Adaptable virtual reality interface for powered wheelchair training of disabled children

I A Adelola[1], S L Cox[2] and A Rahman[3]

[1,2] Department of Mechanical and Aeronautical Engineering,
[1,3]Department Electronics and Computer Engineering,
University of Limerick, Limerick, Ireland

ifedayo.adelola@ul.ie, *sara.cox@ul.ie*, *Abdur.Rahman@ul.ie*

ABSTRACT

Childhood development is directly related to being able to independently explore, manoeuvre and interact with one's environment. However, severely disabled children having motor dysfunction often experience impeded motor development, and consequently lack independent mobility. This work relates to the development of the Virtual Environment Mobility Simulator (VEMS) to provide a simple and cost effective choice for powered wheelchair training and rehabilitation. The current area of interest is to study the effects of using real-time wheelchair motion as input for interacting with the home environment. This system provides a home environment delivered on a flat screen computer monitor, and offers simple tasks along with game elements to motivate the user. The widely varied nature of disability, however, requires adaptability of the virtual reality system to specific user training needs. In this paper we propose a conjoint analysis technique to analyse user behaviour, preferences and disability to gear towards the needs of providing an effective training.

1. INTRODUCTION

Childhood development is directly related to being able to independently explore, manoeuvre and interact with one's environment. This idea is now widely accepted amongst, social scientists, cognitive psychologists, and early childhood education specialists. Over the years, several published works have emphasized the importance of independent mobility to a child's developmental process (Rosenbloom, 1975; Bertenthal et al., 1984). It has been noted that spatial perceptual and cognitive abilities are developed during self-locomotion. Spatial perception encompasses the ability to localize one's self in space, depth perception, shape recognition, visually guided reaching, awareness of self-motion, as well as cognitive mapping and problem solving in multidimensional space. Cognitive mapping is a vital developmental "process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in there everyday spatial environment" (Downs and Stea, 1973). Independent mobility, or self-locomotion, is highly dependent on human motor development. The experiences needed for the development of motor skills are best gained through progressive learning and training, in the early years of life. However, severely disabled children having motor dysfunction often experience impeded motor development, and consequently lack independent mobility. Thankfully, in order to replace some of the developmental experience that may otherwise be lost in disabled children, several research works have been focused on the training of severely disabled children to use powered wheelchairs safely and functionally (Furumasu et al., 1996; Nisbet et al., 1996). Accordingly, the use of virtual reality (VR) technology in the training and rehabilitation of powered wheelchair users have been researched (Inman et al., 1995; VanSickle et al., 1995). This is largely due to the several advantages that VR offers. VR offers safe and risk free training environments that requires less effort and cost, relative to other training method. Motivation factors can be introduced more effectively in the virtual environments.

In view of this, in the last four years, our group at the University of Limerick has focused its attention in researching the use of virtual reality technology to deliver a (non-immersion type) three-dimensional graphics environment on a computer workstation (Desbonnet et al., 1997; Cox et al., 1999). Two virtual environments were initially developed. These environments were explored using a wheelchair DX-joystick interface. Severely disabled children at St. Gabriel School, Limerick benefited immensely from the fun elements incorporated into the environments. In turn, the experience of working with these children has widened the research scope opening pertinent areas needing attention. Thus, the current area of interest is to study and assess, by an experimental method, user interaction and performance in the virtual environment. Hence, the current stage of development in our Virtual Environment Mobility Simulator (VEMS) suffices for this study.

It has been generally established that there is correlation between training in a VR environment and real world training (Standen and Cromby, 1995; McComas et al, 1998). The widely varied nature of disability, however, requires adaptability of the virtual reality system to specific user training needs. In this paper we propose a conjoint analysis technique to analyse user behaviour, preferences and disability to gear towards the needs of providing an effective training. This therefore requires the monitoring of preferences and behaviour, and the creation of individual user profile based on experimental data.

2. OBJECTIVES

The long-term goal of this research is to deliver a simple and cost effective choice for wheelchair training and rehabilitation using virtual reality technology. The ultimate approach is to help the children to learn while they play, or play while they learn, in the virtual environment. Perhaps the skills learnt will be transferred from virtual reality into real world settings. In harmony with this goal, our immediate objectives are

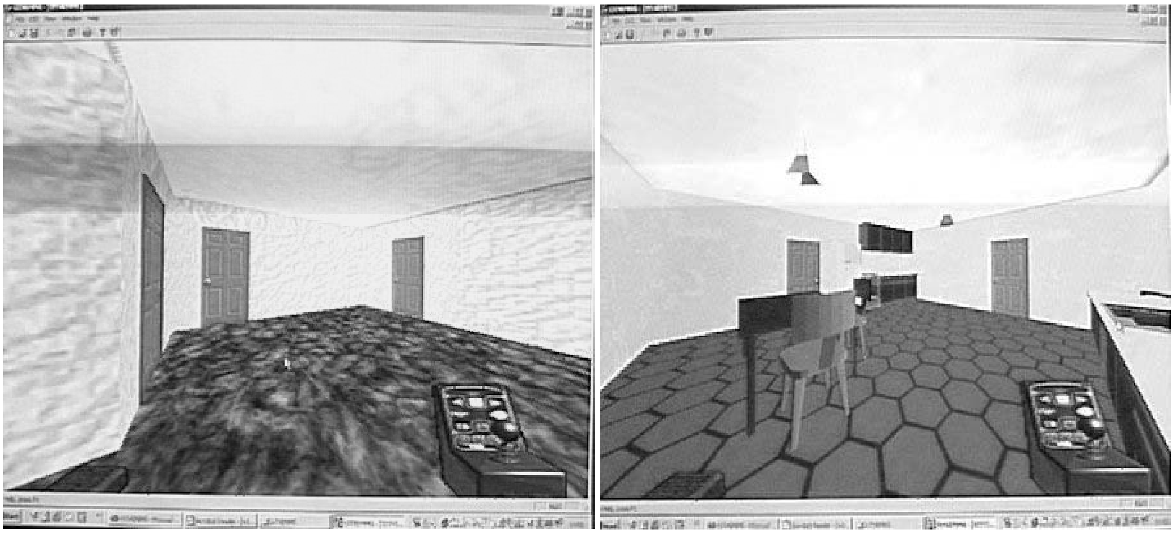
- To investigate an experimental method for the assessment of user interaction and training performance in the virtual environment.
- To ascertain the effectiveness of using the wheelchair motion as an input for interaction and training.
- To adapt the VR environment to user preferences, disability and training needs in order to provide a more effective training environment.

3. APPLICATION DEVELOPMENT

The work done to date required the development of the Virtual Environment Mobility Simulator (VEMS). This system entailed two design elements—the software and hardware developments.

3.1 Software Development

This involved modifications to the existing home environments developed by the research group. The development involved the use of three software packages, AutoCAD 2000, WorldToolKit (release 9) and Microsoft Visual C++ (version 6.0). AutoCAD 2000 was used for construction and modification of existing 3D virtual objects. WorldToolKit (release 9) provided a C/C++ language library of functions that can be coded in Microsoft Visual C++ (version 6.0) for dynamic manipulation of the virtual objects. Also, Microsoft Visual C++ (version 6.0) provided the platform for compiling and executing the program at run time. The home environment developed using this software packages included a bedroom, bathroom, living room, study, and kitchen with connecting corridors. This environment is delivered on a flat screen computer monitor, and offers simple tasks along with game elements to motivate the user. The screen displays two windows, the large window and the bird's eye window, for viewing the environment. The large window holds the real-time location of the user view during motion within the virtual environment. The bird's eye window can alternate between a static view and a dynamic view. The static view observes the position of the wheelchair object from the house plan. And the dynamic view tracks the position of the wheelchair object from the rear. The VEMS will eventually be programmed to record and replay the path followed by the wheelchair object in the virtual house. At this stage of development, the mouse can be used as the motion input to the wheelchair object travelling through the home environment. Also the mouse allows for disabling and enabling of other input devices, thereby providing the therapists with absolute control over the system. Figure 1 shows the screen shot of the hallway and the kitchen in the VEMS house environment.



(a) *(b)*

Figure 1. *User View of the VEMS House Environment: (a) Hallway (b) Kitchen.*

3.2 Hardware Development

The element of the VEMS development involves the design and construction of a wheelchair platform incorporating a roller unit. This roller unit is the functional part of the platform designed to serve as a mechanical interface between the wheelchair and the computer. The roller unit was designed to keep the wheelchair stationary, while allowing the rotation of the wheels. This unit consists of two pairs of rollers (shown in Figure 2) , each fitted with reflectors and sensors to track the motion of the wheelchair. Digital signals are obtained from the sensors as the wheels rotate. And the principle of odometry is applied to determine the components of translation and rotation for the wheelchair transformation in the real world. The roller has been tested and it provides the reading of the exact distance travelled by the wheelchair in the real world. This facilitates the accurate determination of the appropriate speed involving the translation and rotation of the wheels. Consequently, this transformation is applied to the simulation of the wheelchair object in the virtual house. An alternative hardware input device that can be interfaced to the computer for motion tracking is a standard wheelchair joystick.

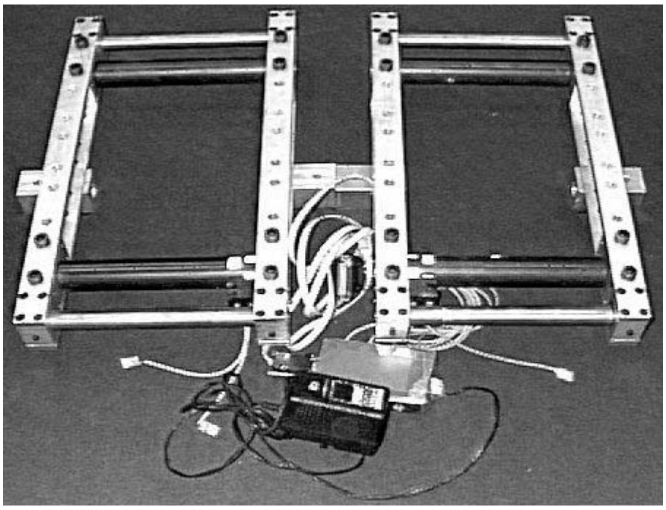


Figure 2. *Functional (roller) unit of the wheelchair platform.*

4. EXPERIMENTAL METHOD

The task of analysing preferences and behaviour is based on conjoint measurement method. Conjoint analysis presents experimental and statistical techniques for the measurement and prediction of consumer preferences or choices for product or services. It has proven useful to academic and professional researchers in the past

25 years. Experimental designs in conjoint study often involve the design and analysis of hypothetical decision tasks requiring the subjects, or respondents, to make judgements. Thus, conjoint measurement theory investigates the functional relationship between multi-attribute stimuli and the subjective value as perceived or expressed by the respondent. Multiple hypothetical alternatives, for product or services, can be presented in harmony with the principles fundamental to the design of statistical experiments. The fundamental interest of a conjoint analyst lies in the composition rule that allows the consumer to aggregate the utility associated to each attribute to yield the value or importance attached to a product or service. This rule, known as *preference model*, facilitates the development of simulation models that can be used to predict consumer choices for future product and services. Utility (or part-worth) here refers to the index number or coefficient representing the weight a subject places on a particular attribute or feature in a given product or service. Thus, given an assumed preference model, the importance of each attribute-level combination can be estimated based on the explicit preference measures for each of several alternative products. Traditionally, most conjoint experiments involve verbal presentations of hypothetical alternatives, while some have been pictorial.

Virtual reality, on the other hand, can combine both verbal and pictorial presentation formats with significant improvements to the realism of hypothetical alternatives. An outstanding advantage of virtual reality for the purpose of presentation is to provide the subject with an improved feeling of product realism, through visually active involvement, before any choice or preference is made (Dijkstra et al, 1996). VR technology facilitates the development of immersion and non-immersion environments that allow the subjects to experience the advantages, or otherwise, of the various features proposed in the modifications to products or services. VR will allow the observation and recording of subjects' reaction to alternatives for the purpose of evaluating their preferences, even into the future. Conjoint analysis will be applied to measure and predict the action or reaction of respondents to combinations of stimuli in varying hypothetical scenarios. Since the objective is to evaluate powered wheelchair-driving skills, hypothetical settings involving multi-attribute alternative scenario designs are being investigated. It is proposed that a preference model of performance can be obtained for each user.

4.1 Experimental Design

The subject (i.e. wheelchair trainee) will be required to accomplish a combination of simple tracking tasks making up a scenario. Each tracking task will test a wheelchair-driving skill. For the purpose of this experiment, in accord with the design requirements for conjoint analysis, some of the basic driving skills of interest necessary for the control of powered wheelchair are described as follows:

- Forward Motion – Ability of the user to drive wheelchair forward when prompted in the virtual environment.
- Reverse Motion – Ability of the user to drive wheelchair backward when prompted in the virtual environment.
- Left control – Ability of the user to accomplish a left-turn task while exploring the virtual environment.
- Right control –Ability of the user to accomplish right-turn task while exploring the virtual environment.
- Speed – Ability of the user to respond to changes in the speed of task presented in the virtual environment.
- Stop – Ability of the user to respond to stop signs in order to avoid collision with specific object in the virtual environment.

For conjoint analysis these driving skills are the attributes, and the scenarios are the hypothetical alternatives. Since each attribute is presented as one of six possible tasks in a given scenario, and given six scenario levels, 46656 (i.e. 6^6) hypothetical scenarios can be generated for full factorial design. However, the fractional factorial design is favoured for the experiment. Thus, 6 hypothetical scenarios may be selected for the experiment. Table 1 provides the design specification for 6 multi-attribute hypothetical scenarios.

4.2 Experimental Procedure

A game environment incorporating features of the real world will be presented to respondents. The respondents are required to accomplish simple tracking tasks within the virtual environment. These tasks involve driving the wheelchair to hit several primary and secondary target objects positioned in various places within the rooms of the virtual environment.

Table 1. *Experimental Design Specification for Six Hypothetical Scenarios.*

Attributes	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Forward Motion	Task No. 1	Task No. 2	Task No. 3	Task No. 4	Task No. 5	Task No. 6
Reverse Motion	Task No. 2	Task No. 3	Task No. 4	Task No. 5	Task No. 6	Task No. 1
Right Control	Task No. 3	Task No. 4	Task No. 5	Task No. 6	Task No. 1	Task No. 2
Left Control	Task No. 4	Task No. 5	Task No. 6	Task No. 1	Task No. 2	Task No. 3
Speed	Task No. 5	Task No. 6	Task No. 1	Task No. 2	Task No. 3	Task No. 4
Stop	Task No. 6	Task No. 1	Task No. 2	Task No. 3	Task No. 4	Task No. 5

In order to motivate the trainee, visual and audio cues will be given for successes. This will include visible scoring of successes. They will be penalised with a reduction in score for hitting the wrong objects such as room wall, chair, table, etc. Further, for conjoint analysis, the trainee will be scored accordingly for each primary or secondary target objects successfully hit while accomplishing the tracking tasks. This will help determine the preference score for each multi-attribute scenario level and their attribute utilities, respectively. The steps involved in the evaluation of the users are described as follows:

4.2.1 Experimental Sessions: Two experimental sessions will take place. The first session will allow the selected pupils to play the game in the VE for as long as they can bear. This enables the determination of the minimum duration for the second experimental session. The results from the first experiment will be used to obtain several simulations of sample data required for resolving vital issues involving the set-up of the second experimental session. More importantly, the first experiment will enhance the investigation of the key issues of interest in a subject, so that the second experimental session can be modified appropriately. Hence, the second experimental session will be used to create a detailed profile of the pupil for future training modifications.

4.2.2 Simulation: Several issues need to be investigated in order to obtain consistent experimental results required for modelling performance and, ultimately, to create detailed profile for the user. These issues include the determination of sample size required for a particular user, the number and selection of appropriate hypothetical scenarios, the determination of the subject's possible weak driving skills, etc. However, in order to reduce unnecessary fatigue on the disabled user when obtaining the experimental data samples required, it is possible to carry out several simulations of data samples based on the first experimental results. Thus, the simulation will facilitate the introduction of necessary features to the second experimental session, and adaptation of the training sessions to suit the subject.

4.2.3 Profile. In order to provide an effective training for a disabled child using VR scenarios, a detailed understanding of the subject's behaviour regarding various stimuli is important. Such understanding will enable the creation of user profile to check the correlation between their disability and training performance. This will certainly guide a rehabilitation specialist towards more focused and improved training. Thus, conjoint analysis provides a means for studying the action or reaction of subjects to combinations of stimuli in varying hypothetical scenarios.

Since the objective of this work is to evaluate powered wheelchair-driving skills, the content of the user profile for this research focuses on factors involving direction (forward, reverse, left- or right-turn) control and the user response when prompted to change speed or stop. For example, it should be possible to determine a child's weak driving skills, the relative importance of a particular skill in relation to others and how specific skills affect the actual user performance. Likewise, an understanding of the subject's action or reaction to a given task can be profiled. For example, does the child move the wheelchair joystick backwards when tasked to move forward? This will certainly have negative effect on the related attribute utility. Further, the profiled driving skills will be better refined in consultation with the therapists. Indeed, the focus of any user profile in a conjoint study will vary from one researcher or specialist to another.

5. DISCUSSION

Traditionally, conjoint analysis has been a multiple regression problem. The multiple linear regression equation can generally be given as shown in equation (1) below. In ANOVA, the respondent's rating for the hypothetical alternatives provides the dependent variables used in the statistical analysis. And the attribute levels serve as the independent variable. The estimated β coefficient associated with each independent variable is the utility for that specific level.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_N X_N \qquad (1)$$

where Y = the dependent variable
X_N = the N^{th} independent variable
β_N = the regression coefficient for respective independent variable
N = Number of possible observations of the independent variable

Although several statistical methods exist for conjoint analysis, the type of data collected, and the subjects of interest in the analysis often determine the regression technique used. Further, the technique applied is usually a reflection of the algorithmic differences and alternative approach to data collection and measurement. It is of interest to examine the correlation between a subjects' response and that predicted. Validation of preference model for overall fit is vital. In other words, it is necessary to check the goodness-of-fit of the derived model in comparison to the actual performance. This will help check the effect of introducing new or adapted alternative scenarios to the training system.

In conjoint analysis, measurement error can be reduced by large amount of sample data. However, the subjects can become fatigued, and there is a limit beyond which responses are no longer reliable. The situation may be hindered further by the condition of the disabled. They may not have the needed energy and patience to provide a large amount of sample data. Thus, it is important to strike a reasonable balance between overworking the respondents (yielding noisy data) and not having enough data to significantly obtain stable estimates. For investigational work and development of hypothesis in market research, a sample size of 30 to 60 has been recommended (Orme B., 1998). It is therefore useful to investigate this issue for the VEMS training experiments.

Table 2: *Example Preference Scores for 4 Hypothetical Scenarios*

Sample	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	5	2	4	6
2	2	6	5	4
3	4	5	5	5
4	6	1	5	4
5	2	8	6	5
6	5	5	7	7
7	7	4	8	7
8	2	1	8	5
9	5	7	3	5
10	8	5	3	6
11	3	3	6	4
12	5	8	4	6

In view of this, the procedure to carry out several simulations based on the first experimental result should prove effective for the modifications of appropriate parameters during the second experiment. For example, if the sample data provided in Table 2 represents the preference scores for a particular subject after the first experiment. Assuming these preference scores for 4 hypothetical scenarios are based on a scale of 1- 10. It can be observed from the sample data for scenario1 that the preference scores ranges between 2 to 8. Also, the preference score range changes from one scenario level to another. Thus, it is possible to generate preference scores that take into account the first experimental results regarding the range and consistency of preference scores in each scenario level. The same procedure will be applied to attribute utilities. As noted in the table above, the maximum size obtained for the trainee is 12. By generating the required data, it is possible to determine if fewer or more samples will be required to stabilise our estimates in the second experiment.

Consequently, a software program has been written to generate a large amount of sample data (i.e. preference scores, attribute utilities) for as many scenario levels as may be required, and to simulate parameters relevant to the design of experiments using conjoint analysis. This program is currently been tested.

6. CONCLUSION

This work proposes a technique for monitoring and adapting a VR training system to user needs and disability profiles. This research work is directed towards showing that user performance is measurable during training in the VEMS. And the potential benefits of the proposed approach may prove significant to future research in rehabilitation.

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