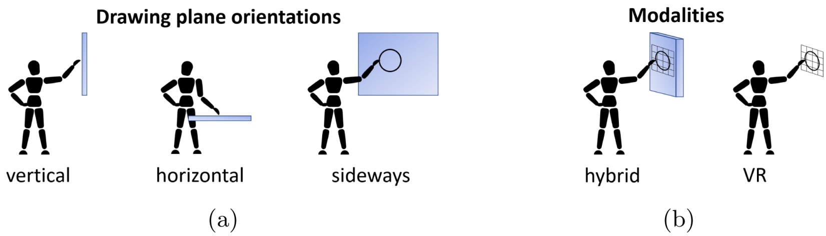


Fig. 3. Representations of a) the three *drawing plane orientations* and b) the two *modalities*.

hybrid modality, the surface was tracked by attaching a HTC Vive Tracker to it. In both *modalities*, a grid was displayed as visual guidance modality (Fig. 2b), aligned with the physical surface in the *hybrid* modality. When using the pen, participants were able to exploit the sensorized tip to draw automatically when pressing it on the surface (in *hybrid* modality), or by using the second force sensitive control when drawing mid-air (in *VR* modality).

Strokes were sampled 60 Hz, and samples were represented in local coordinates relative to the target. A median filter with a window size of 6 was applied to the sampled points; afterwards, a piecewise linear approximation was exploited to resample strokes to a set of 100 equidistant points in order to facilitate the mean stroke calculation over the three trials. Similarly to what done in [2], some of the strokes performed with the *VR* modality were characterized by small tails drifting apart from the drawing plane, either at the start and at the end of the drawing; these artefacts were due to the slight delay between the time the participant decided to start/stop drawing and the time he or she actually pressed/released the trigger.

These artefacts were removed by discarding all the initial and final samples based on their deviation from the local Z axis; in particular, samples were iteratively discarded until a sample characterized by a deviation from Z lower than the average Z deviation (over the whole stroke) was found, and that became the first sample (or the last, when removing the artefact at the end). Finally, all the strokes were processed ("translated") to align their starting point with that of the target stroke, thus mitigating the impact of positional errors caused by a misjudgment of the displayed target's position. If the starting point was previously filtered out as part of a tail, a dummy point, obtained by replacing the Z coordinate of the first point with the average Z value over the whole stroke was generated, and used as a reference for the alignment phase (and then discarded, in order to avoid deleterious translations due to particularly bad starts). As result of this, a resampled and translated stroke S is obtained, defined as a sequence of points $P_1, P_2, ..., P_{100}$ where each point is represented by a 3D vector $P_i = (X, Y, Z)$.

For the objective evaluation, two metrics were used. The first one is the *Mean Overall Deviation* that, for lines, is defined as:

$$MOD_L = \frac{1}{n}\sum_{i=0}^{n-1}\sqrt{(P_i.Y)^2 + (P_i.Z)^2} \tag{1}$$

where $P_i.Y$ and $P_i.Z$ are respectively the Y and Z components of the local position of the i-th point of the stroke, and n is the number of points on the stroke. It basically corresponds to the average deviation from the local X axis. For circles, it is defined as:

$$MOD_C = \frac{1}{n}\sum_{i=0}^{n-1}\sqrt{(\sqrt{(P_i.X)^2 + (P_i.Y)^2} - l/2)^2 + (P_i.Z)^2} \tag{2}$$

where $P_i.X$, $P_i.Y$ and $P_i.Z$ are the three components of the local position of the i-th point of the stroke, n is the number of points on the stroke, and l is the diameter of the target circle. It corresponds to the average deviation from the target circle.

A further metric was introduced to evaluate the deviation from the target shape for the *VR* modality. This metric, named *Mean Projected Deviation*, is obtained by settings the Z term to zero in the previous equations:

$$MPD_L = \frac{1}{n}\sum_{i=0}^{n-1}|P_i.Y| \tag{3}$$

$$MPD_C = \frac{1}{n}\sum_{i=0}^{n-1}|\sqrt{(P_i.X)^2 + (P_i.Y)^2} - l/2| \tag{4}$$

For the *hybrid* modality, *MOD* and *MPD* are expected to be equivalent, since the projection plane coincides with the drawing one, net of eventual tracking issues.

For what it concerns the subjective evaluation, after the experiment the participants were asked to fill in a post-test questionnaire (available for download at http://tiny.cc/ld7msz) including two sections. The first section was aimed to evaluate the usability of the two input interfaces by means of questions in the standard System Usability Scale (SUS) [8]. In the second section, participants were requested to rank the input interfaces based on a number of criteria (1 for best, 2 for worst) and to provide comments on their experience, similarly to what done in [32]. The list of ranking criteria is reported in Table 2.

4 Discussion

Results obtained by applying the evaluation criteria described in the previous section were used to compare the two input interfaces. For the testing activity, 11 participants were involved, 6 males and 5 females, aged between 20 to 61 years ($\mu = 27.91$, $\sigma = 11.55$). For what it concerns familiarity with VR sketching tools, participants would be considered as amateurs, since they reported limited to no prior experience with it.

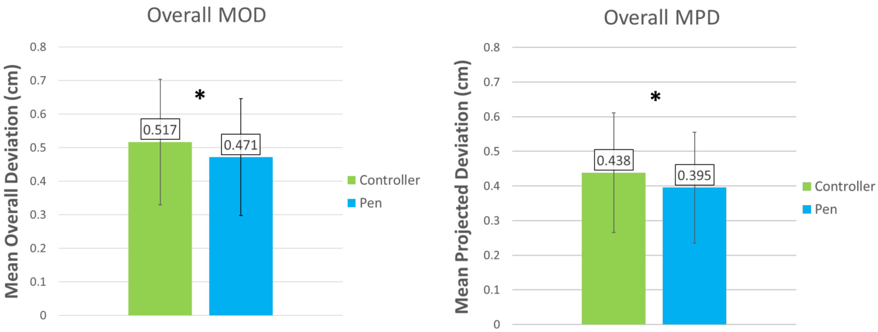
4.1 Objective Results

The overall MOD and MPD averaged among participants, strokes types, stroke shapes, and drawing orientations are reported in Fig. 4. Wilcoxon signed-rank tests for paired samples ($p < 0.05$) were used to compare *controller* and *pen*. Before applying the statistical test, outliers were detected and removed in pairs of controller-pen strokes from the same user. For example, if a controller stroke with a given modality, orientation, shape and size is detected as outlier, it is removed along with the same stroke drawn with the pen by the same user, in order to preserve the equality of the two sample sizes and guarantee applicability of the paired statistical tests. In the plots, statistically significant results are marked with the * symbol.

It can be observed that, overall, the *pen* allowed participants to obtain more accurate strokes as confirmed by the lower values achieved with this interfaces with respect to the *controller* for both the MOD (0.52 vs 0.47, $p = 0.0027$) and MPD (0.44 vs 0.39, $p = 0.0035$) metrics. It should be noted that MPD, being basically the MOD without the depth (local Z) deviation, can be helpful to spot whether the inaccuracy is simply caused by an erroneous depth perception (in such a case, MPD would be low, whereas MOD would be high).

In order to deepen the analysis, it is possible to study the two metrics aggregating their values by considering different sets of conditions. Data averaged considering the *modality* (*hybrid* or *VR*) will be presented first. Then the analysis will consider the *drawing plane orientation* (*vertical*, *horizontal*, and *sideways*) perspective. Finally results categorized by *stroke shape* and *stroke size* will be reported.

Focusing on the *modality* (Fig. 5), with the pen participants were significantly more accurate than with the controller in the *VR* modality both in terms of MOD



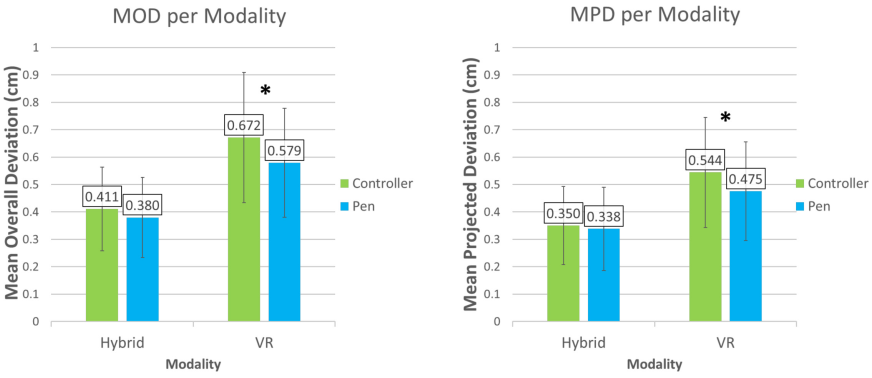
(a) (b)

Fig. 4. Mean Overall (a) and Projected (b) Deviation for *controller* and *pen*. The lower the score, the better the result. Standard deviation is expressed via error bars. Statistical significance is indicated by the * symbol.

(0.67 vs 0.58, $p = 0.0019$) and MPD (0.54 vs 0.47, $p = 0.0059$). This result was not observed for the *hybrid* modality, probably because of the presence of the physical surface, which acted as a guide for the drawing and mitigated the inaccuracies of the controller, as shown in Fig. 5 (and as already observed in [2]). The improved accuracy brought by the physical surface reduced the differences between the two interfaces, leading to more comparable performance.

An interesting result comes up when analysing results aggregated by *drawing plane orientation* (Fig. 6), where the *pen* showed its superiority with respect to the *controller* for drawing *sideways*. In fact, results obtained in [2] indicated that drawing sideways was the worst condition, with the highest values of MOD and MPD. The results of our experiments suggest that the *pen* allows participants to improve their accuracy under this condition, letting them obtain lower values of MOD (0.55 vs 0.48, $p = 0.0096$). As revealed in the comments collected after the experiment, this result could be related to the possibility to grip the pen in a more comfortable and natural way compared to the controller while drawing in this "critical" situation. The differences were not statistically significant in terms of MPD, even though the p-value ($p = 0.0554$) is close to the chosen threshold; hence, a significant difference might be found by increasing the group size.

For what it concerns the *stroke shape* (Figs. 7 and 8), it can be observed that, except for the MPD in the *hybrid* modality where the p-value was slightly greater than the threshold, participants were significantly more accurate when operating with the *pen* to draw *v-lines* in terms of both MOD (*hybrid* 0.28 vs 0.23, $p = 0.0323$, *VR* 0.54 vs 0.44, $p = 0.0112$) and MPD (*hybrid* 0.23 vs 0.19, $p = 0.0694$, *VR* 0.45 vs 0.36, $p = 0.0162$). This result could be related to how the hand controller has to be handled. In fact, as can be seen from Fig. 1 the actual shape of the controller was a source of occlusion by itself (because the tip hid the stroke origin), whereas with the pen the user were able to slightly rotate it to disalign the pen body from the stroke. When users were requested to



(a) (b)

Fig. 5. Mean Overall (a) and Projected (b) Deviation per *modality*. The lower the score, the better the result. Standard deviation is expressed via error bars. Statistical significance is indicated by the * symbol.

draw a *v-line*, the controller handle contributes to such occlusion too, possibly reducing the sketch accuracy.

Finally, regarding *stroke size*, no statistical difference was observed between the two *interfaces* for any of the three size values although, as found in [2], both MOD and MPD increased with the target stroke size.

4.2 Subjective Results

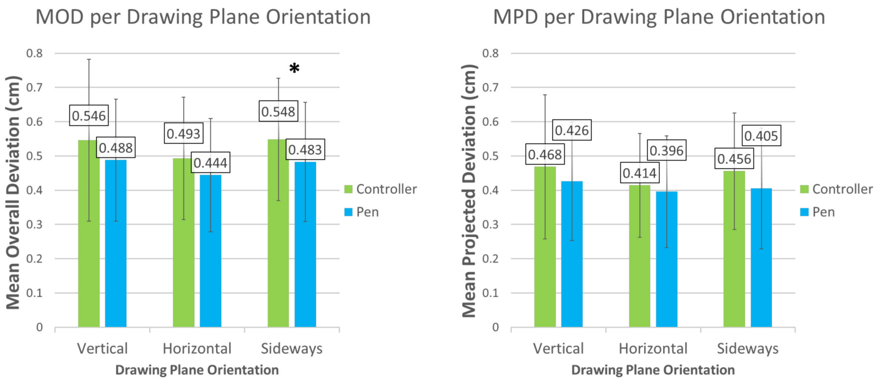
For the subjective analysis, statistical significance was tested with the same methodology adopted for objective measures.

Starting from results concerning the SUS [8] that are reported in Table 1, it can be noticed that participants perceived both the input interfaces as characterized by a high usability, with scores that were greater than 80.3 (threshold for *Excellent*). No statistically significant difference was observed between the two interfaces although, according to the categorization in [6], the *controller* was rated as grade A, whereas the *pen* obtained a grade equals to A+.

Table 1. Subjective results about overall usability according to SUS [8].

Interface	Score	Grade	Adj. Rating
Controller	82.04	A	Good
Pen	85.68	A+	Good

Regarding the preferences expressed by the participants for the ranking criteria proposed in [32], focusing only on statistically significant results it can be observed that the superiority of the *pen* already observed above was confirmed.

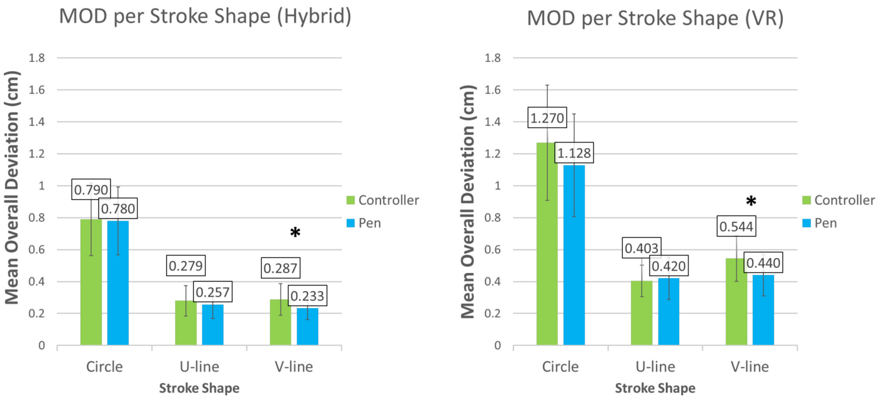


(a) (b)

Fig. 6. Mean Overall (a) and Projected (b) Deviation per *drawing plane orientation*. The lower the score, the better the result. Standard deviation is expressed via error bars. Statistical significance is indicated by the * symbol.

In fact, participants judged the VR Ink as easier to use for drawing (90.90% vs 9.09%, $p = 0.0163$), more comfortable (90.90% vs 9.09%, $p = 0.0163$) and natural (100.00% vs 0.00%, $p = 0.0163$) compared to the controller.

Comments provided by the participants at the end of the experiment could explain the reported results. In fact, the participants highly appreciated the possibility offered by the *pen* to automatically trigger the drawing when the tip touches the drawing surface. Moreover, the pose assumed by the hand to handle

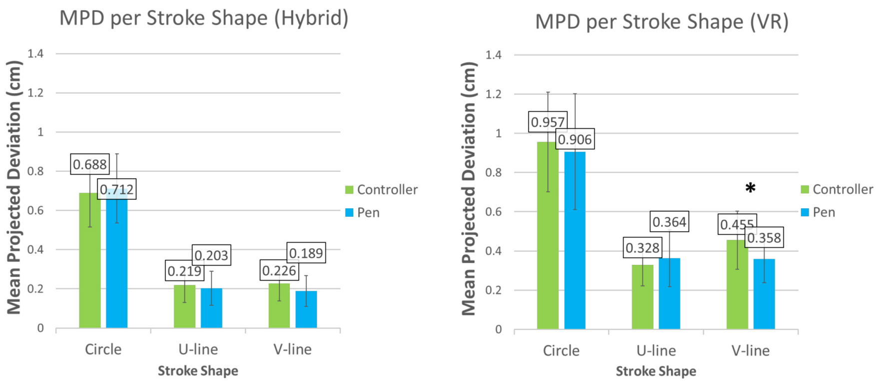


(a) (b)

Fig. 7. Mean Overall Deviation per *modality*, *hybrid* (a), *VR* (b), per *stroke shape*. The lower the score, the better the result. Standard deviation is expressed via error bars. Statistical significance is indicated by the * symbol.

Table 2. Results for the ranking criteria derived from [32], expressed as a preference between *controller* and *pen*. Statistical significance is indicated by the * symbol.

Ranking criteria	Contr.	Pen	p-value
Which interface helped to **enjoy** the sketching task best	36.36%	63.64%	0.4235
Which interface was the **easiest** for drawing*	9.09%	90.91%	0.0163
Which interface could improve the task **efficiency** best	27.27%	72.73%	0.1823
Which interface was the most **comfortable** to operate*	9.09%	91.91%	0.0163
Which interface helped you **feel** most **in control of** the stroke trajectory	45.45%	54.55%	0.7896
Which interface was the most **natural** to operate*	0.00%	100.00%	0.0033



(a) (b)

Fig. 8. Mean Projected Deviation per *modality*, *hybrid* (a), *VR* (b) per *stroke shape*. The lower the score, the better the result. Standard deviation is expressed via error bars. Statistical significance is indicated by the * symbol.

the stylus while drawing was considered much more similar to that adopted in real drawing and, hence, more natural and comfortable for long lasting sketching. There is no physical click associated with activating the VR Ink trigger for mid-air drawing. This mitigates some of the potential accuracy issues associated with the Heisenberg effect of spatial interaction [7,33]. However, the lack of this feature was lamented by a small number of participants. VR Ink includes a haptic module and in future we could imaging creating a haptic effect to provide such feedback to the participants. Regarding the *controller*, apart from an initial astonishment phase for participants who never tried the VR before, it was perceived as more cumbersome and unpractical when compared with the stylus, especially in the most critical configurations.

5 Conclusions and Future Work

In this paper, a new consumer-grade pen-shape interface for 3D mid-air sketching in VR is compared with the standard hand controller bundled with the commercial VR system the said interface was designed to be integrated with.

The experiment carried out in this work showed the superiority of the pen interface with respect to the controller from several viewpoints. In particular, the pen interface allows the users to improve the final accuracy of the sketching output in a number of conditions, in particular when no physical guidance is available (which is a common situation in VR). Moreover, participants judged the pen as the most natural, comfortable and easy to use interface.

Future works will be devoted to deepen the analysis by including in the experiments more complex drawing tasks, as well as by involving professional artists and designers in order to make the experimental conditions closer to real application scenarios. Moreover, the adherence of the user's intention with what is actually sketched could be investigated too, possibly finding a proper set of objective measures for evaluating any stroke shape.

Moreover, the development of OpenXR [31] standards also makes it much easier for application developers to create software that works across a range of platforms and with different controllers. Recent years have seen the development of a range of application software that attempts to enhance productivity and creativity in VR. However, there are many differences in designing interactions for use with a stylus grip versus the typical "pistol grip" controllers most commonly used in VR today.

Finally, as said, the use of mid-air sketching started to be applied not only for creative and artistic purposes, but also in different application domains ranging from virtual character animation to 3D modelling, etc. Thus, new tasks as well as a different set of metrics could be considered in order to investigate the effectiveness of using the pen interface in such scenarios, e.g., to create poses for virtual characters or controlling 3D modeling tools (like, for instance, sculpting and prototyping).

References

1. Arora, R., Habib Kazi, R., Grossman, T., Fitzmaurice, G., Singh, K.: SymbiosisSketch: combining 2D & 3D sketching for designing detailed 3D objects in situ. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, pp. 1–15 (2018)
2. Arora, R., Kazi, R.H., Anderson, F., Grossman, T., Singh, K., Fitzmaurice, G.: Experimental evaluation of sketching on surfaces in VR. In: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, pp. 5643–5654 (2017)
3. Autodesk® Alias CreateVR. https://www.autodesk.it/products/alias-products. Accessed 3 Aug 2020
4. Bae, S.H., Balakrishnan, R., Singh, K.: ILoveSketch: as-natural-as-possible sketching system for creating 3D curve models. In: Proceedings of the 21st Annual ACM Symposium on User Interface Software and Technology, pp. 151–160 (2008)

5. Bae, S.H., Balakrishnan, R., Singh, K.: EverybodyLovesSketch: 3D sketching for a broader audience. In: Proceedings of the 22nd Annual ACM Symposium on User Interface Software and Technology, pp. 59–68 (2009)
6. Bangor, A., Kortum, P., Miller, J.: Determining what individual SUS scores mean: adding an adjective rating scale. J. Usability Stud. **4**, 114–123 (2009)
7. Bowman, D., Wingrave, C., Campbell, J., Ly, V.Q.: Using Pinch Gloves™ for both natural and abstract interaction techniques in virtual environments. In: Proceedings of HCI International, pp. 629–633 (2001)
8. Brooke, J., et al.: SUS - a quick and dirty usability scale. Usability Eval. Ind. **189**, 4–7 (1996)
9. Buxton, B.: Sketching User Experiences: Getting the Design Right and the Right Design. Morgan Kaufmann Publishers Inc. (2007)
10. Cannavò, A., Demartini, C., Morra, L., Lamberti, F.: Immersive virtual reality-based interfaces for character animation. IEEE Access **7**, 125463–125480 (2019)
11. Cannavò, A., Lamberti, F.: A virtual character posing system based on reconfigurable tangible user interfaces and immersive virtual reality. In: Livesu, M., Pintore, G., Signoroni, A. (eds.) Smart Tools and Apps for Graphics - Eurographics Italian Chapter Conference, pp. 45–55 (2018)
12. Cannavò, A., Zhang, C., Wang, W., Lamberti, F.: Posing 3D characters in virtual reality through in-the-air sketches. In: Tian, F., et al. (eds.) CASA 2020. CCIS, vol. 1300, pp. 51–61. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-63426-1_6
13. Celozzi, C., Paravati, G., Sanna, A., Lamberti, F.: A 6-DOF ARTag-based tracking system. IEEE Trans. Consum. Electron. **56**(1), 203–210 (2010)
14. Do, E.Y.L.: Create instant 3D worlds by sketching on a transparent window. Proc. CAAD Futures **2001**, 161–172 (2001)
15. Drey, T., Gugenheimer, J., Karlbauer, J., Milo, M., Rukzio, E.: VRSketchIn: exploring the design space of pen and tablet interaction for 3D sketching in virtual reality. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, p. 114 (2020)
16. flyingshapes GmbH: flyingshapes°. https://www.flyingshapes.com/. Accessed 3 Aug 2020
17. Google: TiltBrush. https://www.tiltbrush.com/. Accessed 3 Aug 2020
18. Gravity Sketch: Gravity Sketch. https://www.gravitysketch.com/. Accessed 3 Aug 2020
19. HTC: Vive LightHouse 1.0 - Base Station. https://bit.ly/3gqovlQ. Accessed 3 Aug 2020
20. Igarashi, T., Matsuoka, S., Tanaka, H.: Teddy: a sketching interface for 3D freeform design. In: Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques, pp. 409–416 (1999)
21. Israel, J., Wiese, E., Mateescu, M., Zöllner, C., Stark, R.: Investigating three-dimensional sketching for early conceptual design-results from expert discussions and user studies. Comput. Graph. **33**, 462–473 (2009)
22. Kim, Y., An, S.G., Lee, J.H., Bae, S.H.: Agile 3D sketching with air scaffolding. In: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, pp. 1–12 (2018)
23. Kwan, K.C., Fu, H.: Mobi3DSketch: 3D sketching in mobile AR. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, p. 1–11 (2019)
24. LAB4242: PaintLab VR. http://paintlabvr.com/. Accessed 3 Aug 2020

25. Lamberti, F., Cannavò, A., Montuschi, P.: Is immersive virtual reality the ultimate interface for 3D animators? Computer **53**, 36–45 (2020)
26. Lee, J.H., Ham, H.G., Bae, S.H.: 3D sketching for multi-pose products. In: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–8 (2020)
27. Li, N., et al.: Get a grip: evaluating grip gestures for VR input using a lightweight pen. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–13 (2020)
28. Logitech: VR Ink Pilot Edition. https://www.logitech.com/en-us/promo/vr-ink.html. Accessed 3 Aug 2020
29. Pham, D.M., Stuerzlinger, W.: Is the pen mightier than the controller? A comparison of input devices for selection in virtual and augmented reality. In: 25th ACM Symposium on Virtual Reality Software and Technology (2019)
30. The Blender Foundation: Blender. https://www.blender.org/. Accessed 3 Aug 2020
31. The Khronos Group Inc.: The OpenXR Specification. https://bit.ly/33nFdiq. Accessed 3 Aug 2020
32. Wang, S., et al.: Holding virtual objects using a tablet for tangible 3D sketching in VR. In: 2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), pp. 156–157 (2019)
33. Wolf, D., Gugenheimer, J., Combosch, M., Rukzio, E.: Understanding the Heisenberg effect of spatial interaction: a selection induced error for spatially tracked input devices. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–10 (2020)