Designing a workplace for workers with motion disability with computer simulation and virtual reality techniques

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ABSTRACT

This paper describes preliminary results of a project aimed at adapting workplaces for workers with motion disability with computer simulation and virtual reality techniques. For this task, special software called the Troll and a computer human model with a visualization of maximal arm reach and preferred working space were developed. The Troll can be used to create a virtual working space, to adjust the human model's measurements and constraints to reflect a disabled person, and to analyze necessary modifications. The Troll also makes it possible to conduct research in an immersive virtual reality environment to assess a modified workplace and, if necessary, add further modifications.

1. INTRODUCTION

Employment of disabled people is a very serious social problem in Poland. According to data obtained from the Economic Activity Survey (conducted by Poland's Central Statistical Office), in 2009 nearly 2.1 million people with disabilities were of working age. Of these, only ~508 000 people are occupationally active, and ~443 000 actually worked. Persons with disabilities constitute nearly 10% of the working age population, but their share in total employment is lower than 4% (Chłoń-Domińczak and Poznańska, 2007). Such a low share of employed persons with disabilities may be caused by greater than average difficulties in finding a job, or less willingness or capacity to enter the labour market. The odds of finding work by occupationally active disabled people are about 20–40% lower than those of healthy people (Chłoń-Domińczak and Poznańska, 2007). Therefore, the crucial issue is to facilitate employment of people with disabilities to the extent to which they retain their ability to work and can use their skills and capabilities. One of the important aspects of this issue is adaptation of working environments for disabled people.

At the same time, computer simulation and virtual reality have become in recent years powerful tools that can be used in research on ergonomics and safety in the workplace (e.g., Foster and Burton, 2003; Mujber et al, 2004; Nivolianitou, 2006). In the USA, advanced research in this area is, for example carried out by the National Institute for Occupational Safety and Health (Department of Health and Human Services, Centers of Disease Control and Prevention). They study the use of virtual modelling for analyzing and assessing ergonomics and risk at workplaces in mines (Ambrose et al, 2005). Also in Japan, research on applying virtual simulation in analyzing accidents in the mining industry was conducted (Fukaya et al, 2003). Further examples of the application of virtual reality are research in the field of ergonomics of mining machinery operators (Foster and Burton, 2003) and identification of hazards and simulation of accidents, undertaken in order to improve the efficiency of decision-making (Duffy et al, 2004). In 2005 the European Union FP6 project VIRTHUALIS (Virtual Reality and Human Factors Applications for Improving Safety) was undertaken. As part of this project research is done to develop a method of using virtual modelling to consider the human factor when designing industrial installations, mainly in the chemical and petrochemical industries.

Research on the use of computer simulation and virtual reality in simulation of working conditions, accidents at work and ergonomic analysis is also performed in Poland, e.g. in the Institute of Mining Technology KOMAG (Winkler et al, 2006) and in the Central Institute for Labour Protection – National Research Institute (Budziszewski et al, 2010; Milanowicz and Budziszewski, 2010).

Computer simulation and virtual reality tools can be also used to adjust a workplace to the needs of a person with a disability at the design stage and to study adjusting existing working environments. A strictly virtual environment, created with a computer simulation, makes it possible to study several variants of the same workplace at the same time and to make further modifications relatively easily. Furthermore, because there is no need to use an existing workplace (nor any actual objects), it is possible to adapt workplaces while they are still being designed. This facilitates creating workplaces tailored to the needs of people with disabilities, thereby enabling their employment.

2. METHODOLOGY

This research aims to develop a method of adapting workplaces for workers with motion disability with computer simulation and virtual reality techniques. This is a two-step task. Firstly, a person's ability to work is analyzed with a computer human model with applied restraints caused by their disability. Then all necessary modifications of the workplace are proposed and introduced. In the second step, research in a virtual reality environment is carried out with the participation of a person with a disability. Their task is to assess the adjusted workplace and propose additional modifications reflecting comfort of work and personal preferences.

To analyze the ability to work by a person with disability at workplaces thus prepared, a computer human model was created with a visualization of maximal arm reach and preferred working space (Gedliczka et al, 2001; EN ISO 14738:2008). Its basic geometry was based on the 50th percentile of male and female population (Gedliczka et al, 2001; EN 547-3:1996+A1:2008). However, this model can be used to reflect the measurements of any person with restraints caused by their disability. Modifications can be introduced to reflect the needs of a specific person, but also of a model person representing a group of people with disabilities. The model consists of a chain of rigid bodies (corresponding to segments of human bodies) connected with joints with applied constraints. Visualizations of maximal arm reach and preferred working space are calculated according to these constraints and the length of the body segments.

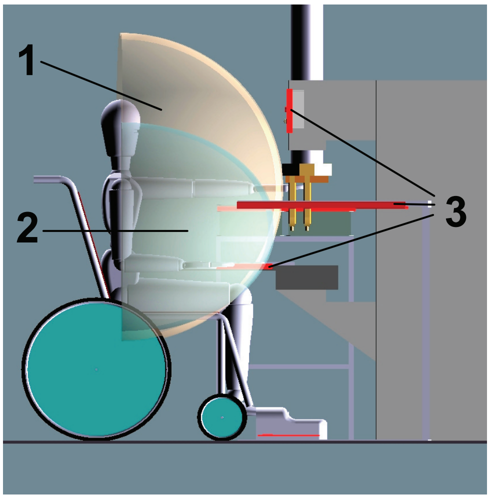

Figure 1. *Computer model of a person in a wheelchair with a visualization of maximal arm reach (1), preferred working space (2) and accessible working areas of the workplace (3).*

Special software, the Troll, was developed as part of this study, too. It can be used to operate virtual environments and the computer human model. It has the form of a graphical editor that makes it possible to import CAD models and to assemble them into a virtual workplace. The human model is imported into such a working environment. All body segments can be scaled to reflect the person's measurements, and the constraint in all joints can be modified according to their disability restrictions. In further work an automatic scaling tool will be implemented. It will then be possible to generate a basic human model according to basic parameters such as body height and weight. However, it will still be necessary to adjust this model to the measurements and constraints of the person concerned.

In the next step, a visualization of maximal arm reach and preferred working space is generated. It is calculated on the basis of the geometry and the constraints of the model. After this step, the model is placed in the virtual workplace and can be moved to each area of the work cycle. In this way, designers can analyze whether all areas to be accessed during work are in the range of the person concerned and whether all areas where work is done more permanently are in the preferred working space. They can also evaluate if the worker will be able to access easily the necessary areas of the working environment, which is especially important for people in wheelchairs. The collision detection mechanism, which has been built into the Troll, makes those analyses easier. They result in suggestions of ways to modify workplaces so that they meet the needs of disabled people.

In the second phase, people with disabilities will take part in tests involving virtual reality. With this in mind, an additional module was developed for the Troll, to make stereoscopic visualization of a virtual workplace possible. This will be done with either a quad-buffer feature of some video adapters for devices with one video input or a dual video source rendering for devices with two inputs (one for each eye). All necessary operations can be programmed using the Troll's scripting features. The goal of this research will be to assess the results of the first phase (proposed modifications) and to suggest further modifications that should reflect individual needs. For this task, yet another feature was added; it is now possible to record in a log file various parameters such as the position and rotation of selected virtual work-related objects and trackers. This information can be used to calculate work efficiency, the accuracy of the performed tasks and the number of the worker's moves, leading to an evaluation of various variants of the modified workplaces.

A separate module was developed to help implement the modifications proposed by a disabled worker. It makes controlling the Troll engine via a TCP/IP network possible. Thus, all objects can be modified during the simulation.

The Troll has been built on the Open Source Ogre 3D rendering engine for visualization; physics is supported by the Bullet Physics Engine.

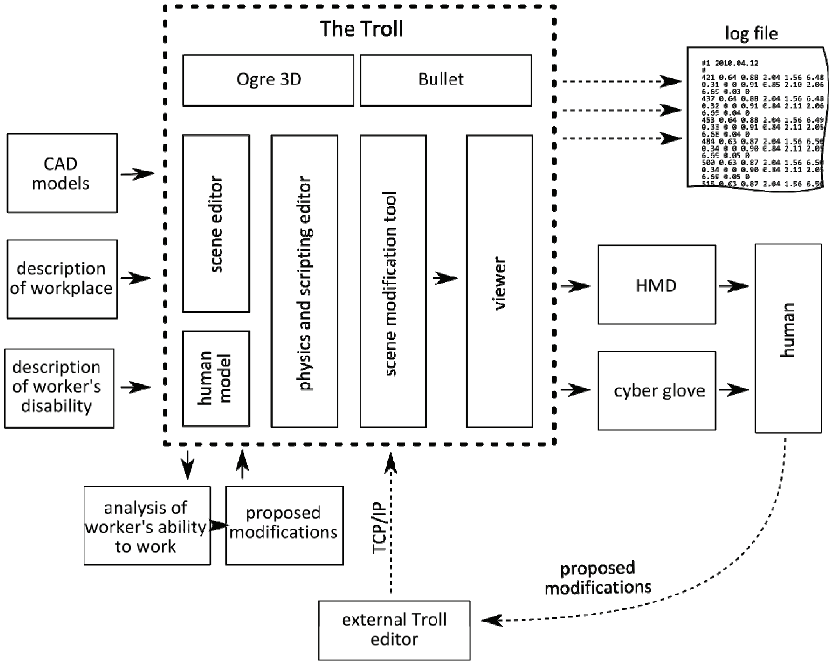

Figure 2. *Functional diagram of the Troll software. Notes. HMD – head mounted displays.*

The following equipment is used to access the virtual reality environment:

- eMagin (USA) Z800 head mounted displays to visualize 3D scenes; it is small and light, so it hardly restricts movement;
- a pair of 5DT (USA) Data Gloves 14 Ultra with 14 sensors to move objects in the virtual reality environment;
- Polhemus (USA) Liberty magnetic tracking with a long range transmitter to move around the environment. Three sensors are used to capture and record positions and rotations of the hands and the head. An additional sensor is attached to the wheelchair to visualize its movement and check for collisions with objects in the virtual workplace.

3. FIRST STAGE OF RESEARCH

The procedure and the tools described in section 2 were tested at four real-life workplaces for workers with disabilities, located in two different companies. They were workplaces with a welding machine, a grinding machine and two sites for manufacturing rubber products (such as gloves and rubber pipes). Various workers with various disabilities were actually employed at each of these workplaces, so for the purposes of this research these workplaces were adapted for people from the following groups (one person per workplace):

- workers in wheelchairs,
- workers with a disabled right upper extremity,
- workers whose disability coincides with short stature.

Even though the methodology, software and models described here make it possible to consider people with multiple restrictions related to their disabilities, it was decided that the workplaces would be prepared for people with single disabilities only. For each of those groups of disabled people a sample person was selected and a human model was adjusted to their measurements and disability. A model of a wheelchair was also created, with the main geometry based on a typical wheelchair (it can be modified to reflect other models as well). For each model a visualization of maximal arm reach and preferred working space was generated.

In the first phase all important objects at selected workplaces and their placement were measured, work procedure was videoed. In the next step, computer models of all objects important for working at these workplaces were created. In the case of some equipment CAD models were available (provided by the manufacturer), but for most objects models had to be created on the basis of field measurements. All CAD models were prepared in CATIA and imported into Blender modelling software, where complete workplaces were assembled and textures were applied. A thus prepared scene was transferred then to the Troll. Next, work performed at each workplace was analyzed (on the basis of the videos and other collected information) and all areas that should be reached during work were selected and marked.

Figure 3. *Site for manufacturing rubber products: real (left-hand side) and virtual (right-hand side) working environments.*

Computer human models with applied maximal arm reach and preferred working space were placed in virtual working environments and necessary adaptations were analyzed. The results are as follows:

- in all four workplaces 22 zones that had to be accessed during work were identified,
- 13 of those workplaces could not be accessed by the people with disabilities selected for each workplace,
- people in wheelchairs had no problems moving around in any of the workplaces.

In all zones where access was not possible, modifications of workplaces were proposed. In most cases it was necessary to move the actuators or other operating device, in two cases rearrangement of the workplace was necessary. All modification were implemented in the virtual workplaces.

4. SECOND STAGE OF RESEARCH

In the next, currently on-going stage of the project, research that involves virtual reality is carried out. A person with a disability (like earlier) is asked to access a virtual reality environment with immersive virtual reality equipment and to simulate work. This will allow the experimenters to assess the proposed modifications. In the next step, further modifications will be proposed according to the preferences of the disabled workers. These modifications will focus on ergonomics. The modified workplace will be assessed by measuring the performance of work and by considering the disabled worker's opinion.

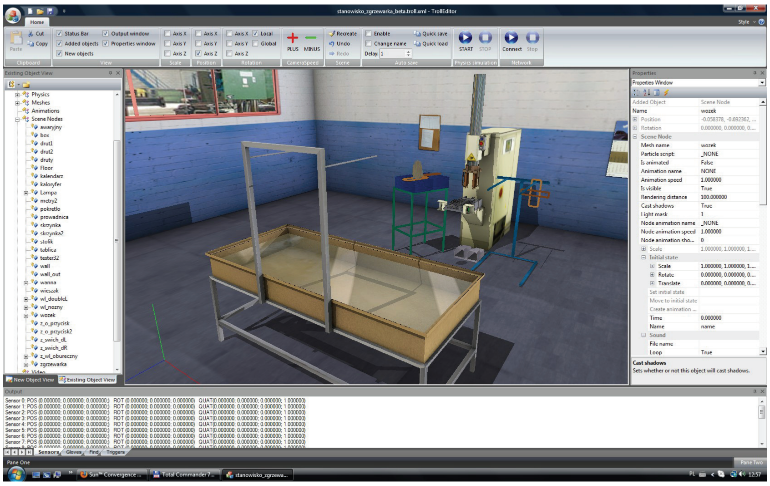

Figure 4. *Workplace with a welding machine in the Troll editor.*

Twelve disabled people from aforementioned groups will participate in this research. They will access a few variants of each workplace: an unmodified one, one with earlier modifications and one with modifications introduced according to their measurements. There will also be one or more additional variants of the workplace, reflecting the opinion of the person studied. There will be twofold evaluation of all variants:

- the efficiency of work, accuracy of performed tasks and movements done during work will be measured;
- a subjective evaluation of work places and each modification will be done with a questionnaire was prepared in cooperation with psychologists.

Each person will spend in the virtual environment approximately 270 min during 3 days of tests. To minimize discomfort after long exposure to immersive virtual reality, one session will take no longer than 30 min, with 20-min breaks in between.

5. CONCLUSIONS AND FURTHER WORK

The results of the first stage of the study show that computer simulation can be used to determine if a worker with a disability can accee all important areas of a workplace and to propose necessary modifications. A virtual environment makes simple, one-step modifications possible. The second stage will consist in verifying the proposed methodology through research with people with disabilities and virtual reality .

The Troll will be developed further to increase its capabilities and ease of use. There are plans to implement an automatic tool for scaling the computer human model. The user will provide information such as gender, body mass and body weight, and the human model will be scaled according to that information. As a result, the user will obtain a basic human model, which will have to be adjusted to the measurements of a person. Ways of analyzing maximal and optimal loads for upper extremities in various points of the arm reach area is another problem. A tool for this task was partially implemented in the current version of the Troll on the basis of Gedliczka et al (2001); however, Gedliczka et al's data on maximal and optimal loads were collected for ergonomic purposes and concern only the 5th percentile of males and females. What is more, these loads are described for the sagittal plane only. That is why this tool was not used in this research. Additional research must be conducted to fully implement an analysis of load for other cases, too.

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