The CAT for efficient 2D and 3D interaction as an alternative to mouse adaptations

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ABSTRACT

We present the first usable prototype of the CAT (Control Action Table). The CAT is a 6 degree of freedom freestanding device, mixing isotonic and isometric sensing modes. It allows a group of users to interact with virtual environments by means of 3D and 2D interaction techniques. The innovating design of the CAT unifies the principle advantages of existing input devices while rejecting their main limitations. We present the resulting characteristics and compare the CAT to existing input devices. A 3D docking task experiment and a demo application have shown that the CAT can be used more efficiently than an 3D isometric desktop device and that the users preferred the CAT. The CAT is contributing to the development of real VR applications.

Categories and Subject Descriptors

I.3.1 [**Computer Graphics**]: Hardware Architecture – Input Devices; I.3.6 [**Computer Graphics**]: Methodologies and Techniques – Interaction Techniques; H.5.2 [**Information Systems**]: Information Interfaces and Presentation – User Interfaces

Keywords

Input device, evaluation, user interface

1. INTRODUCTION

The unceasing development of computer capacities, and especially graphics hardware, enables to handle more and more complex 3D interactive graphics. A similar development can be noticed for high performance display systems such as immersive projection technologies, resulting in a widespread use of 3D interactive graphics in different real application areas.

On the other hand, the development of input devices for interaction with virtual environments (VEs) has difficulties to go farther than the academic research field. They are often put aside to the benefit of simpler and better known devices, bridling the potential of 3D interactive graphics.

Whereas the mouse had been accepted as a real standard for 2D Graphical User Interfaces, none of the existing input devices has emerged as a standard for 3D interfaces. Although existing input devices have interesting characteristics, they have important drawbacks, too. For example, 2D input devices are accurate for 2D interaction tasks, but their limited degrees of freedom (DOF) make them not intuitive for many 3D interaction tasks. Flying mice (e.g. the Bat [14]) are more intuitive as they offer 6 DOF by freely moving them in space. However, they have strong limitations like the fatigue or the difficulty of device acquisition. The 6 DOF desktop devices (e.g. the Spacemouse) induce less fatigue and allow an easier device acquisition. However, these devices are hard to learn.

The CAT (Control Action Table) is a 6 DOF freestanding input device, coming from the concept of the *Anonymous-name* [7]. The name CAT has been chosen to break with the mouse and its adaptations (eg. Cubic Mouse, Spacemouse, flying mice). The CAT has been primarily designed for interaction in immersive large display environments. However, it is not limited to such systems. In this paper, we present the characteristics of the first concrete usable prototype of the CAT that is shown in Figure 1. We also present a first experiment and a demo application for the evaluation of the device. The CAT takes advantages from the benefits of existing input devices by unifying their principle advantages in a unique device while rejecting their main limitations. Many 2D and 3D interaction techniques can be used to accomplish various interaction tasks with the CAT.

The aim of the CAT is to provide an effective and efficient device for interaction by giving users the possibility to think about what they want to do rather than what they can do and how they can do it.

Section 2 describes our current prototype of the CAT. In Section 3, we recall how the CAT can be used to interact with VEs. Based on the device characteristics presented in Section 4, we compare the CAT to classical existing input devices in Section 5. The evaluation of the device is presented in Section 6. Finally, in Section 7, we conclude and

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Figure 1: Our current prototype of the CAT.

give directions to future work.

2. PHYSICAL DESCRIPTION

The CAT looks like a classical circular table. The tabletop can be oriented in space thanks to three nested rotation axes called Yaw, Pitch, and Roll. These axes are illustrated in Figure 2. The tabletop can rotate infinitely around each axis. Three angular sensors, located in the joints, enable to recover the orientation of the tabletop at any time. Moreover, the tabletop is equipped with a potentiometer allowing to recover the forces applied on it, in any 3D direction.

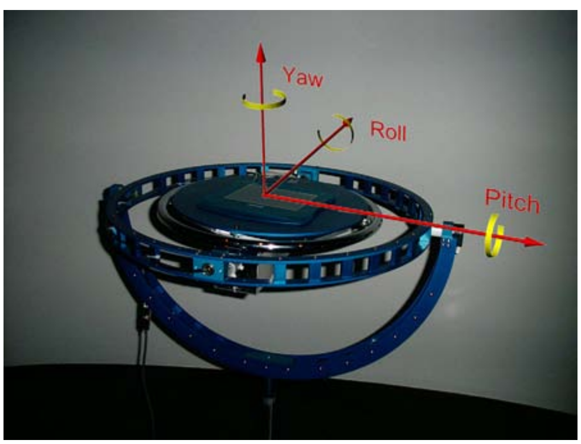

Figure 2: The CAT rotation axes.

Consequently, the CAT is a 6 DOF device that is mixing different sensing modes. The tabletop can be oriented in space without any resistance, this corresponds to an isotonic sensing mode. The tabletop does not move when forces are applied on it, this corresponds to an isometric sensing mode. Finally, a standard tablet is fixed on the tabletop. It allows to precisely recover the position of a pen on it.

3. INTERACTION WITH VIRTUAL ENVIRONMENTS

The CAT is one of the few devices enabling 3D as well as 2D interaction. We present in the following how the CAT can be used for both of these interaction modes.

3.1 3D interaction

Manipulating virtual objects in space, or controlling camera viewpoint trajectories, are 3D interaction tasks where 6 DOF have to be controlled. These tasks can be performed by means of 2D input devices. However, the limited DOF of 2D input devices make them ineffective for 3D interaction.

The 6 DOF of the CAT, associated with appropriated transfer functions, allow effective 3D interaction. The isotonic component of the CAT enables to perform rotations while its isometric component is used to perform translations in 3D environments. The transfer functions to use depend on the tasks to accomplish.

As a general rule, position control is associated to the isotonic component of the CAT, i.e. the rotations applied to the tabletop are directly mapped onto the rotations applied in the VE. Furthermore, rate control is associated to the isometric component of the CAT, i.e. the forces applied to the tabletop are mapped onto the velocity of translation applied in the VE. These associations follow the results of the experiments of Zhai [18], who has shown that isotonic devices outperformed isometric devices in position control, and isometric devices outperformed isotonic devices in rate control.

By manipulating the tabletop of the CAT, users are able to manipulate 3D objects. For example, we have implemented the *scene in hand metaphor* proposed by Ware and Osborne [15]. By mapping the orientation of the tabletop to the orientation of the 3D scene, both the tabletop and the scene always have the same orientation. Users can modify the orientation of the scene by freely orientating the physical tabletop. Rotating the scene to a specific orientation can simply be done by orientating the tabletop to the corresponding orientation. While users are applying forces to the tabletop, the scene is translated. The forces are recovered in the tabletop frame and the orientation of the scene corresponds to the orientation of the tabletop. Consequently, the scene is translated in the direction of the applied force. Hence, scene translations are coherent to user actions. The velocity of the translation is proportional to the amount of force applied to the tabletop. Figure 3 illustrates the correspondence of the orientation of the tabletop and a 3D cursor for intuitive object manipulation.

The 6 DOF of the CAT can also be used to modify the position and the orientation of the camera viewpoint. Once again, the transfer functions to associate to the isotonic component of the CAT depend on the task to accomplish. If users want to look around, position control should be preferred. In this case, the rotations of the camera viewpoint are directly mapped onto the rotations applied to the table-

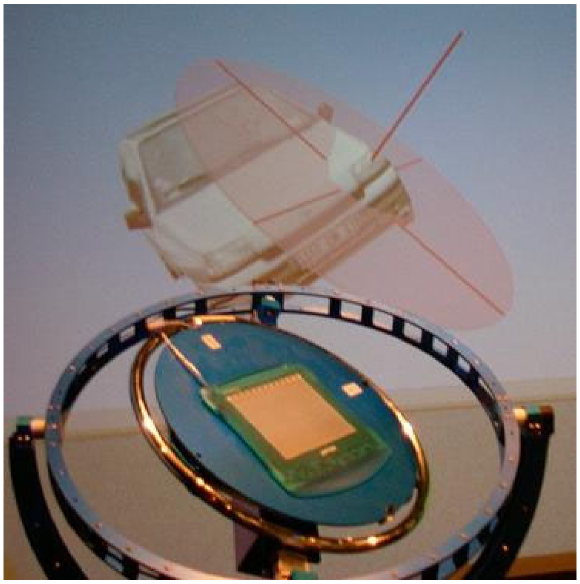

Figure 3: Object manipulation.

top. On the other hand, if users want to travel in large zones, rate control should be preferred. Associating rate control to the isotonic component of the CAT allows users to move the camera viewpoint smoother as the rate control mechanism acts as a low pass filter.

3.2 2D interaction

When dealing with 3D interactive graphics, many interaction tasks are better performed by 2D rather than 3D interaction techniques. Some interaction tasks are intrinsically 2D, as for example writing an annotation. Poupyrev et al. [13] propose to use the Virtual Notepad to handwrite in immersive VR. Some other interaction tasks are better performed when 2D constraints are added. For example, ErgoDesk [6] enables the sketching of objects from 2D input on the display surface. 2D interaction has the advantage to be accurate and to enhance user performance for some interaction tasks.

The tabletop of the CAT represents a physical workspace which can be used for 2D interaction. The tablet fixed on the tabletop precisely recovers the position of a pen on it. We propose two metaphors for 2D Interaction techniques: the *virtual tabletop* metaphor and the *virtual screen* metaphor.

The idea of the virtual tabletop metaphor is to display a representation of the physical tabletop in the 3D environment, inspired by the Virtual Tricorder [17]. We call this semi-transparent representation the virtual tabletop. The virtual tabletop is translated and oriented by means of the physical tabletop. The position of the pen on the physical tabletop is indicated by a 3D cursor on the virtual tabletop. This 3D cursor moves on a 2D plane which is oriented in 3D space. Hence, 2D interaction techniques can be used in the 3D environment. For example, translating objects on a 2D plane can be performed with higher accuracy than translating them in an unconstrained 3D space.

The idea of the virtual screen metaphor is to add a virtual screen in the 3D environment. This virtual screen can be translated in space by means of the tabletop. In contrast to the virtual tabletop, the virtual screen always faces the virtual camera, regardless of the orientation of the tabletop. Sliding the pen on the tablet moves a 2D cursor on a vertical plane. The interest of the virtual screen metaphor is to take advantages from the benefit of some well-known 2D interaction techniques used with classical monitor desktops, as for example object picking. These techniques can be performed while keeping immersed in the 3D environment. Figure 4 shows the virtual screen metaphor used for the control of an application by a 2D graphical menu.

The virtual tabletop metaphor is dedicated to constrained 3D interaction tasks (e.g. manipulation of objects or selection of 3D points), whereas the virtual screen metaphor is dedicated to interaction tasks requiring only two dimensions (e.g. writing or reading a text).

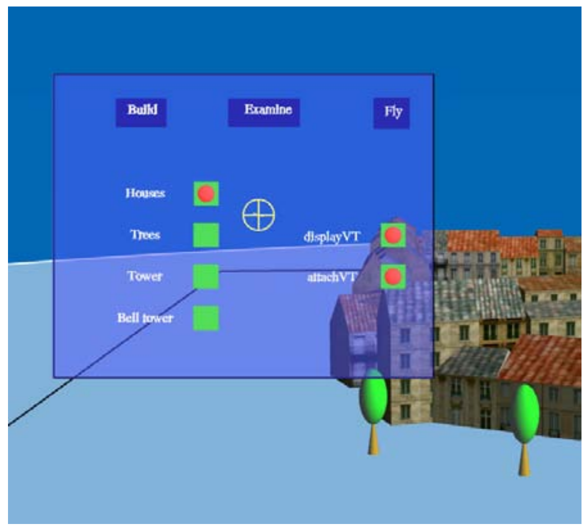

Figure 4: The virtual screen metaphor.

4. DEVICE CHARACTERISTICS

The design of the CAT is innovating, none of the existing devices looks like the CAT. In the following, we enumerate the characteristics of such a new design.

4.1 Affordances and mapping

Affordances can be seen as the possibilities that an object offers (or appears to offer) to perform an action upon it. According to Norman's recommendations [11], the mechanical construction of the CAT provides affordances. When seeing the CAT for the first time, users do not need long explanations before using it. Novice users immediately understand possible movements.

Moreover, the described interaction techniques have good mappings. For example, when using the scene in hand metaphor, rotating the tabletop to the right induces the scene to be rotated to the right with the same rotation angle. In a given orientation, pushing the tabletop translates the scene in the corresponding direction.

4.2 Feedback

The mechanical construction of the CAT provides a direct feedback concerning rotations. The angle input variables provided by the CAT correspond to the orientation of the physical tabletop. If these inputs variables are used to orient an object, both the tabletop and the object have the same orientation. Hence, users “hold” the object through the tabletop, and the CAT provides a sense of passive haptic feedback.

4.3 Constraints

The CAT tabletop provides a physical constraint for 2D interaction. Adding constraints in VEs can be very helpful as has been shown by Bowman and Hodges [2]. The virtual tabletop metaphor enables the users to move a 3D cursor on a 2D plane. This task can be performed accurately as the pen is moved on a physical surface. Lindeman [9] has experimented that adding physical constraints is increasing user performance.

4.4 Separable DOF and coordination

The DOF of the CAT can be controlled separately. For example, it is possible to modify the Yaw angle of the CAT without modifying the other DOF, and it is possible to apply forces in the tabletop plane without applying force in the normal direction of this plane. Certainly, the 6 DOF of the CAT can also be controlled at once with a good coordination, as we will see in the evaluation section.

4.5 Device acquisition and location persistence

The freestanding construction of the CAT allows an easy device acquisition. Moreover, the CAT is a location persistent device, i.e. its physical state does not change when released. These characteristics make the user not dependent from the device. The CAT can be used in collective applications, as every user can easily acquire the device. When released, the physical state of the CAT does not change, and therefore, the continuity of the application is ensured.

4.6 Fatigue

Fatigue is an essential component that needs to be taken into account for a prolonged use with real applications. As the CAT is a freestanding device, the users do not have to carry anything. The CAT can be used during a long period with reduced fatigue, as the tabletop gives the user a physical support.

4.7 Input variables

The CAT provides input variables within a short time lag. Hence, the response of an action is immediate and the use of the CAT is comfortable according to MacKenzie and Ware [10], who have shown that lag is a determinant concerning human performance in interactive systems.

4.8 Environment invariance

The CAT can be used with different display systems for different kinds of applications. Indeed, the real environment can be either visible or not, and the display can be either stereoscopic or monoscopic. Moreover, the CAT can be used for different tasks within different ranges of virtual space. Finally, the CAT does not produce interferences and is not sensible to them. Hence, it can be used in addition to other devices.

4.9 Limitations

Some limitations are induced by the design of the CAT. Even if any rotation is theoretically possible with the CAT, some few of them are hard to perform, because of the nested axes of rotation. We hope making these rotations easier to perform by improving the mechanical structure of the device. Concerning translations, some of them can be performed without any difficulties, but others are performed with a reduced comfort due to ergonomic considerations. For example, it is easier to apply translations when the tabletop is in its horizontal plane rather than when it is oriented with 90 degrees to left. Consequently, the CAT is used more comfortably in some orientations, in which the users' arms allow to apply translations without any difficulties.

5. THE CAT COMPARED TO CLASSICAL EXISTING INPUT DEVICES

The CAT inherits several characteristics of existing input devices. The integrated standard tablet is a 2D input device. The isometric component of the CAT brings it close to 6 DOF desktop devices, and its isotonic component brings it close to flying mice. The physical tabletop, which is oriented in 3D space, brings the CAT close to tracked tablet and pen based devices.

5.1 2D input devices

2D input devices, such as the mouse, are very efficient when performing 2D tasks. Systems based on laser pointers [12] and systems based on handheld computers [16] have been developed to adapt the mouse to large displays. Generally, a very short learning period is necessary to use 2D input devices for 2D interaction techniques with speed and accuracy. The tablet of the CAT takes advantages of the benefit of 2D input devices for 2D interaction.

One of the disadvantages of 2D input devices is the limitation to 2 DOF making some 3D interaction tasks hard to perform. The CAT goes without this limitation. Moreover, the majority of interaction techniques used with 2D input devices are based on the interpretation of a cursor position on the screen. The presence of a cursor on the screen is disturbing when using immersive technologies. Moreover, the use of stereo viewing makes some cursor-based techniques unusable. The interaction techniques we use with the CAT are not dependent on the screen, allowing to stay immersed in the 3D environment.

5.2 6 DOF desktop devices

6 DOF desktop devices are isometric devices allowing to control 6 DOF at the same time. Among these systems, we state the Spacemouse and the Spaceball. According to Zhai [19], isometric devices induce less fatigue, allow a faster acquisition, are location persistent, increase coordination, and allow smoother movement. The CAT has been designed to take advantages from these benefits.

On the other hand, isometric devices are hard to learn, suffer from a lack of feedback, and moreover, it is quite impossible to operate on one of the DOF without operating on the others. The orientation of the tabletop gives a strong feedback to the user. Every DOF can be controlled separately. We will see in the evaluation section that users find the CAT easy to learn.

5.3 Flying mice

Flying mice, as for example the Bat [14], are isotonic devices. They are generally instrumented with magnetic trackers for 6 DOF sensing. Zhai [18] has shown that these devices are easy to learn. They tend to outperform other types of input devices in speed, particularly for novice users. The isotonic component of the CAT makes it easy to learn. Indicating an orientation to the system can be done with speed.

The CAT is not concerned by the disadvantages of free input devices. These disadvantages are the fatigue induced by a prolonged use, the difficulty of device acquisition, the limited movements, and the lack of coordination. Free input devices are well suited to operate only within a reachable virtual space. As the CAT is not dependent on the length of the users' arms for the translations, it can be used in various range of spaces.

5.4 Tracked tablet and pen based devices

Tracked tablet and pen based devices use tracked physical surfaces to allow 2D interaction while keeping immersed in the 3D environment. For example, Coquillart and Wesche [4] use the Virtual Palette to operate in a semi-immersive environment. All the interaction techniques used with the tablet and pen based devices can be adapted to the CAT.

On the other hand, contrary to the CAT, tracked tablet and pen based devices are generally used by one head-tracked user. Therefore, these systems are not adapted to collective applications. Moreover, the user has to carry the physical support, which can become tiring and cause problems of stability. The CAT avoids this problem by providing a physical support for the tablet.

5.5 Other devices

Other devices can hardly be compared to the CAT. This is the case for gesture recognition (gloves or video based systems) or speech recognition, see for example Bolt [1]. This is also the case with task-dedicated devices as for example a steering-wheel which has been conceived for the drive metaphor.

Force feedback systems are indispensable for some applications, see for example Brooks et al. [5]. However, their use is complex and constraining. Even if the CAT has not been designed to provide force feedback, its mechanical construction allows to add a partial force feedback system.

6. EVALUATION

6.1 Experiment

We conducted an experiment to investigate the user performance with the CAT for an accurate 3D docking task. We made the hypothesis that the current version of the CAT is at least as efficient as a 3D isometric desktop device. We chose the Spacemouse as a popular representative for the 3D isometric device. In the evaluation we examined the completion time, the error rate, and the coordination of the subects. Moreover, by means of questionnaires, we made a qualitative evaluation of the users' preferences between the CAT and the Spacemouse.

6.1.1 Apparatus

The experiment was conducted using an SGI reality center consisting of a 10x3 meters curved screen, three high resolution video projectors, Crystal Eyes shutter glasses, and an Onyx2. The application was developed with OpenSG and runs with stereo vision. During the experiment, the currently used input device was located in front of the center of the screen.

6.1.2 Task

Subjects were asked to superpose a source chair with a semi-transparent target chair as illustrated in Figure 5. They were asked to superpose the two chairs as quick as possible. At the beginning of each trial, the source chair appeared in the center of the 3D space while the target chair appeared in a randomized location and orientation. When the location and the orientation of both the source and the target chair were identical besides an error tolerance, the color of the target chair changed. If the source chair stayed in the tolerance volume during 0.5 seconds, the trial was deemed completed with success.

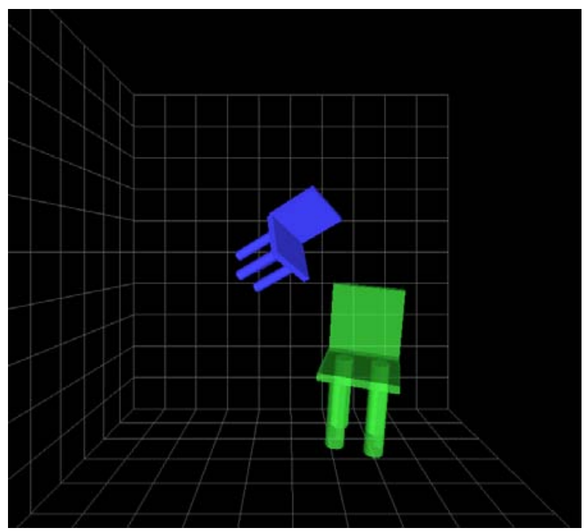

Figure 5: 3D docking task.

6.1.3 Procedure

16 subjects completed this experiment (11 males, 5 females). None of them had prior experience with using 6 DOF input devices. All were students between 20 and 25 years of age. After a short demonstration, subjects were asked to perform the task during almost half-an-hour with each device. In order to avoid the order effect, 8 subjects began with the CAT and the other 8 began with the Spacemouse. Every 5 minutes, a measured test occurred, resulting in 5 tests ($T1 - T5$) by subject and by device. A test consisted of 8 trials where the target chair appeared in each of 8 pre-set locations and orientations.

Table 1: Experiment's results

	T1	T2	T3	T4	T5
Time (sec.)					
CAT	12.60	9.62	8.02	6.64	5.67
Spacemouse	11.62	9.69	7.64	6.16	5.21
	t(15)=.652; *NS*	t(15)=-.052; *NS*	t(15)=.364; *NS*	t(15)=.591; *NS*	t(15)=.654; *NS*
I^{trans}					
CAT	1.94	1.39	1.06	.70	.73
Spacemouse	2.81	2.14	1.62	1.27	.93
	t(15)=-3.176; **p=.006**	t(15)=-2.46; **p=.027**	t(15)=-3.055; **p=.008**	t(15)=-3.912; **p=.001**	t(15)=-1.502; p=.153*NS*
I^{rot}					
CAT	2.64	2.43	2.19	2.13	1.85
Spacemouse	3.09	2.56	1.98	1.85	1.80
	t(15)=-1.607; *NS*	t(15)=-1.752; *NS*	t(15)=1.181; *NS*	t(15)=.955; *NS*	t(15)=.198; *NS*
$I^{trans-rot}$.					
CAT	2.79	2.55	2.29	2.22	1.94
Spacemouse	3.13	2.58	2.00	1.87	1.79
	t(15)=-1.135; *NS*	t(15)=-.092; *NS*	t(15)=1.689; *NS*	t(15)=1.178; *NS*	t(15)=.51; *NS*
Error rate					
CAT	.22	.39	.37	.37	.39
Spacemouse	.41	.34	.39	.42	.33
	t(15)=1.858; *NS*	t(15)=-.574; *NS*	t(15)=.312; *NS*	t(15)=.531; *NS*	t(15)=-.723; *NS*

6.1.4 Results

The paired t-test was performed to determine if there is a reliable difference between the performance of users for the CAT and the Spacemouse at a significance level of $p = .05$. We compared the completion time and the error rate, as well as the coordination which we based on the inefficiency quantification proposed by Zhai and Milgram [20]. The inefficiency I can be described as the ratio $\frac{l-d}{d}$ between the length l of the trajectory covered by the subject and the shortest distance d separating the source from the target. We measured the translation inefficiency I^{trans}, the rotation inefficiency I^{rot}, and the inefficiency $I^{trans-rot}$ in the *translation-rotation* space. Table 1 summarizes the obtained means and the statistical significances.

Users statistically have the same completion times with the CAT as with the Spacemouse. Whereas some trials have been completed in a short time with the CAT, others have been completed slower. We think that this is due to the limitations for the translations and rotations discussed in the limitations section. We believe that though the CAT is not faster than the Spacemouse on the average for accurate 3D docking tasks, it can be used with higher speed for more general interaction tasks, as for example examining 3D models from different viewpoints. These interaction tasks will be evaluated in further experiments.

Subjects performed more coordinated translation movements with the CAT than with the Spacemouse during the twenty first minutes as shown by the tests $T1$ to $T4$. Figure 6 shows the obtained results. This can be explained by the fact that the design of the CAT allows to act on some degrees of freedom without acting on the others. For example, users can translate an object in the X-Y plane without changing its Z information, which is not easy to perform with a Spacemouse. Consequently, the CAT reduces the unwanted extra translations, resulting in more coordinated movements.

Zhai and Millgram showed in [20] that whereas the users of free moving devices (position control) had shorter completion time than the users of elastic rate controllers (rate control), their movement trajectories were less coordinated. Consequently, as we found that the users had better per-

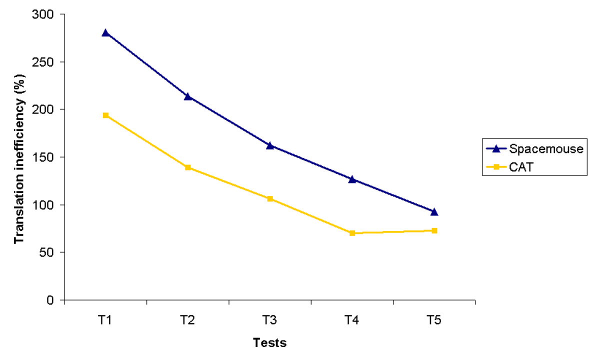

Figure 6: Mean translation inefficiency over time.

formance in translation with the CAT than with the Spacemouse, we can make the hypothesis that the CAT can be used in a more efficient way than the free moving devices in 3D docking tasks.

Concerning rotations, users apply as coordinated rotations with the CAT as with the Spacemouse, though the rotations for the CAT operate in a position control mode. Once again, it can be explained by the fact that the tabletop can be oriented in a given orientation without unnecessary rotations. Moreover, contrary to the free moving devices, the applied rotations are not dependent on the human joints coordination, resulting in more coordinated rotations.

Finally, the experiment showed that the performance of users is statistically the same with the two devices in the *translation-rotation* space. The identical error rate means permit to conclude that the CAT is as accurate as a Spacemouse.

The obtained results have to be qualified by the fact that, in contrast to the Spacemouse, the CAT is not in its final version. By making its structure more lightweight and by improving the sensibility of the sensors, we hope to obtain a higher performance for future versions of the CAT.

6.1.5 User preferences

After the experiment, we ask the users to answer a questionnaire to know their feeling about the different devices. Subjects were asked to compare the CAT to the Spacemouse. For each question, they had to decide which device they prefer. Figure 7 shows the obtained results.

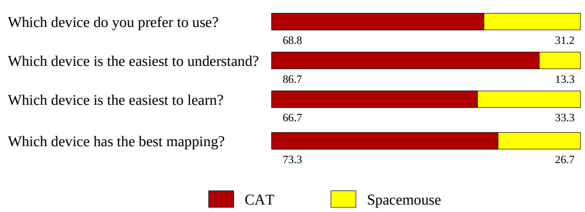

Figure 7: Questionnaire results

The main information that can be extracted from the questionnaires is that the majority of subjects preferred using the CAT rather than to use the Spacemouse. The subjects found the CAT easier to understand and to learn than the Spacemouse, and found that the mapping is better when using the CAT. This can be explained, at least partly, by the feedback provided by the orientation of the tabletop.

6.2 Application

In addition to the described experiment, we evaluated the differences in use between the CAT and a Spacemouse in an application of an interactive theater. This application enabled us to highlight some advantages of the CAT.

In collaboration with a theater company, we have put on a play using a large display environment as an interactive scenery. During the play, actors travel with the audience in and over a virtual city, according to the audience requests. In this part, the actors must have the possibility to easily travel in complex and smooth trajectories. Hence, we initially decided to use a 6 DOF desktop device.

The first version of the play has been acted with a Spacemouse. Several disadvantages have been highlighted with this device. First, days of practice had been necessary before the actors managed to use the Spacemouse effectively. Second, software constraints had to be introduced for the different tasks. For example, some constraints were applied when the actors were driving in the city, then by pressing a button on the Spacemouse, other constraints allowed them to fly over the city. Because, the actors had difficulties to land, a button was dedicated to activate an automatic landing process. Finally, a button was used to re-initialize the camera viewpoint as the actors usually lost the scene.

The current version of the play is acted with the CAT. We associate rate control to the Yaw axis of the CAT and position control to its Pitch and Roll axes. Very little time has been necessary before actors managed to travel in complex trajectories. No software constraints are necessary anymore. Thanks to the separable DOF of the CAT, actors can drive inside the city, then take off to fly over the city, and land to drive again. The actors do not get lost anymore as the orientation of the tabletop provides a strong feedback of the camera viewpoint orientation. The actors are not physically linked to the CAT. At any time, they can stop using the device to play with the audience. Then, they can use the CAT again with an easy device acquisition.

7. CONCLUSION

This paper presents the first concrete usable prototype of the CAT for interaction with VEs. The CAT takes advantages of the benefits of different existing input devices while rejecting their limitations. We showed that it can be used more efficiently than a Spacemouse for a 3D docking task, and that the user preference is in favor of the CAT. In addition to 3D interaction, 2D interaction techniques can be used with the CAT for system control or object selection. These techniques can be used while keeping immersed in the VE.

The CAT has been primarily designed for immersive large display environments. These systems are usually underused because of the difficulty to interact with 3D environments. For example, Buxton [3] has noticed that the potential level of interactivity of large displays has not been fully exploited in automotive design. He states that the limitation comes from the unadapted standard desktop input devices.

The contribution of the CAT is to provide effective, efficient, intuitive, accurate, sensitive, and non-constraining interaction. We think that the CAT has a high potential for real applications.

For instance, the CAT can be used for complex CAD applications. In addition to control the view to the model, accurate manipulations can been performed by means of the tabletop. For example, rather than trying to directly position an object in the 3D space, it can be better to first, choose a translation plane and then, translate the object in this 2D plane with speed and accuracy. Another application field concerns volumetric applications. By moving the virtual tabletop inside the data, users can manipulate cutting planes. This kind of use can be very helpful for medicine applications, as has been investigated by Hinckley et al. [8]. The continuity of the applications is ensured even when the user changes, thanks to the location persistence and the ease of acquisition of the CAT.

Our current prototype works well. However, we continue to improve the mechanical and electronical aspect of the device. We plan new experiments to complete the evaluation of the device, especially for navigation tasks.

8. ACKNOWLEDGEMENTS

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