An integrated Approach to Virtual Tape Drawing for Automotive Design

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Abstract

The present paper describes a multimodal approach to authoring in immersive virtual environments. The technique for 3D curve input presented here is based on Taping, which is widely used in automotive design to create and modify characteristic lines of a model on a white board. Taping is used both at design review sessions or at model creation, in which designers fasten tape to back-projections of 3D models or on clay models. Currently, this approach requires designers to make photographs of their intended changes so they can later be transferred to the 3D CAD representation of the model. This process is time-consuming and can lead to miscommunications between designers and product engineers on how certain curves are to be interpreted. SketchAR is a multimodal immersive authoring system for Virtual Environments which uses sketching and calligraphic input as its main organizing paradigms. Within SketchAR virtual tape drawing has been integrated as a two-handed multi-modal interaction technique. Using optical tracking and multimodal interactions we have achieved a gadget-free interaction technique to input three-dimensional curves in 3D. Our approach uses passive optical tracking devices for high-precision and low latency input. Menu free interaction is accomplished through a synergistic combination of hand motion tracking and speech.

(Fig. 1 - Virtual Tape Drawing)

1 Introduction

Nowadays designers most preferred tool still is pen and paper. Though a lot of mainly young designers already started using computers, the interaction paradigm has not changed. Whether pen or tablet, or paper or paint software is used, the first sketches in the automobile design process are always perspective sketches on a 2D medium. Only after pre-selecting first concept drawings, a 3D model by using computer aided styling tools is created. Current CAS systems do not support direct 3D input. To use 2D input and output devices to create 3D models, highly trained engineers with good mathematical foundations are needed.

The 3D model evolves in collaboration between engineers, designers and customers, which is an immensely time consuming task. SketchAR's aim is to reduce the gap between perspective 2D drawings and 3D modeling by developing a 3D styling tool, which can be used by designers as intuitively as pen and paper. In general to reach this goal, there are two possible approaches. One is to create 3D curves and surfaces using 2D interfaces. The other is to create a model directly in 3D space using an immersive environment. SketchAR supports the latter. Regardless of which approach, one main drawback of CAD is the inherent mathematic nature of its operations and representations. Making the system accessible to designers means, that this characteristic has to be hidden by interaction tools as much as possible, without loosing control over the results. Though this seems contradictory, SketchAR focuses on presenting a viable solution to this challenge.
A crucial part of the collaboration between product engineers, designers and customers are design review sessions. In automotive design it is common practice to visualize a new model on a backprojection display in 1:1 scale so the customer or the management board may express changes to the design, which are then transfered to the back-projection wall by using taping to anotate the desired shape changes of characteristic curves of the car (Fig.1). Currently a picture is taken of the back-projection wall and the taped changes, so they can later be transfered to the CAD geometry of the model by product engineers. The taping technique integrated in SketchAR and presented in this paper eliminates the need for the latter procedure. Instead it is possible to anotate shape changes of curves by taping on the virtual model of the car itself and therefore add those curves directly to the CAD model to be further refined by the product engineer.

2 Related Work

In the past few years design and modeling in virtual environments has been more and more a subject of research. Starting with simple visualization systems and point-grab-and-move interaction, more complex applications are now ported to and developed for VR.
One of the first modeling applications using immersive VR technology was 3DM by Butterworth et al. [1] Stereoscopic output was realized by a head-mounted display (HMD). The modeling functionality was limited to the creation of compound objects from standard primitives like spheres and cylinders. Free-form modeling functionality was not supported. In non-immersive applications, Steed and Slater [2] have evaluated different metaphors for 3D interaction with a desktop bat (a 5 DOF device). They focused on picking and moving objects as well as on navigation through space; object creation and modification were not addressed. Chu et al.[3] are working on a multi-modal VR-CAD system. Forsberg et al.[4] have extended their SKETCH system towards 3D and use two magnetic trackers at a VT for object transformation with the non-dominant hand and 3D sketching with the dominant hand. Hummels et al. [5,6] examine the working situations of car designers and suggest a gesture-based virtual environment. Most of the gestures should be two-handed. Further research and implementation was done by Dani et al. [7]. Their Conceptual Virtual Design System (COVIRDS) explores the multi-modal use of different input streams, like speech-input, gesture-recognition and 3D I/O devices for modeling 3D objects. In Fiorentino et al. [8] presented Spacedesign, which is the predecessor of SketchAR. Spacedesign used a similar setup to the one described here and offered functions to create curves and surfaces in an immersive environment.
There have already been attempts to translate taping into a two-handed interaction technique, in particular by Buxton et al. [9] who use electromagnetic tracking to compute the position of the user's dominant and non-dominant hand. However due to the tracking system used and the fact that each tracked interaction artifact contains a button to fasten and de-fasten the tape the user is tethered, while in the solution we present in this paper, the user is completely un-tethered. In Grossman et al. [10] virtual taping is used to draw the characteristic lines of a car. For this purpose taping is used on the three faces of a cube representing side, front and top view of a car, which can be moved in depth. In SketchAR, taping can be applied to freely but accurately positionable work planes including the three canonical orthogonal planes as well as directly in free 3D space to create real 3D curves in one pass without the need to project them on a previously defined curved projection plane. This allows SketchAR to be used in AR set-ups to tape-draw on physical clay models of a car. The presented work elaborates on and extends previous work done in SketchAR on virtual tape-drawing [11]. Initially the user had to wear a taping finger artifact which would correspond to the dominant hand and use the interactive pen with the non-dominant hand to be able to tape. Fastening of the tape would be triggered by pen buttons.
In the current version and to allow un-tethered and gadget-free interaction SketchAR uses speech recognition to issue commands to control taping while remaining focussed on the design task at hand. The major companies producing speech recognition programs are IBM (ViaVoice), Scansoft (Dragon Dictate) and Microsoft (Speech

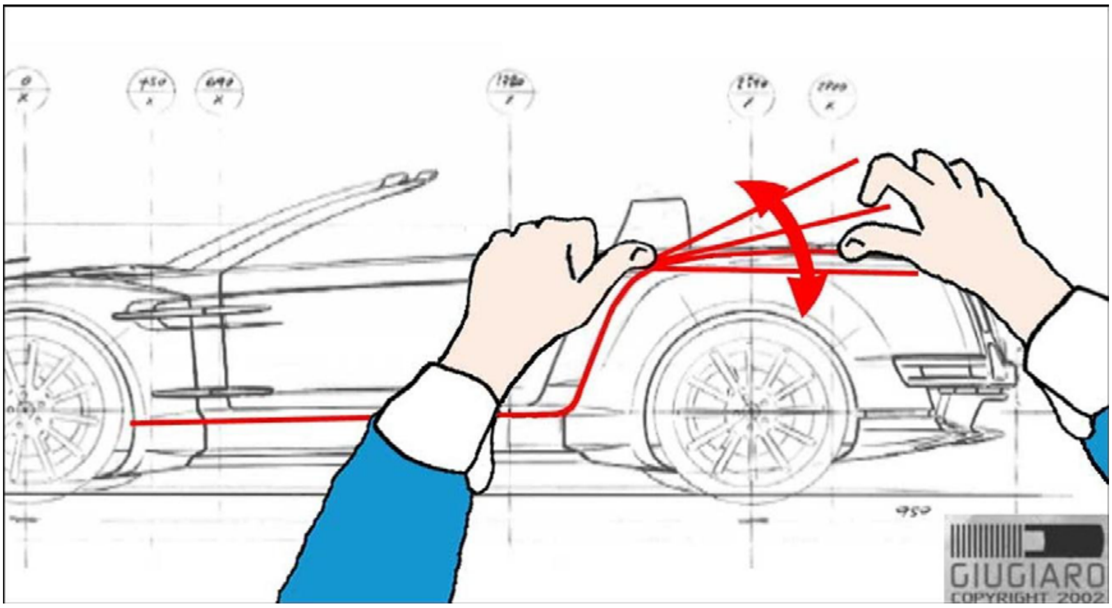
SDK). Since the functionality needed in SketchAR only requires command input and not full sentence analysis, we chose to use Microsoft Speech SDK.

3 SketchAR

SketchAR is one of the first immersive design and styling systems for early stages of product design. It is based on the following base components:

- OpenTracker: Opentracker [12] provides a unified abstract interface to many tracking systems, such as the optical A.R.T. tracking system used by SketchAR to provide gadget-free finger-tracking interaction.
- Open Inventor: Open Inventor [13] is an object-oriented library that simplifies and abstracts the task of creating graphical primitives, setting material properties, light and camera positions. Moreover Open Inventor implements a scene graph which structures and groups the objects to be rendered in a scene.
- Studierstube [14] is a software framework built on top and tied into OIV. Studierstube complements the OIV foundation with the interfaces (classes) necessary for creating multi-user, multi-tasking applications with complex 3D interactions such as SketchAR.
- ACIS Modeling Kernel: ACIS [15] is an object-oriented three-dimensional (3D) geometric modeling engine from Spatial Technology Inc. (Spatial). ACIS integrates wire frame, surface, and solid modeling by allowing these alternative representations to coexist naturally in a unified data structure, which is implemented in a hierarchy of C++ classes. While OpenInventor is used to preview the outcome of stroke and surface operations, SketchAR uses ACIS to create the final CAD model, tesselating surface geometry into polygonal mesh representations.

SketchAR itself is a multi-user application defined by the following paradigm: "users operate on shapes". The architecture is therefore organized accordingly and provides interactive curve generation, free-form surface generation, software work planes to accurately draw on and many other tools, always attempting to ease interaction by providing the user with multi-modal input capabilities including gestures, speech recognition, pie menus and pen&paper metaphors. SketchAR can be set-up for usage on a virtual table or on a back-projection system and also in augmented reality, which would allow to do virtual tape drawing directly on physical mock-ups like clay models of cars.



(Fig. 2 Tapedrawing)

4 Method

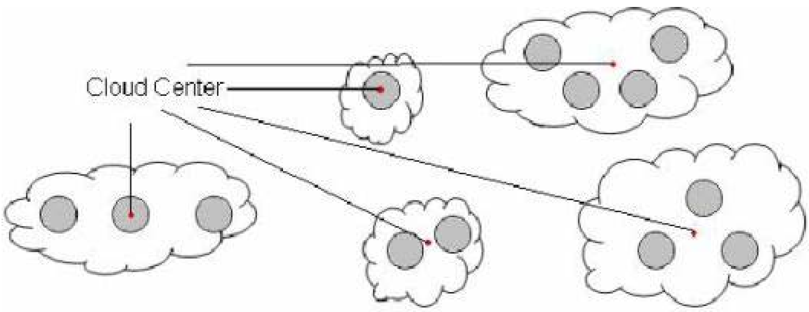
This section briefly describes the functionality of the taping paradigm in SketchAR (Fig.2). For ease of understanding the non-dominant hand fastening the tape is called the left hand and the dominant hand is further denominated as the right hand.

In SketchAR virtual tape-drawing is implemented in the following way. We have developed a finger-tracking module to track the user's both hands' forefingers using an optical tracking system. The user wears two small rings at both his forfingers. Each ring is composed of two optical markers. The finger-tracking algorithm detects groups of two markers which are not associated to geometries of markers pertaining to other tracked artifacts in SketchAR, such as an interaction pen to draw in 3D or a model artifact which controls the position of the created model. After selecting virtual tape drawing and before starting to tape, a piece of virtual tape connects both forefingers visualized by a small red and blue cross respectively.

The left hand controls the fastening of the tape while the right hand controls the tangent / direction of the tape. By simply going backwards, one can de-fasten the tape as happens with physical adhesive tape. As opposed to previous implementations start and end taping are invoked by speech and confirmation of commands is done through speech synthesis, thus not requiring additional interaction devices which would have to be manipulated by the user, since he/she is in a hands-busy and eye-busy situation [16]. Further speech commands have been added that change the colour and thickness of the tape according requests from designers during usability tests of SketchAR, which are also presented in this paper.

5 Finger-Tracking

SketchAR uses finger-tracking to identify the position of the left and right hand's forefinger. The A.R.T. [17] optical tracking system used with SketchAR is supported by an appropriate module embedded in OpenTracker, the unified abstract tracking layer. The tracking system allows detection of tracked artifacts composed of different geometries of retro-reflective markers and reports them as so called stations to this module, which in turn reports them to SketchAR. Among the stations reported may be interaction pens, model artifacts or physical work planes. In addition the tracking system will also report remaining single markers to OpenTracker if configured to do so. Therefore an additional OpenTracker module was created which is responsible for receiving the extra marker positions, computing the markers representing the left and right hand and transparently pass this information on to SketchAR as two additional stations. The process of identifying possible candidates for the left and right hand's forefingers is described here.



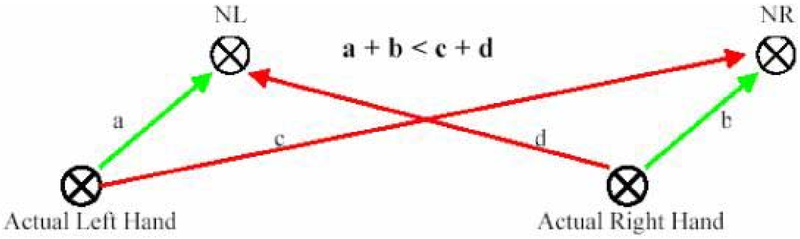
(Fig.3 - Clouds of remaining single markers)

The user wears a ring with two markers on each forefinger. The Opentracker module receives all single remaining marker positions from the tracking system and starts to create so-called clouds for each marker. If a marker is already inside the range of another cloud, it is added to this cloud and no cloud is created for it. The minimum number of markers per cloud should be two, because a cloud with only one marker can be just a reflection of environmental light or a lost marker in the room. The clouds with only one marker are then deleted as are the clouds with more than two markers. Only the position of the cloud is calculated and not the orientation as is done for the calibrated geometries of markers - the interaction artifacts - in the A.R.T. system (Fig.3).

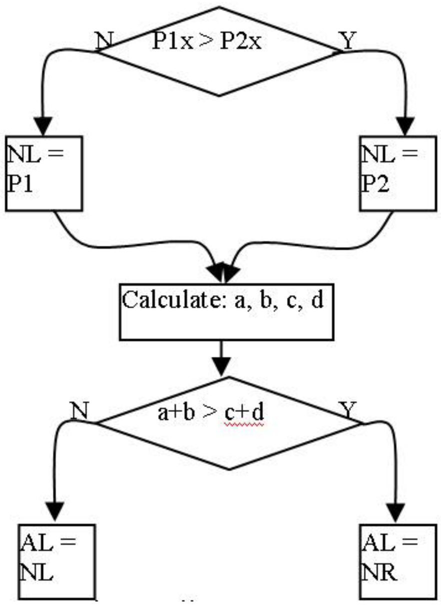
For Taping the orientation of a cloud is not important, whereas the position of the cloud defines the position of the forefingers in 3D. How to distinguish between the left hand and right hand without mixing them is described in the following section.

6 Dominant and Non-Dominant Hand

Taping in SketchAR is usually done in front of a back-projection wall from left to right, so the first step is to decide from the two cloud centers (P1 and P2) which one is more left and more right on the X-axis (Left-Right). After this preliminary identification the two candidates to new hand positions are called NL and NR, "new Left" and "new Right" respectively. Then the distances a, b, c, and d (Fig. 4) are calculated and the final test is made: If a+b < c+d then AR=NR and AL=NL, else AR=NL and AL=NR. (Fig. 5).



(Fig. 4 - Distances a,b,c and d)



(Fig. 5 - Distances Test)

This test corresponds exactly to the trivial question: "Are the hands crossed?" Note that a+b is always bigger than c+d except when the user crosses his hands.
Where,

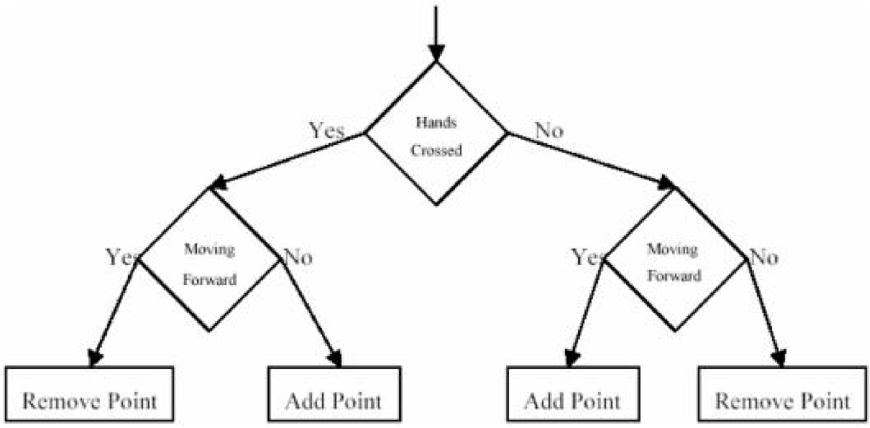
- P1 = (P1x, P1y, P1z); P2 = (P2x, P2y, P2z);
- NL = New Point Left; NR = New Point Right;
- AL = Current Left; AR = Current Right;
- a = distance between AL and NL;
- b = distance between AR and NR;
- c = distance between AL and NR;
- d = distance between AR and NL.

Looking at this test in more detail seems to reveal one singular case where it may fail. This singularity happens when the distances a+b and c+d are equal. However in practice both artifacts can never be colinear as to make this happen, since they are worn on the forefingers of two different hands. In addition if they were colinear one would obstruct the other and just one finger would be recognized(Fig.4).

7 Gesture Recognition

Gesture recognition in the taping context attempts to mimic the natural gestures made by a designer using traditional tape-drawing. When a mistake occurs the designer does not explicitely say he wants to un-fasten the tape, neither does he press a button as opposed to Grossman et al.[10]. In fact the designer simply moves his left hand back along the previous taping direction and de-fastens the tape. This section explaines in more detail how gesture recognition is implemented in SketchAR for taping purposes.

Figure 6 represents a flow diagram which describes all different possible situations that can occur while the user is taping (fastening and un-fastening the tape).



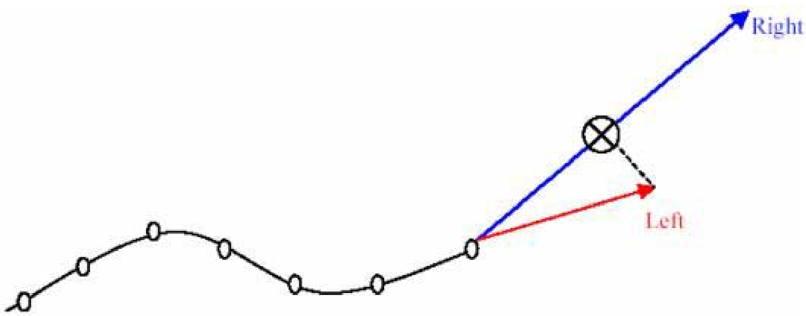
(Fig. 6 - Gesture Test)

When the user is drawing normally his hands are not crossed so the first test is false. If his left hand moves forward, he is fastening the tape, otherwise he is un-fastening the tape.

When the hands are crossed, the first test is true. If the left hand is moving backwards then it is moving in towards the right hand, so it is a "Taping" operation; otherwise it the tape is being un-fastened. The vectorial calculus used to make the tests presented above is as follows:

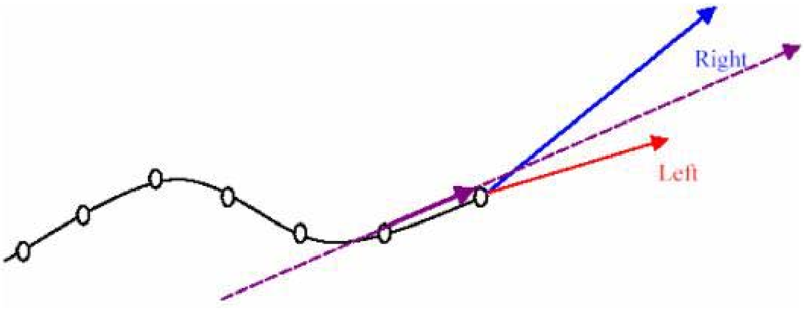
The simplest case is the taping operation where a new point is added to the line. This new point is the projection of the new left hand position in the derivate vector (right hand vector) as illustrated in Figure 7.

If the user is un-fastening the tape, the point to be deleted is always the last point of the sequence, so there is no special calculus to perform. The difficulty resides in recognizing the users' gestures to correctly perform the gesture recognition tests.



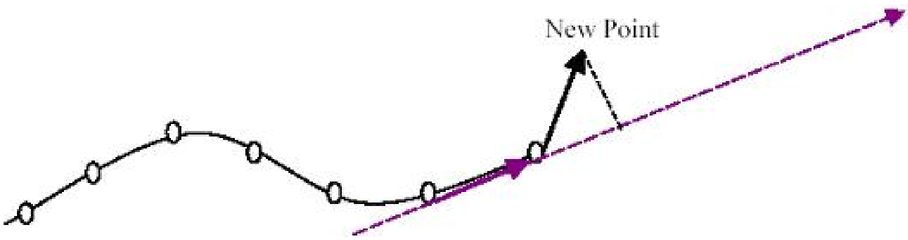
(Fig. 7: - New point)

To decide about the direction of the taping, both hands' positions must be compared. The comparison criterium is the most recent drawing direction. The most recent direction vector is colinear to the vector that connects the two last points in the sequence as shown in Figure 8.

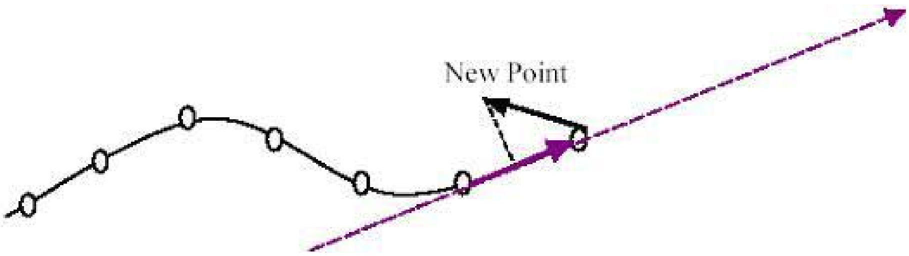


(Fig. 8 - Recent Direction Vector)

Once the recent direction vector is calculated, both hands' positions are projected on an imaginary axis with the same direction and orientation of the recent direction vector. By comparing these position in this new axis it is possible to say which hand is further ahead of the other in the drawing direction.
To decide if the left hand is moving forwards or backwards, a projection of the "hypothetical" new Point is made on the most recent direction axis. If the projection is colinear with the recent direction vector then the left hand is moving forwards, otherwise, if the direction of the projection is opposite the recent direction vector, the left hand is moving backwards. The following pseudo-code describes the test which is illustrated in Figure 9 and Figure 10.



(Fig. 9 - Fastening Tape)



(Fig. 10 - Fastening Tape)

8 Speech Recognition/Synthesis

According to Jakob Nielsen, one of the most notable human computer interaction specialists [16], "Voice interfaces will not replace screens as the medium of choice for most user interfaces." Nielsen emphasizes, that all that voice does, is let users speak rather than write commands and parameters. According to him auditory interfaces will never be able to communicate as much information as visual interfaces. Therefore usage of voice only makes sense in special cases such as the following [16]:

- "Users with various disabilities, who cannot use a mouse and/or a keyboard or who cannot see pictures on the screen. Voice output is the main way for visually impaired users to interact with computers, and because these users rely so heavily on audio presentation of information, it is very important to design Web pages with voice-only browsers in mind. "

- "Users who are in an eyes-busy, hands-busy situation. Whether or not they have disabilities, the keyboard-mouse-monitor combo fails users in these situations, such as when they're driving cars or repairing complex equipment."
- "Users who don't have access to a keyboard and/or a monitor. In this case, users might, for example, access a system by payphone."

The second scenario mentioned in Nielsen's recommendation perfectly matches the situation of virtual tape-drawing in SketchAR, where the designer is in fact in an eyes-busy, hands-busy situation. The designer is focussing on his task and does not want to be distracted from his work by habing to issue commands through interaction devices. He wants to keep his hands where they are while deciding to tape or to change the colour or thickness of the tape. This is why in SketchAR as opposed to Buxton et al.[9] we decided to use speech recognition for command input while taping to allow the designer a greater sense of freedom and preserve his creativity as well as speech synthesis to give a feed-back on the selected functionality.
To minimize errors in speech recognition, we elaborated a command-set which consists of two-word commands which were followed by a two-word reply:

- "start taping" - "taping started"
- "stop taping" - "taping stopped"
- "colour <colour name>" - "<colour name> colour"
- "thickness <thickness in pixel>" - "<thickness in pixel> thickness"

9 Usability Tests

Several tests were conducted with professional automotive designers who frequently use tape drawing. It was interesting to verify, that although most of the test candidates only had little time to get used to the system, the results were very positive. Users felt immediately comfortable with the multi-modal interaction paradigm using finger-tracking and a small set of voice commands to control virtual tape drawing. Many users emphasized the very smooth and accurate control, they would have over the curves while tape drawing on the back-projection display and being completely un-tethered. We carried out two types of tests. On one hand we wanted to now how robust the new virtual tape drawing implementation would work and on the other hand we compared the current implementation to traditional tape drawing using real tape on a board and to the previous implementation of virtual tape drawing.
The results of the first test can be found in table 1.

Duration of use	Pass (no limit found)
Number of curves in the system	Pass (no limit found)
Size of a curve	Pass (no limit found)
Presence of tracked bodies	Pass (the number of tracked and calibrated bodies does not affect the virtual tape drawing)
Light variations	Pass (the system is robust to different light conditions)
Sound variations	Fail (noise in the room may interfere with speech recognition)

(Table 1 - Robustness Tests)

To make speech recognition work as reliable as possible, a two-word command-set was defined to reduce the number of accidental recognitions. Furthermore instead of using a table-top microphone, users were given an ear-plugged combination of a headphone and microphone.
In the following we compared the performance of the traditional tape drawing using real tape to the previously implemented virtual tape drawing and the current virtual taping method. Each test candidate had one attempt at each method. De-fastening was forbidden. We measured the average approximation of the user generated lines with the different methods to the same previously given reference lines. Each user tried to tape-draw as close to the reference line as possible. Success was measured by calculating the percentage of superposition with the reference line (Table 2).

Sketch	Taping Method	Aprox (%)
Straight Line	Traditional Taping	98%
Straight Line	Previous Virtual Taping	73%
Straight Line	Current Virtual Taping	91%
Smooth Curve	Traditional Taping	92%
Smooth Curve	Previous Virtual Taping	56%
Smooth Curve	Current Virtual Taping	85%
Long Path	Traditional Taping	89%
Long Path	Previous Virtual Taping	51%
Long Path	Current Virtual Taping	81%

(Table 2 - Performance Tests)

10 Results

This paper presented a multi-modal, gadget-free approach to virtual tape drawing and integrated it into SketchAR, one of the first immersive modeling and styling systems for early stages of product design. The combined use of finger-tracking, speech recognition and synthesis, represents a major advantage in terms of usability which is summarized as follows:

- Strokes resulting of virtual tape drawing are used during the creation or alteration of a 3D model or can be added to an imported CAD model or made on top of a physical mock-up of a model in the augmented reality setup of SketchAR, thus being integrated in the model creation or review process, as opposed to traditional tape drawing on a real whiteboard. Results from those processes are saved in CAD formats.
- SketchAR supports automatic de-fastening of the virtual tape by simply going backwards with the left hand.
- Due to the user's eyes- and hands busy situation, SketchAR uses voice recognition and synthesis to invoke and confirm commands - no additional interaction devices are needed.
- Usability tests have proven that virtual tape drawing as implemented in SketchAR has been very well accepted by professional designers. Usability tests will be presented in the final paper.
- SketchAR's virtual tape drawing reduces time consuming transfer of changes to the CAD representation of a model and misunderstandings between designers and product engineers on how the designer's intention is to be interpreted.

11 Conclusion

The integration of virtual-tape drawing in SketchAR, one of the first immersive design and modelling systems, has been evaluated by professional designers and product engineers and has received a very positive feed-back as the results of usability tests confirm. Users emphasized that the combination of multi-modal input techniques helped them to fully concentrate on their task, because they didn't have to use obtrusive interaction devices to input their commands to the system. In addition, the advantage of using digital tape-drawing on loadable and storable CAD geometries helped to bridge the gap between designers and product engineers, since the latter would immediately be able to postprocess the designer's changes, therefore drastically reducing the amount of time needed with their previous methodology.

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