Development and evaluation of a virtual reality based training system for disabled children

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ABSTRACT

Children need mobility for normal development. An electric wheelchair can provide mobility for severely disabled children, but this requires training, which may be difficult. This virtual reality based training system is aimed at solving these difficulties in a practical, cost-effective way. The project involved the construction of two virtual environments for training these children. This was achieved by developing a software solution using WorldToolKit and AutoCAD.

1. INTRODUCTION

Children need mobility for normal development, and the absence of this mobility can cause a cycle of deprivation. Bertenthal et al. (1984) found that self-locomotion is very important in the development of a child's perception of spatial orientation, social communication and concept formation. For severely disabled children, an electric wheelchair can provide a substitute for "normal" mobility, however, there are some difficulties associated with training children to use them.

Before they are one year old, children begin to interact with their environment, and influence it. This was called the "contingency experience" by Brinker and Lewis (1982) who stated that a lack of this experience can lead to a "learned helplessness" whereby the child has lost motivation and is no longer interested in controlling or interacting with their environment. Brinker and Lewis stated that one of the reasons a child may miss out on the contingency experience is a lack of locomotive ability, and hence an inability to interact with their environment. Some disabled children are denied these stimuli and this can lead to a cycle of deprivation (Nisbet 1996, Figure 1). Verburg et al. (1984) have shown that for disabled children, mobility using powered wheelchairs can replace some of this lost developmental experience.

Traditionally, there has not been a structured system for training a child to use a powered wheelchair. The Occupational Therapist at St. Gabriel's School for disabled children, stated that the children were placed in their powered chairs without any guidance and simply encouraged to explore the environment (Personal Communication). However, Furumasu et al. (1995) have been working on the development of training programmes to standardise the training procedure.

Ultimately, using a 'real' electric wheelchair is undeniably the most effective way of training children to use their wheelchairs. There are, however, several problems associated with this:

- Potential damage. Electric wheelchairs are heavy and can move at speeds of up to 3mph. A poorly controlled chair can cause damage to the furniture in a home or injury to the child or other persons.
- Frustration. Initially, children learning to use electric wheelchairs are often frustrated, as they do not have adequate control over the chair, and bump into walls and other obstacles.
- Motivation. It can sometimes be difficult to motivate a child to use an electric wheelchair, particularly if they find the task difficult or frustrating.
- Space. A large area is required to enable the child to learn how the wheelchair responds to their control inputs with minimum risk of injury through collision. While a child is learning, she/he must be closely supervised.

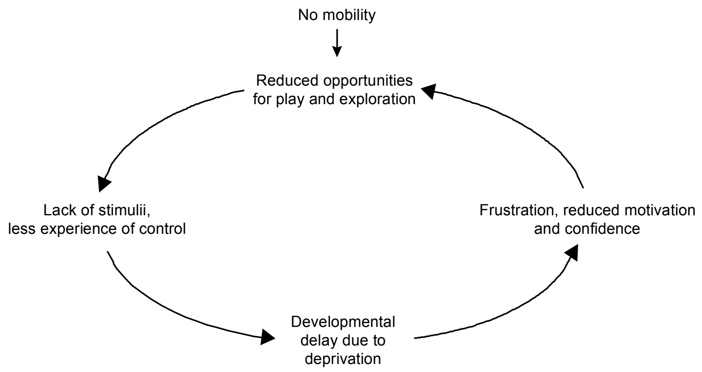

Figure 1 *Cycle of Deprivation (Nisbet 96)*

The use of a virtual reality simulator can address these problems in a number of ways.

- There is no danger to the child or the surroundings while using the simulator since they are not actually moving.
- When starting on the simulator the child may initially be placed in a large specially designed 'practice room' which will provide motion cues, but without obstacles, so that they can become accustomed to the response of the wheelchair to their hand/arm movements.
- While the simulator will mimic the motion of an electric wheelchair, the environment will have a game-like feel, making the simulator more enjoyable to use. The child can be given a task or a goal to instil a sense of purpose in their movement through the environment.

The VR simulator approach has also been developed by a group in the U.S. under Dean Inman at the Oregon Research Institute (Inman et al. 1995). However, there are differences between their Virtual Mobility Trainer (VMT) and our Virtual Reality Training System (VRTS):

The VMT wheelchair platform incorporated shaft encoders to physically measure the motions of the wheelchair. The CPU used these measurements to update the wheelchair's location in the virtual environment. The VRTS uses an interface system to directly read the joystick speed direction variables from the wheelchair control system. The VMT platform did not incorporate any motion feedback, whereas, in the VRTS simulator, it is ultimately intended that the wheelchair will be mounted on a platform that can be tilted, providing valuable motion cues to the user.

The VMT system used a Head Mounted Display to provide the visual feedback. The VRTS uses the more simple 'Window on World' display where the user views the virtual environment through a standard PC monitor. Although using this approach results in the loss of a certain degree of realism, this decision was taken to avoid the potential negative effects of using immersive VR systems (Wilson, 1996). It also has the positive effect of making the system less complex and more cost effective.

2. SIMULATOR DEVELOPMENT

At the start of this project two very important areas were researched.

1. Research into the childrens' disabilities, how children are currently trained, and how this might be improved using the simulator.
2. Development of the simulator software and wheelchair interface.

These two areas are closely linked. The limits of the children's' abilities will affect the development of the software, the introduction of new concepts or removal of non-useful ones. Identifying criteria that will give the best training experience will involve several iterations over the design loop.

Initial research has identified and assessed the problems of both disabled children learning to use electric wheelchairs and their therapists while training them. St. Gabriel's School, Limerick, a school and centre for disabled children, was visited where training methods were observed. Children trying to control an electric wheelchair for the first time, were recorded photographically. This allowed personal experience and observation of some of the problems described above.

To give the children a broad range of training scenarios, it was aimed to develop three different virtual environments:

- A domestic setting. Mastering this environment would help the child cope with the necessary task of getting about in their own homes. In this environment, the child can learn all the basic tasks required to control a powered wheelchair: starting/stopping, negotiating doors and corridors.
- A road crossing situation. This would simulate a potentially dangerous scenario involving moving objects.
- A shopping centre. This environment would introduce the child to more difficult situations - those which involve places/buildings which may not cater as effectively for their disabilities. The introduction of other mobile obstacles (people and mobile equipment) make this a more challenging setting.

Due to the limited processing power of the computer system, only the first two of the above environments have been created, and most of the emphasis was put on the home environment since this can be used to learn the basics of wheelchair control.

2.1 Software

The software used to execute the virtual environment is the WorldToolKit (WTK) from Sense8 Corporation, which is a C language library of functions with a built-in simulation manager. The virtual environment is run on a computer system based on a 200 MHz Pentium Pro processor.

The WorldToolKit library implements functions for the creation and manipulation of a virtual environment in which the real-time simulation manager presents the virtual environment to the user. The toolkit manages the tasks of rendering, reading the input devices, importing the model geometry and performed simulation functions (such as moving cars) which simplifies the development of a virtual environment.

Creating the virtual environment involved writing program code for the WorldToolKit and the construction of a three dimensional model which the WorldToolKit displayed. This required a CAD(Computer Aided Design) program with three dimensional capabilities. AutoCAD from Autodesk was used for this operation.

AutoCAD provides a powerful and flexible development environment. It has a wide variety of commands for creating 3D meshes, and is ideal for creating 'square' objects such as buildings and rooms. However (at release 13) it is not possible to completely specify the models with AutoCAD unless some customisation software is written. For example textures and arbitrary RGB colours can not be applied in a manner that WTK can understand (WTK can import DXF files and allows for texture application through the AutoCAD layer mechanism, but this is fairly crude and not feasible for large complicated meshes).

This difficulty was overcome by using AutoCAD's built in programming language, AutoLisp, to write a custom software extension which allowed for storing extra data with the objects in AutoCAD. In this way colour and texture information could be applied. A further extension allowed for the application of basic tasks such as translation, rotation, and scaling. For example the rotation task was used extensively to allow doors to open when the user approached them. These features facilitate the development of future environments since they can be nearly completely described inside AutoCAD, and with a minimum of extra WTK code development.

All this extra data was stored as extended entity data and written out as a DXF file. A C++ program was written to read in a DXF file including extended entity data, process it, and write an output file in the WorldToolKit's own model file format. Figure 2 shows the VRTS with it's various components and how they interact with each other.

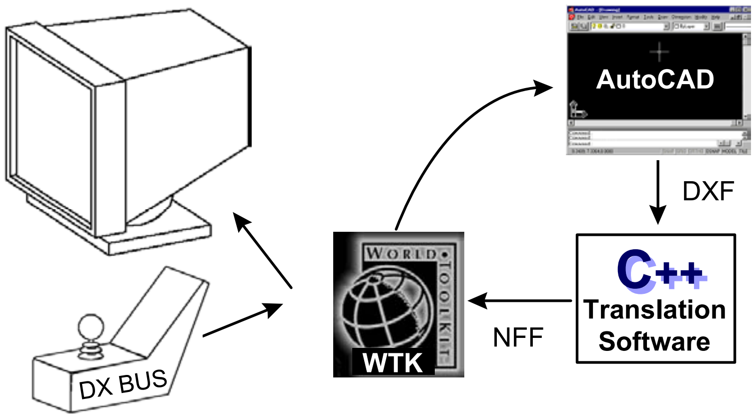

Figure 2 *VRTS setup*

In creating the virtual environments, there is a balance to be achieved between having realistic looking sophisticated environments, and the speed with which the simulator can run these environments. A minimum frame rate of about 10-12 frames per second(fps) is recommended by Bryson (1992), and Wilson (1996). If the frame rate falls below 6 fps, the simulation becomes jerky and difficult to use, especially for some disabled children who are visually impaired. During the development of the home environment, the emphasis was initially placed on maximising the realism, making much use of texture application. However, it was found that this reduced the frame rate to unacceptable levels (< 5 fps). Removing many of the textures, especially large textures that were used to give a view outside the house, dramatically increased the simulation speed with very little detraction from the visual appeal of the environment.

2.2 Wheelchair Interface

The interface between the virtual environment and the user is an important component of this simulator. To optimise the usefulness of the simulator as a training tool, it was designed to interface directly with the controller on the child's wheelchair. Ideally it should be possible to interface to a wide variety of different makes of controllers on different wheelchairs, however, this requires an open standard interface specification, and although such a standard does exist (M3S 1998), it is not yet widely used in wheelchairs in Ireland.

St. Gabriel's School, whose pupils are collaborating in the evaluation of the simulator, have decided that all new electric wheelchairs that they acquire will be fitted with the DX system produced by Control Dynamics Ltd. Therefore, it was decided to tailor the VRTS to this wheelchair control system. The DX system is also suitable because it is a sophisticated system consisting of various modules communicating with each other at a high level over the DX bus which is based on the CAN communications protocol (Bosch 1991). A DX bus module, the DX key was purchased from Control Dynamics Ltd., and this provides a direct interface between a personal computer and the DX bus system.

This DX key interface enables the user of the simulator to navigate within the virtual environment using the controller fitted to their own chair. This controller is usually a joystick, but may be one of a range of other devices such as push button switches, position sensing devices or sip-puff switches. This is transparent to the simulator since the DX key monitors the speed and direction requirements sent to the power module, and these are independent of the modules which generate these values. Other features of the DX bus controllers can also be integrated into the simulator, for example, lights and environmental controls allowing the user a greater degree of interaction with the environment.

3. DISCUSSION

A preliminary evaluation has been performed, and the simulator system running the home environment was demonstrated at St. Gabriel's School to the occupational therapist, and four disabled children. Three of the children had previous experience using powered wheelchairs, and successfully maneuvered their wheelchair around the virtual environment. The fourth child had no previous experience with powered wheelchairs, and could not navigate independently in the environment. She demonstrated poor grasp of the concepts required to control the wheelchair, i.e. she would drive into a wall and not stop. She did not explore of her own volition, and only went where she was told.

The feedback from this evaluation was positive, and all four children enjoyed using the simulator, one boy was very enthusiastic. The therapists suggested improvements to the simulator that would make it more useful and accessible for the children. These were as follows:

1 More sound. Sound is a very important aspect of simulation since some of the children have visual impairments. Sound also makes the simulator much more exciting and novel.

2 More interaction. Introduce more sophisticated dynamic objects such as falling objects: if the chair hits a table, then have a cup or a plate falls off and breaks. Hide and seek - hide an object in the house and have the child go and search for it.

3 Develop the outside of the house, have paths leading from front door around to the back. The occupational therapist reported that in her experience children had greater difficulty manoeuvring outside than inside a building possibly due to the lack of reference data points.

The simulator was improved and some of the suggestions above were implemented. A second more thorough evaluation was then undertaken with five disabled children who had not taken part in the previous evaluation. Figure 3 shows the simulator being used by one of the children. The results of this evaluation showed that four of the children were able to use the simulator with degrees of ability varying from very good control to only gross directional ability. Only one child required constant help in using the simulator.

A significant point that arose in both trial runs was that children's ability to use their powered wheelchairs was reflected in their competence in the use of the simulator. For example one girl who had mediocre control in the simulator, and found especially difficult to go through doors, also had the same problem in reality with her own chair (Occupation Therapist, personal communication).

Figure 3 *Wheelchair simulator in use*

4. CONCLUSIONS

The evaluations of the simulator have shown that the system can play a useful role in training disabled children to use powered wheelchairs. The fact that children who could use their powered chairs could also manoeuvre successfully in the simulator shows that the virtual wheelchair bears a reasonable resemblance in look and feel to a real chair. However, the current system is of limited benefit as a training tool since due to the limited processing power of the simulator computer, there is limited visual realism, and relatively crude modelling of the wheelchair (i.e. the virtual wheelchair does not behave in the simulation exactly like a real wheelchair).

Future development of the system would involve the up-grading of the computer hardware and the construction of a platform on which the child's wheelchair could be mounted. This will enhance the system by providing motion feedback, which will greatly reinforce the visual cues received from the monitor.

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