Design for Accessibility: Enabling a Motion-impaired Artist to Control a 3D Virtual World

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1 Introduction

The application of 3D virtual worlds is not restricted to immersive or desktop virtual environments. Concepts and techniques that became mature in Virtual Reality applications are now finding their way in artistic performances. This paper presents an example of the mutual inspiring effect of art and technology, where the origin and nature of technology itself is used to come to a new artistic solution and language. More specific, we describe our approach to give a disabled person the opportunity to play a major role in artistic performances. In the end, the performance should not only be appealing for the attendance, but especially for the actors involved in the show. The wheelchair of the motion-impaired actor is enhanced by non-intrusive technology, allowing him to navigate in and interact with a 3D virtual world. This way, he controls the performance by determining the images perceived by the attendance. The intriguing 3D virtual worlds are presented to the public via a projection system.

Universal accessibility of computer applications nowadays gets a lot of attention in the HCI community. Tools and techniques have emerged that enable persons with particular handicaps to access common software. Of course it is justified to support professional tasks, but the quality of life depends not only on serious software applications. Beyond that level of accessibility are opportunities in personal development, entertainment etc. Continuing on that path, we realised our solution that enables the disabled actor to be an active player. This solution will be described from a usability as well as a technological point of view.

The next section provides the necessary background of the "Icarus man-o-war" artistic project, which is the context of the accessibility design. In the remainder of

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this paper we present the design considerations and explain hardware and software issues of the current realisation. Topics with regard to the user's satisfaction are mentioned. Possible improvements and extensions to the system are suggested.

Up to now we are not aware of any project combining virtual reality and theatre in a similar way, and allowing a motion-impaired artist to play a dominant role in creating the performance. Especially the imaginative 3D-ribbon scenes provide the artists and actors (with whom we closely collaborate) with powerful means to explore new forms of drama, and to play with pain and pleasure of the human mind. Related work on highlighted aspects are mentioned in appropriate sections.

2 The "Icarus man-o-war" Artistic Project

'Icarus man-o-war' is an artistic project intended to experiment with 3D virtual worlds in a theatre. The set-up in the theatre is shown in Figure 1. The images of the 3D virtual world are projected behind and onto the platform, on four big projection screens.

The "Icarus man-o-war" project is concerned with several aspects of the artistic performance such as the overall concept of the performance, image generation and projection, and relating actions of the physical actor to the virtual world. Details for most of these issues are beyond the context of this paper, where we focus on interfacing the motion-impaired actor to the 3D virtual world.

The actor moves around on the platform, in front of the projection screens. The movements and actions of the actor are used as input for the virtual world being displayed. Movements of the physical actor are translated to navigation in the 3D virtual world, thus changing the images that are shown to the attendance. The experience for the public is based on the simultaneous perception of the 3D virtual world and the physical actor controlling it.

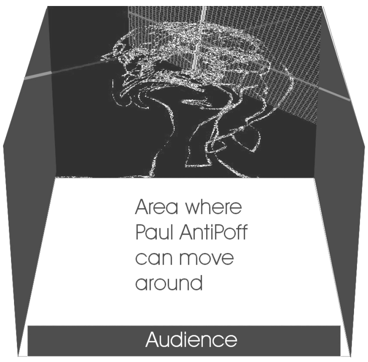

Figure 1. Sketch of actual set-up on stage. The room was too big to take a picture.

A particular kind of imagery is used to create the virtual worlds. All scenes are composed of ribbon-like structures. An example of such a scene representing a head is shown in Figure 1. Obviously, the images built with ribbon-like structures leave room for the spectator to fill in the details using his/her imagination, and therefore involve the spectator in composing the overall story.

Precomposed ribbon scenes allow the actor, and with him the attendance, to exploratory navigate in the virtual world to get insight in the 3D structure. Real-time addition and editing of the scenes is also possible. The modelling part of the software is based on Microscribe-3D (Microscribe) input devices, providing the artist with natural interaction for sketching in 3D. Microscribe-3D is based on a mechanical tracker and is for instance used in other projects to scan 3D clay models.

For more detailed information regarding the creation of the 3D-ribbon scenes for the virtual worlds, intuitive modelling tools using the Microscribe input devices and the integration of the scenery in the theatre we refer to (De Weyer *et al.*, 2001).

3 Designing for Accessibility

3.1 The Design Challenge

One of the artists involved in the “Icarus man-o-war” project is Paul Antipoff, see Figure 2, who is disabled after getting a rare muscle disease. He can only move his neck and his head and is thereby totally dependent on his wheelchair. We took the challenge to enable Paul to be as actively involved in the performance as other, not disabled actors are. In particular we want him to navigate the 3D-world of ribbons and drive his wheelchair at the same time.

It is obvious that in this situation a special purpose design for accessibility is envisioned. In everyday life Paul uses a joystick, steered by his chin, to drive around his wheelchair or to adjust the position of his chair. Besides the joystick he disposes of two buttons that are pressed with his tongue. So in order to let him navigate through the 3D virtual worlds of “Icarus man-o-war” we confront ourselves with the following design problem: design a system that links Paul’s everyday way of moving around with navigation through the 3D-world, and that is non-intrusive (it may not inhibit his moving around or introduce too much additional equipment). In the remainder of this section we explain our design for accessibility under the aforementioned conditions, and in the next section we explain the system that results from this design.

Figure 2. Paul Antipoff in wheelchair

3.2 Design Considerations

We will describe the design considerations and technology selections that gradually resulted in the current system design. Our design approach for accessibility is similar to the three-stage user-centred design approach presented in (Keates *et al.*, 1999). The first stage aims at defining the problem and gaining an understanding of the current shortcomings of the interface designs. In the second stage a solution is developed, that includes consideration of disabled users. The final stage evaluates the solution and ensures that the approach is effective. The next sections and the section on user satisfaction further in this paper provide the information related to each stage.

3.3 A Laser-activated Keyboard

In a first attempt to solve the problem of letting a motion-impaired person navigate through a 3D-world by driving the wheelchair, we used a keyboard adjusted for disabled people. This keyboard uses a laser pen to select a letter, and each letter has its function: forward, backward, turning, etc. An initial problem with this system is that the interval between the selection of two letters is too long. This is solved by making continuous movements until he/she selected another letter. If the user selected the forward key, the system would go forward until he/she selected the stop key or another direction key.

A second problem inherent in the keyboard is that the navigation with buttons is far from natural for the user, familiar with moving himself around by the joystick and tongue buttons. Also, the user cannot steer the wheelchair and navigate by means of the keyboard at the same time.

3.4 Rejected Alternatives

So we had to search for an alternative solution to navigate the 3D-world in an easy and natural way. There are existing solutions for similar problems, but it turns out that they can not easily be adjusted for this particular situation.

One of the possible solutions would be to use speech recognition as described in (Pieper *et al.*, 1999) in the context of writing letters and poetry. The authors report that they had to make severe modifications on existing speech recognition systems for several reasons. The main point in their situation is that the patient should be able to use his/her respiratory device. Also, the patient could not say very long words because talking is restricted to in between the respiratory cycles. Because our user has the same problems, we have to consider similar restrictions in the context of virtual world navigation. If the artist stayed in one place and there was no additional changing sound, we could use a similar speech recognition system. But a suitable system should work in a theatre where the user is moving around, and while doing so all kinds of sounds are generated in the 3D-world. It is thereby probably not feasible to use speech recognition in our particular situation.

A hands-off human-computer interface (HOCHI interface) is proposed in (Barreto *et al*., 1999). Three different mechanisms are used: brain-computer interface, facial muscles interface and tracking the point of gaze on a computer screen. Each of those mechanisms has its disadvantages and advantages, so they combined the three methods. But even together these mechanisms have significant limitations according to the authors, in particular the stability, fine movement capability and reliable clicking. Considering a similar system in our situation, there would be two more problems: firstly the person in the wheelchair should be moving together with the navigation of the 3D-world and can only do this by using the joystick, so muscular tracking is not possible. The second problem would be the eye gaze tracking, it is difficult to mount the hardware onto the wheelchair. Furthermore it will be rather dark or heavily lighted at some moments during the performance because the wheelchair user is on the stage in between the four big projection screens used in the play. The continual change of light intensity would make it impossible to track the eye gaze. (Schnipke *et al*., 2000) warn for additional drawbacks of eye gaze tracking, such as the limited percentage (37%) of the participants that could be successfully tracked. Even if these systems are improving, the cost of such systems is another prohibiting factor. The "Icarus man-o-war" research project envisions inexpensive solutions.

In conclusion, every solution we found for similar problems was not adjustable enough to the conditions of the artist and the theatre performance. That is why we decided to design our own solution.

3.5 Accessibility Solution

The accessibility solution is based on using the steering mechanisms (see Figure 3) of the wheelchair to enable natural navigation in 3D-virtual worlds. Another advantage of using the steering mechanisms of the wheelchair is that the person in the wheelchair can drive around the scene and navigate the 3D-world at the same time, and this was the purpose of our system.

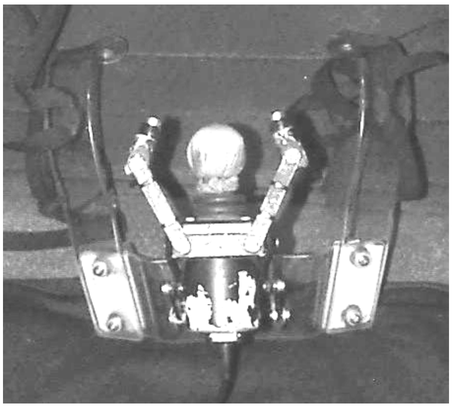

Figure 3. Chin joystick and tongue buttons

By reusing existing hardware on the wheelchair and tapping the signals of the joystick and the tongue buttons we managed to design a system that is inexpensive and easy to use. Both these aspects have been found to be of major importance for the feasibility of the system (Fanshawe, 1999).

How people with disabilities can use their input devices to navigate in a virtual environment has been investigated by (Boschian *et al.*, 1999). The authors conclude that navigation in 3D-worlds requires several directions of movement or a large number of switches. Adapted input devices can overcome these problems. This approves our approach, using Paul's joystick and tongue buttons. The major difference is that we use the devices simultaneously for steering the wheelchair and for navigating the 3D-world.

A design issue raised by (Kobayashi *et al.*, 1999) is that it should be possible for the disabled person and for the computer assistant to operate the computer simultaneously. This also should be possible by using their own specific input devices. In order to do so they used a microprocessor that read the input devices of both of them and combined them into input for the computer. According to them the combination of the devices should be so that the different users can work in one program simultaneously or work in two different programs simultaneously. In our system one user can navigate through the 3D-world on the main computer and simultaneously the disabled user can give his input for navigation.

4 System Realisation

In this section we describe the technological aspects that are part of translating the design mentioned above to a working system. Hardware as well as software issues are mentioned.

4.1 Overview of the System

Paul Antipoff steers his wheelchair by a joystick and two tongue buttons. The overall concept of the system consists of tapping the input signals provided by the joystick and the tongue buttons, and feeding it to the computers involved in the system. Figure 4 shows an overview of the system set-up. The joystick provides input, which is read by the microprocessor and sent to the portable computer on the wheelchair. Wireless communication using the TCP/IP protocol forwards the input to the main computer. The two tongue buttons are used to select the working mode of the joystick. There is one mode to drive, several modes to adjust the position of the chair and one mode to disable the joystick.

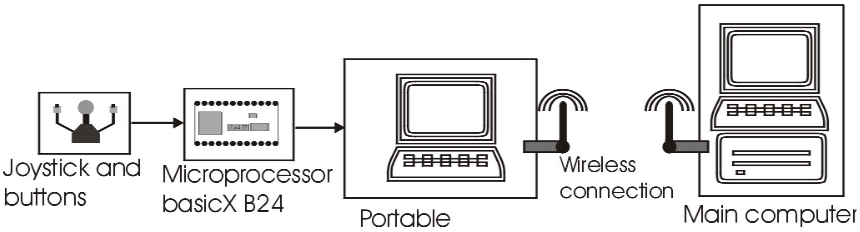

Figure 4. System overview

4.2 The Steering Signals

The microprocessor plays a central role in collecting the input signals and, after conversion, forwarding them to the wheelchair electronics and the portable PC. The basicX B24 microprocessor is used because it has enough digital analog converter ports (dac) and digital ports. It can conveniently be programmed in Visual Basic instead of the assembler most microprocessor require.

The joystick inputs two analogue signals to the dac ports of the microprocessor, and the speed factor of the joystick is read by a third dac port. The steering electronics of the wheelchair adjusts the values of the analogue signals and the speed factor, and directs the signals into the two electric motors that drive the wheelchair, see Figure 5.

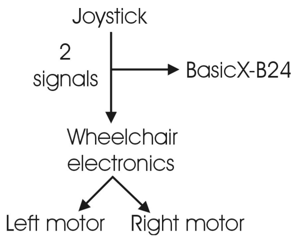

Figure 5. Wheelchair interface and basicX connection

The microprocessor checks if the value differs from the previous one and only then recalculates the wheelchair movement. The microcomputer will then send the movement to its internal com-port. In this way we do not waste any processing power of the chip. When the microprocessor is started the program of the chip waits for a signal of the portable computer, before it begins to scan the wheelchair signals. This enables the user of the wheelchair to drive to the centre point of the 3D-world and after that to start the program on the microchip.

Besides being fed to the wheelchair steering electronics, the transformed data from the joystick provides the system with information related to the navigation in the virtual world, which eventually is used to calculate the imagery. Therefore three numbers for position and three numbers for orientation are sent to the com-port of the portable computer.

The two tongue buttons provide digital input signals and enter the system through a digital port of the microprocessor.

4.3 The Role of the Portable Computer

The portable computer collects the information from the steering signals, possibly after transformation by the microprocessor. It sends this information to the main computer through a wireless network connection.

The portable computer starts the microprocessor by sending a specific string to the chip, and then constantly scans the com-port for input from this microprocessor. When input is received, it will be encoded into a number and sent to the main computer through the wireless network. This encoding reduces the network traffic to a minimum.

The portable computer is also equipped with a special keyboard, to be activated by a laser beam. The input from that keyboard is also sent to the main computer so that the user can also use keyboard input for some tasks.

4.4 The Main Computer Controls the Performance

Based on the information of the viewpoint in the virtual world coming from the portable, the main computer calculates the images, and controls the display of the 3D virtual world through projectors onto the four screens as shown in Figure 1.

The main computer produces the central projection image, and communicates the changes of the scene to three other computers, responsible for the left, the right and the bottom projection image. UDP multicast is applied for this communication.

5 Assessing User Satisfaction

Measuring the user's satisfaction is usually part of usability testing. Even if there are no commercially available alternatives to improve the accessibility, and if the system is tailored to the needs of the artist, such as in this situation, it remains important to listen to the user's experiences. Due to the involvement of the artist in the design, informal interviewing and observation are useful to assess the level of satisfaction, and to collect information for future improvements.

When asking Paul Antipoff about his experiences in the theatre, after a season of performances in Belgium and the Netherlands, his determination is striking. Paul was already active in the theatre before he got the muscle disease that immobilised him. He definitely wants to show that his personality has not changed since he became disabled, but only the way he fulfils his tasks is different now. The artist is notably happy that the current version of the system enables him to prove his artistic talent, and to be actively involved in the performance. He claims that some tasks during the performance are even better performed by a person in a wheelchair with the new technical system than by a person without all these. Paul was invited to take part in the principal role in a play called "Icarus man-o-war". He symbolically interprets a person in a labyrinth who wants to get out by making wings with feathers and wax. Paul compares his joystick with the wings, because it gives him such a freedom to move around.

Paul also says that the new techniques resolve his disabilities, like the joystick that enables him to drive around without any help. The new techniques sometimes even make it better than before, for example the keyboard lets him type his texts faster than before, when he typed with his hands.

The joystick has become a part of him, he does not even have to think how he has to steer the wheelchair in everyday life or now, with our system, to control the 3D-world. Using the joystick quickly became a natural interaction method for him, and he compares it with walking for not disabled persons. Steering his wheelchair with millimetre precision is possible and allows him during the performance to steer the 3D-world with great precision.

The intuitiveness of the joystick is important when navigating the 3D-world. The speed and direction parameters are now combined in one function, namely moving the wheelchair by using the joystick. Otherwise, when using the keyboard, he would have to press one letter for the direction and another letter to control the speed. Finally the audience does not only see the navigation of the 3D-world but also sees the wheelchair that moves in the same direction, which is very interesting in order to get the audience involved in the play.

6 Conclusions and Future Work

In this paper we have described the “Icarus man-o-war” artistic project, in which virtual worlds consisting of 3D ribbons are created and navigated. A solution is provided to enable a disabled artist to take part in the life performances. The design makes use of the same input devices as used for everyday movements. The joystick and tongue buttons are used to navigate the 3D virtual world. The design considerations, as well as hardware and software issues of the current realisation have been presented.

Topics with regard to the user’s satisfaction have been mentioned, and reveal that the system provides a very natural way of interacting with and navigating through the virtual worlds.

We conclude that although a particular user was targeted in this system, similar interaction techniques can serve for other motion-impaired users.

Current experiments, where the artist draws ribbons in the scenes while navigating, reveal the desire for extra drawing functionality for the wheelchair user. In the near future the system will be extended, so that the disabled user can also control the computer with the joystick and tongue buttons, so that there is no need for different input devices for wheelchair steering or computer mouse operating. The disabled artist is very enthusiastic about this idea because it opens perspectives. In a later stadium of our research we want to link the input devices in such a way that the computer sees them as a regular mouse, in which case all programs can be controlled by the wheelchair user.

7 Acknowledgements

We cordially thank Paul Antipoff and Eric Joris for their inspiring involvement in the project, and for their patience and indulgence while striving together for better results.

We also like to thank the manufacturers of the wheelchair for giving us the schematics of the wheelchair joystick and buttons.

Our research projects are partly funded by the Flemish government and EFRO (European Fund for Regional Development). The “Icarus man-o-war” project is directly subsidised by the Flemish government.

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