The SenStylus: A Novel Rumble-Feedback Pen Device for CAD Application in Virtual Reality

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ABSTRACT

We have developed a pen device for CAD applications in virtual reality which provides novel features compared to existing systems. The SenStylus consists of a wireless pen designed to be ergonomically handled by the user for spatial interaction using a six degree of freedom optical tracking. In addition to the classic digital button(s) input, it provides analog multi-axial control, and a dual-rumble feedback output. We have integrated the device into an existing virtual reality CAD environment and extended the application functionalities with new device-specific features. The SenStylus vibration feedback improves perception in the virtual world by controlling frequency, amplitude, and duration of the feedback, simulating a variety of responses during collisions and selection tasks. This capability enforces the visual depth sensitivity, which is critical when working with complex CAD models. The multi-axial analog input provides a natural interaction paradigm to the user, thus simulating pen pressure and angle as in real world sketching and in real clay modeling. Dynamic tool-tip dimensioning and shaping are implemented as extra features. We present some applications to prove the added value of the SenStylus. The evaluation of the device received positive feedback by designers and engineers alike. The new features offered by this device can easily be extended to other VR applications using the API provided.

Keywords

Virtual reality, user interface hardware, CAD, 3D interaction

1. INTRODUCTION

As established by many studies, one of the most limiting factors in desktop CAD is the use of two degrees of freedom devices for creating 3D forms. However, the use of fully 3D environments is limited by the barely explored virtual reality (VR) interface.

For an effective use of CAD in VR, several VR interaction techniques have been explored. In particular, among the many implementations, the so-called *pen&tablet* metaphor has proved to be effective in many applications [Zol97a].

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In the *pen&tablet* interface, the user holds in his/her non-dominant hand a transparent palette, on which menus and buttons are displayed; the other hand controls a stylus for application-related precision tasks.

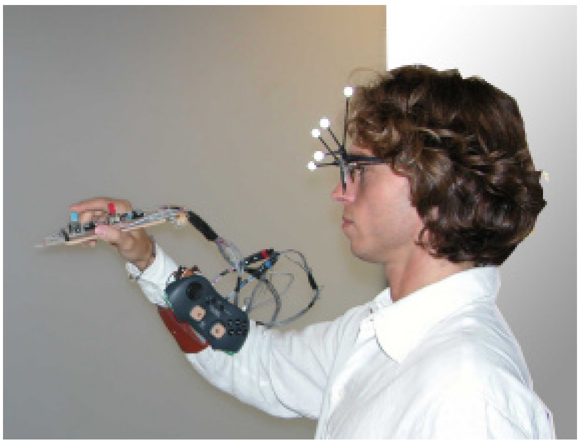

Figure 1. The SenStylus.

In spite of the widespread use of the *pen&tablet* interface both in academia and in the industrial world, none of the stylus hardware implementations fully fulfills our needs for our present and on-development applications. In addition to the classic stylus, providing six degrees of freedom (6DOF) and a few state buttons, we needed a multi-axial analog control for our VR CAD system, and a dual channel haptic feedback output.

Therefore, we decided to design and prototype a novel stylus device called *SenStylus* (Figure 1).

Our SenStylus consists of a wireless pen which is designed to be ergonomically handled by the user for spatial interaction using a 6DOF tracking.

The first goal was to offer different controls in a stylus-shaped design, including buttons, analog joysticks and sliders. The second goal was to provide haptic feedback to add further insight to virtual environments (VE).

Related Works

Spacedesign is an innovative test bed application developed by the authors to address CAD issues using virtual and augmented reality interface. Based on the Studierstube library [Sch96a] and the ACIS [Spa] modeling kernel, Spacedesign uses the *pen&tablet* metaphor (Figure 2).

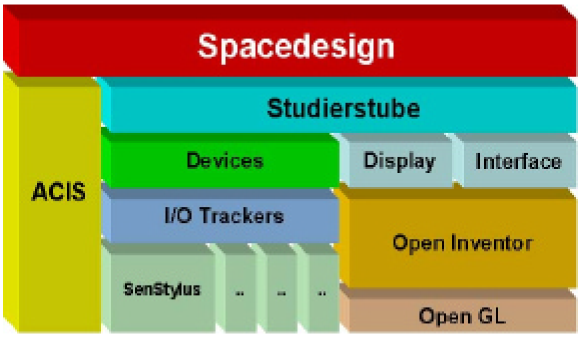

Figure 2. The Spacedesign VR CAD application architecture.

The stylus is the main input device for interaction: it is used for 3D sketching, surfacing, navigation, selection, and manipulation. The user is also provided with a virtual palette (a tracked Plexiglas sheet device) that is used to display information as well as virtual menus and buttons.

In order to improve the CAD functions using the stylus, we started a preliminary research on new available devices suitable for our stylus needs.

Some non-standard interaction devices are commercially available for entertainment and research purposes. Besides the very well known Fastrack Stylus, Fakespace [Fak] produces the NeoWand™, with eleven buttons and ergonomic design, and the Cubic Mouse™ [Fro00a]. The Cubic Mouse - a tracked cube with state buttons and rods protruding from the sides - is designed for 3D volume visualization and clipping planes control in space.

Wanda by Ascension [Asc] is a palm-sized navigation and interaction 6DOF-tracked tool, with 1 joystick and 3 buttons.

However, the 3D interaction efficiency in VE depends not only on the type of device, but also on external factors such as the type of feedback (visual, audio, or tactile), the number of degrees of freedom, and ergonomic and subjective aspects. In [Kon95a], [Lin99a], and [Lin02a], for example, it is demonstrated that the user's performance in VE can be improved with multi-channel feedback (e.g.: tactile and visual). Force-reflecting devices using exoskeletons or pantographs, such as PHANToM [Sen], provide very effective feedback, but their use is limited by their cost and cumber.

As alternative to this solution, the use of vibrating motors, like the ones in game pads or cell phones, is gaining popularity to provide inexpensive *vibrotactile* feedback [Che96a], [Oka98a], and [Cam99a]. Hughes and Forrest [Hug96a] coupled a standard desktop mouse with vibration elements and tested its application.

Logitech's [Log] proprietary *iFeel* technology, implemented in the iFeel mice, uses Immersion's Inertial Harmonic Drive engine and TouchSense API to produce vibrations in one axis. The API controls the vibration wave function through frequency, amplitude, and duration, while the hardware takes care of the rest, combining multiple effects to simulate a variety of responses, including quick pops and different textures.

In this preliminary research on devices suitable for our stylus needs, we found many products offering partial solutions, but none of them completely fulfilled our interface needs.

In the following sections, we describe the SenStylus design and some of its applications.

2. THE SENSTYLUS

Interface Design and Requirements

To exploit the VR CAD potential, users must have the possibility to improve their communication to/from the virtual environment. Our underlying idea was to maximize the number and quality of the input/output channels.

We decided that the SenStylus design had to fulfill the following requirements:

- ergonomic and lightweight (it should be held in one hand and for continuative use);

- wireless;
- vibrating feedback;
- availability of buttons, sliders, and joysticks for digital and analog input.

The SenStylus Prototype

We performed a market research on already existing products, in order to find some wireless, analog input and rumble-feedback pen-shaped device. Several products with characteristics similar to those required, especially oriented to the game industry, are available (i.e. gamepads and joysticks). Unfortunately, their shape is not optimized for VR applications, in which both hands are used independently. As far as the authors know, on the market there is no device meeting all the requirements mentioned above.

The commercial product which comes closest to our needs is the Logitech® *Wingman Cordless Rumblepad* ™.

This device supplies 2 independent vibration channels, 11 push-buttons, 5 analog controls, and 1 wireless communication on a 2GHz bus with a range of 6 meters. We decided to modify this device to obtain a first prototype of the SenStylus. In the following sections, we describe the aforesaid hardware transformation.

Ergonomic Issues

The SenStylus is designed for extensive use. Bad design and uncomfortable grasp can reduce the precision of the interaction, thus causing frustration in the user. The lack of limb support (as provided by the table during drawing) makes the 3D spatial input interaction a big issue. In fact, the VR stylus - differently from other devices like the desktop mouse - requires both power and precision grip. For this reason, weight is critical. Researches on surgical instruments show that the tool weight is a trade-off between filtering hand vibrations (heavier tools) and reducing fatigue (lighter tools). In this first prototype, we decided to split the device in two parts: the first is the stylus itself and the second is the console attached to the user's forearm.

The pen is connected to the console by a soft wire plait.

This solution removes the heavier components (wireless transmitter, battery pack, etc.) from the hand-held device. Moreover, the front buttons on the console are of easy access for the other hand.

In the SenStylus design the thumb and middle finger provide the power grip, while the index reaches the controls located on the top (Figure 3). The stylus cross-section is semi-elliptical for a comfortable grip and to permit adjustability to hand size. Both left- and right-handed people can use the device proficiently. For additional comfort, controls are rounded and covered with padded foam.

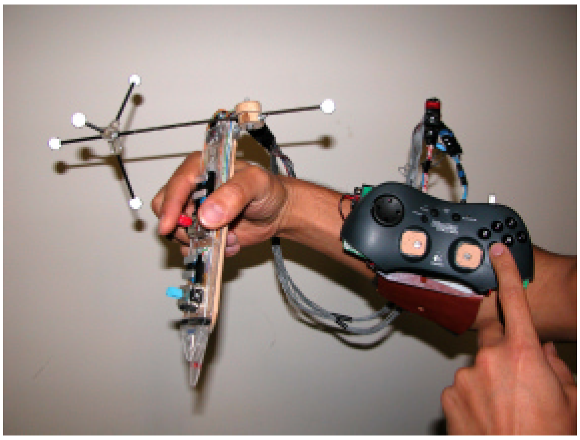

Figure 3. The SenStylus ergonomics.

In order to satisfy the ergonomic requirements mentioned above, some modifications have been made on the device based on the Wingman (Figure 4).

- The shape of the circuit board has been slightly modified for compactness reasons. The wireless transmission module has been removed and reconnected in a different location.
- Four buttons and the two joysticks have been moved from the console to the stylus in ergonomic position.
- The power supply has been modified. The original battery pack (four AA batteries) has been replaced with a single rechargeable 9V battery with tension regulator.
- The two vibrating motors have been moved from the console corners to the pen extremities.

Wireless Connection

VR devices (stylus, tablet, glasses, etc.) must be tracked in order to provide the 6DOF position and orientation necessary for the 3D input. Most of the previous generation tracking systems, such as the magnetic- and acoustic-based ones, needed a wire connection between the tracked device and the central unit. However, a completely wireless device can disclose unknown freedom to the user, who can be free to move in the VR environment without wire jams. The latest optical tracking systems provide a much higher precision in conjunction with no physical connection. Regarding input device controls, such as buttons, joysticks, etc., a wireless communication is needed not to nullify the advantage of an untethered tracking system.

Analog Multi-Dimensional Input

Apart from the 6DOF input, VR stylus devices are usually provided with simple controls: buttons, sliders, and joysticks. One single state button (on\off) is able to command simple operations (i.e. selection and navigation), but in order to be effective, more advanced CAD functions - such as shape modeling and editing - need other and more complex controls in the input interface.

Most of the devices available on the market are provided with discrete state buttons. Many applications though - such as those aimed at expressing ideas in conceptual design - go further than the on\off logic. A clear example of this is free sketching on paper, where the pressure and the inclination of the pen on the paper are used to give expression and "style" to otherwise simple and dull lines. Commonly available desktop interfaces (mouse and keyboard) do not usually gratify the designer's artistic freedom. One of the main goals we want to achieve with the development of the SenStylus is to introduce analog (thus emotional) input into a VR-based conceptual design application.

We adapted two modified 2-axis joysticks of the Logitech Wingman to provide a continuous bi-dimensional analog input. The two joysticks, that we called *indexstick* because controlled by the index finger, are located on the top side of the stylus (Figure 4), just under the user's natural index position. Some applications, especially developed to make use of the indexstick, are described in the application section.

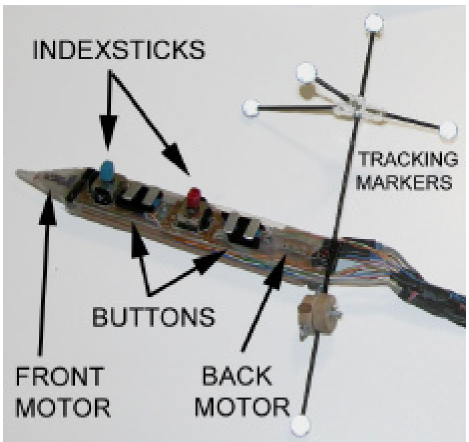

Figure 4. The SenStylus prototype.

Rumble Feedback

Virtual reality technology, by means of stereo vision and tracked point of view, provides an enhanced visualization and an improved understanding of the digital model, especially for complex models.

Although visual stimuli play the major contribution to the human perception model, experiments have shown that users are not capable of judging the added depth dimension as naturally as they do the other two. Novice and experienced VR users alike find difficulties in localizing 3D targets along the depth direction. This can be explained by the following points:

- **occlusion issues**: hand and pen can cover the image on the screen;
- **2D interface influence**: the user thinks and acts on 2D as in desktop interface;
- **attention allocation**: the user concentrates his/her attention just on the plane of the screen.

Force\Rumble feedback can be coupled with the visual stimuli to provide a better perception of the world. Many on-going studies are developing technologies for conveying force feedback in a VR environment. Unfortunately no one provided a definitive solution to issues such as complex set-ups, costs, and low user's acceptance. The vibrating feedback technology instead is nowadays rather widespread. Rumble feedback is common in game controllers, but in some applications, such as the vibrating desktop mice, it is often reported to be uncomfortable and useless.

In VR, a controlled vibration can provide rendering of different material textures or different effects (i.e. collision, snapping, etc.).

The main idea is to use two vibration sources controlled by the application and located at the extremities of the pen (Figure 4). The final aim is to test the feasibility of rumble feedback for VR CAD applications.

Our early experiments with a first SenStylus prototype, using the rumble vibrator motors extracted from the Logitech Wingman, demonstrated that the vibrations commonly used in game controllers are excessive for immersive VR use, and not well accepted during modeling, because annoying and tiring. These considerations made us modify the Wingman motors, using smaller ones commercially available in the mobile phone market.

The effect, even if lighter then the previous one, is nonetheless experienced by the user. Moreover the motor substitution (Figure 5) reduced the encumbrance, the weight, and also the power absorption, allowing us to simplify the SenStylus design.

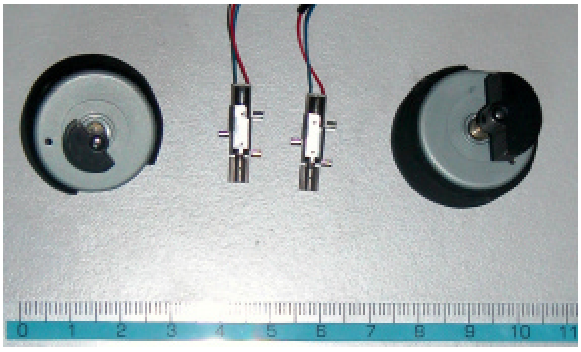

Figure 5. The Wingman vs SenStylus rumble motors.

2.1.1 Rumble effects

Since in our implementation we used two separate rumble vibrators, we can command two independent channels of feedback output. This solution allows to provide a wide spectrum of feedback effects without the need for more expensive haptic displays.

To determine the most effective waveform combination for the use in virtual environments, we tested several waveform effects, using a dedicated editor (Figure 6).

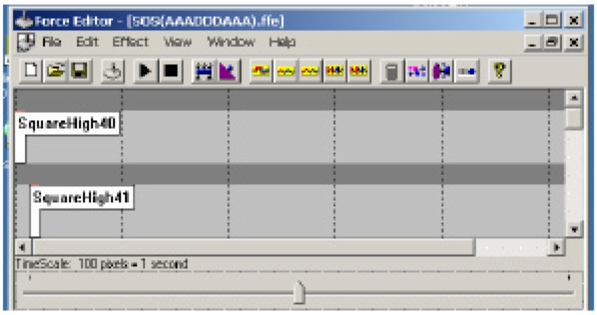

Figure 6. Effects editor.

Using the combination of simple waveforms, it was possible to create a wide list of different effects, clearly discerned by the users (Figure 7). In this way test subjects could accurately detect CAD events like collisions and snapping. Besides, by using the double channel it was possible to convey to the user direction information, such as that indicating collisions in and out of the virtual objects. Subjects could also easily associate a continuous change in the perceived vibration amplitude to a scalar value (i.e. temperature, pressure, or velocity) in a volumetric field data set.

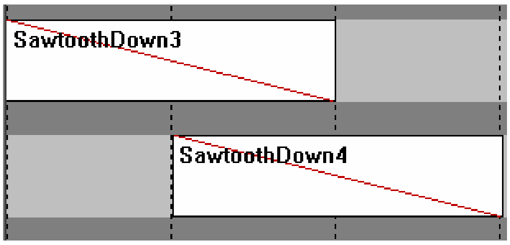

Figure 7. Example of a rumble effects wave shape in the two channels.

Some examples described in the application section demonstrate the effectiveness of vibrotactile stimulation in conveying a wide range of information in a VR CAD system. We are continuously working to develop and test several dual channel effects for a more useful feedback.

Software

Integrating the SenStylus device into the Studierstube framework, which originally has no support for analog controls and force\rumble feedback output, required some effort to preserve the existing architecture and to maintain the compatibility with the previous applications.

In order to implement these new features, the Studierstube API Tracking class was extended with analog input and rumble feedback virtual methods. Then, a new tracker class called *SenStylusTracker* was implemented.

The SenStylusTracker architecture is displayed in Figure 8: the 6DOF input (translation and rotation) of the real stylus device is acquired from the 3D input tracker (i.e. ART Dtrack), and merged with the button and control states coming from the SenStylus driver, using a Studierstube *Buttonfilter*. The SenStylus I\O resources are accessed via a DirectX-based driver.

In the input device market, mostly pushed by the gaming industry, Microsoft *DirectX* has become a standard, thus making the development of new input devices very easy. *DirectX* enables the application to retrieve from each device the features provided and to control them accordingly.

Through action mapping, the applications can retrieve input data without the need to know what device is generating it.

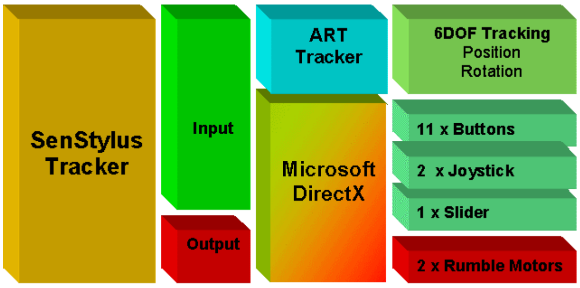

Figure 8. SenStylus Tracker.

The SenStylus tracker maps the button input into an extended Studierstube tracker architecture.

SenStylus is provided with:

- **11 x state buttons,**
- **2 x analog controls,**
- **1 x slider.**

Rumble feedback features are activated according to different modalities. These modalities can be activated by selecting one of the following functions:

- **start constant vibration,**
- **load vibration effects from file (.ffe),**
- **start custom effect,**
- **stop effect.**

The rumble control is achieved in asynchronous mode, thus in a way transparent to the application.

For each custom effect, the user can instantly control the tension applied to the motor in order to vary:

- **phase,**
- **wavelength,**
- **effect shape and envelope,**
- **offset,**
- **max amplitude,**
- **time delay\duration,**
- **axes (front or back motor).**

Effects can be designed and tested using Microsoft Force Editor (provided with DirectX SDK) saving the files as ".ffe", and then retrieving them from the application.

In the following section we present some applications where the added value of the SenStylus is evident.

3. APPLICATIONS

The SenStylus has been integrated in Spacedesign via new software modules. These modules, as described in the next section, have been specifically designed to exploit and test the innovative features provided by the new device.

Enhanced Scene Navigation

In this module we have modified the VE navigation metaphor we had been using for years in SpaceDesign. The previous system was "clutch"-based, which means that the user, by pressing a status button on the stylus, attaches the virtual scene to the tracked device until he\she releases the button. The new navigation idea was borrowed from the AutoCAD "wheeled zoom", which is very effective in 2D modeling. We added a fly-through function to the "clutch" navigation. In the fly-through function the speed is controlled by one of the indexsticks, and the direction is controlled by the orientation of the SenStylus. The swapping between the "clutch" and the fly-through modes is very fast (Figure 9). Our preliminary tests proved this solution to be very effective and more efficient for all users. We are currently working on extensive test cases to give a quantitative measure of the increased performances.

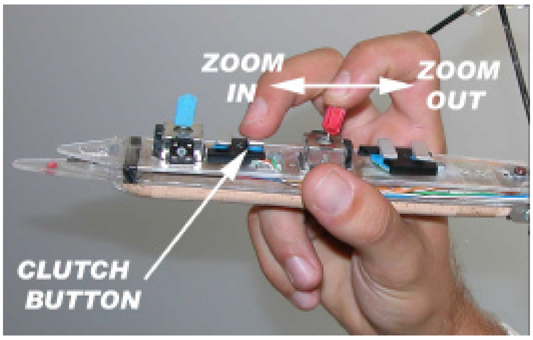

Figure 9. Enhanced Scene Navigation using the SenStylus.

Object Snap

The *3D Object Snap* is the natural extension to the 3D input of the Object Snap tools already available on most Desktop CAD systems. The object snapping can be easily extended to a 3D input in a virtual environment, where they are very useful because of the tracking error, the user's fatigue, the hand vibration, and the lack of limb support. Compared to 2D, the 3D object snapping uses a sensible volume instead of a flat region and the marker is displayed as a "wire framed" 3D geometry depending on the snapped topology (Endpoint, Midpoint, Perpendicular, Centre, etc.). With SenStylus we have added haptic effects while snapping was activated (Figure 10). The waveform of the associated effects varies according to the snapped topology. The use of a two-channel feedback can provide information about the pen movement direction towards the snap point. Another well known issue is the snap volume dimensioning: a small volume increases precision but requires more interaction time for selection, especially in complex scenes. We have used one of the indexsticks to dynamically change the sensible volume dimension interactively, according to the complexity of the model.

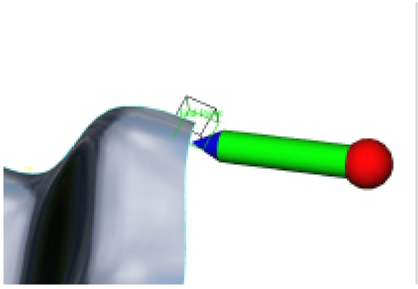

Figure 10. Endpoint snapping example.

Object Collision Feedback

We have used SenStylus dual-channel rumble capabilities to improve the user's perception of the VR model. In our tests, object selection in a VR CAD has proved to be a critical task for complex models, especially in the depth direction. Therefore, we implemented a haptic proximity sensor with two different effects (in/out). A calibrated phase shift between the two channels was used to convey the information about the approach and withdrawal direction (Figure 11).

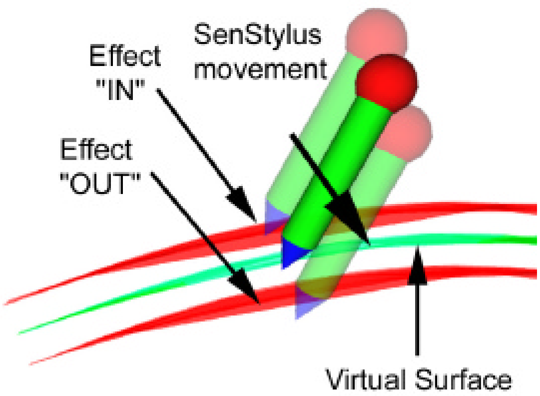

Figure 11. Dual effect collision.

Multiple DOF "Solid Line" Sketching

In this module we tested the SenStylus analog control capabilities for 3D free sketching. With this Spacedesign function the user can draw tubular-shaped lines with multiple degrees of freedom (8DOF). Basically, the user sweeps a profile along the rail drawn in the space by the stylus movement (3DOF). The cross-section is an ellipsoid whose dimensions are constantly controlled by the user with one analog indexstick. During the sweeping, the SenStylus orientation rotates the cross-section plane, in a way similar to the real-world marker pen. Tests showed positive results especially for 3D writing and logo sketching (Figure 12).

Figure 12. "Solid Line" sketching.

Haptic Probing in Volumetric Fields

Virtual reality, through effective visualization and exploration, makes it possible to gain a quick and intuitive understanding of very complex datasets. To extend the data perception in VE we augmented the graphical clues with the two haptic channels available. Moving the SenStylus probe inside the volume dataset, the intensity of the vibration is associated to a selected variable value. Using two channels we convey the instantaneous variable value to the two extremities of the stylus where the vibrators are located. In this way the SenStylus is able to simulate directionality in the feedback without using more expensive force-reflecting devices (Figure 13).

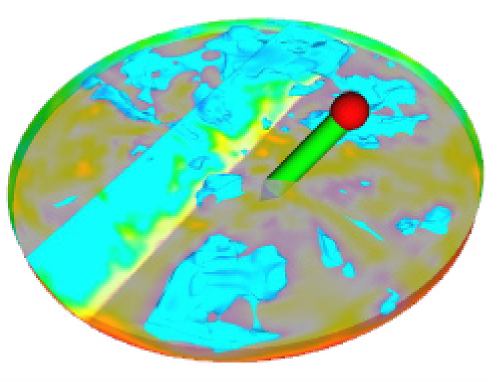

Figure 13. Dual-channel rumble rendering of a CFD dataset.

4. CONCLUSIONS AND FUTURE WORK

This work presents a novel VR device, the "SenStylus", which is expressly designed for CAD in VR. At the moment no commercially available pen-like interface satisfies in one product all the requirements for CAD interaction in virtual environment: ergonomically shaped, wireless, light weight, rumble feedback, analog input. The SenStylus prototype presented here is built using computer shop hardware. Two rumble feedback sources located at the pen's extremities can be activated separately in order to simulate a variety of responses. Analog input is provided by two dual axis joysticks, with which the user can control multiple degrees of freedom operations.

We have developed and implemented some applications especially conceived for testing the Senstylus potentials.

We plan to further test these potentials within a whole VR CAD design session in order to evaluate its global performances. Our intention is to make the SenStylus available to other VR research centers so as to have it tested in different frameworks. Beside the presented prototype, we are currently working on the redesign of the SenStylus in order to integrate all the components in one ergonomic device.

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