Virtual Reality Platform Design for Electric Wheelchair Simulation in an Enabled Environment

Nico Steyn[1,2], Yskandar Hamam[1,2,3], Eric Monacelli[1,2], Karim Djouani[1]

[1] Tshwane University of Technology, French South African Institute of Technology,
Department of Electrical Engineering,
Staatsartillerie Road, Pretoria, South Africa
[2] University of Versailles Saint Quentin
10,12 avenue de l'europe, 78140 Velizy, France
[3] Université Paris-Est, Département Informatique, ESIEE Paris, Cité Descartes,
BP 99, 93162 Noisy-le-Grand Cedex, France

steynn@tut.ac.za (Nico Steyn)

Abstract

This study presents the development of a virtual reality platform for electric wheelchairs with a multipurpose usage in an enabled environment. The platform with the electrical wheelchair will be stationary with pitch and roll actuated actions for possible different uses as electric wheelchair driving simulations, wheelchair training, assistive technology research, architectural route planning and accessibility evaluation. The investigation into the mobility factor of wheelchair bounded users will be beneficial in the area of ergonomic designs of architectural structures. The use of the virtual reality platform can further be extended to the evaluation and training of inexperienced electric wheelchair users. The platform will be a mechatronic design consisting of both mechanical- and electrical properties. The mechanical components will consist of rollers driven by the electric wheelchair and its user placed on the platform where acquired electrical signals of the rotation of the wheelchairs wheels are of importance. The platform will be placed onto actuators for simulating angular movements of the wheelchair approaching an inclining or declining given path. The simulator must map intended motion by an electric wheelchair user into the virtual world with considering influences such as collisions, gradient changes and different surface properties. The design will finally consist of a combination of different engineering disciplines with the relevant kinematics and dynamics controlled in a simulated virtual reality environment.

Keywords: Electric Wheelchair, Motion Platform, Virtual Reality.

Presenting Author's biography

Nico Steyn a professional registered engineering technologist at the Engineering Council of South Africa (ECSA) and a lecturer at the Tshwane University of Technology in the Department of Electrical Engineering. He is a PhD student with the University of Versailles Saint Quentin in Yvelines in the field of the Enabled Environment at the French South African Institute of Technology in South Africa.

1 Introduction

Virtual reality platforms are used for the simulation of real world situations as to be experienced in automobile, aerospace, architectural and medical environments. The development of an electrical wheelchair simulation platform will be beneficial to different user groups and the elimination of certain factors associated with the use in real world situations. The research undertaken is to determine the accessibility of architectural structures and the possibility in training electric wheelchair users with the use of a fictitious environment. The use of electric wheelchairs by persons with disabilities and the rapid building developments has greatly increased the requirements set in the wheelchair accessibility of architectural structures. The increase in the use of electric wheelchairs is due to the advances in transistor technology that in turn improved on assistive technologies to be used by a greater portion of our population with disabilities. In order to achieve this outcome various aspects need to be considered as the mathematical modelling of a mechanical platform and the users interface to a near to real world virtual environment. The generation of feedback as the encountering of obstacles, slopes and different ground conditions need to be analysed and developed in the system.

2 The enabled environment

An enabled environment can be defined as the ability to perform necessary actions by a human with certain disabilities. Human disabilities are minimized or eliminated in the best possible extend in an enabled environment with the aid of assistive technology. The further aim of an enabled environment is achieve these actions to be performed by the person with a disability with the most comfort, effectiveness and shortest time. By the use of assistive technology, day to day activities becomes accessible to a greater portion of our communities.

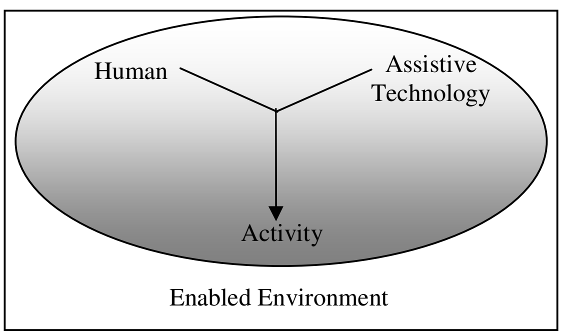

Fig. 1 Human activity assistive technology model (HAAT), [1].

In Fig. 1 the extension of the human activity assistance technology model (HAAT) can be seen to form an enabled environment. In [1] the HAAT model is described as a context for assessing an individual's needs. The HAAT model states here that there must be a person performing a certain task in an environment with the aid of assistive technology. The task mentioned in the latter can be interpreted as a focus on each of the components and their interactions. A challenge to society is to permit persons with disabilities to maximize their potential. The primary issue of concern to persons with disabilities is access to gainful employment, promotion, recreation, socialization and the most important, dignity [2]. Within the HAAT model the relevance of a virtual reality platform is realised to assist in such goals.

3 Existing driving simulators

To develop an electric wheelchair simulator the physical collection of behavioral data of the wheelchair is of great importance. The comparison of the collected data of the electric wheelchairs behavior to a mathematical model can assist in the refinement in the developed platform. This is done in [3] with the aid of strip encoders place on driving wheels, a computer mounted to the chair to collect data and a virtual user interface as seen in Fig 2. Such a data acquisition implementation to assist in system modelling is also briefly discussed later in section 5.2.2.

Fig. 2 Electric wheelchair evaluation [3].

An example of a virtual wheelchair simulator is designed by Mitsubishi for the National Rehabilitation Center for persons with Disabilities in Japan [4]. This system makes use of a Stewart platform (Hexapod) [5] for conveying non-visual effects to be experienced by the user. The chair is fixed and is not interchangeable with other electric wheelchair models. The intended motion is only conveyed by the use of a standard joystick as to be found on most electric wheelchairs. Another wheelchair simulation in virtual reality performed by Dr. M. Grant [6, 7] from the University of Strathclyde uses a custom platform with rollers to map the intended wheelchair motion in a virtual world. This platform is mainly used as a haptic interface which allows wheelchair users to experience a virtual world of different buildings on their own manual or electric wheelchair. This platform has the ability to generate feedback of different floor coverings to the user. On this platform the effect of approaching different slopes is visually experienced with physical feedback onto the rollers as in Fig. 3.

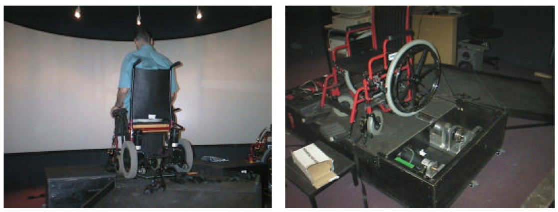

Fig. 3 Wheelchair simulation in virtual reality [6, 7].

On most of the practical implementations of virtual reality platforms for electrical wheelchairs one can see the limitations of the systems.

4 Wheelchair performance

In Tab. 1 the basic important specification and performance of electrical wheelchairs can be seen. The data is collected from nine different manufacturers tabled in [8]. In order to design an effective motion platform for different types of wheelchairs it is necessary to use average performance data, collected from relevant manufacturers of electric wheelchairs. Further specifications for wheelchair required measurements and architectural considerations please consult [9].

Tab. 1 Typical electric wheelchair performance acquired from [8]

	Average	Maximum
Speed	2,2 m/s	3,3 m/s
Turning radius	0,7m	0,96 m
Overall length	0,65 m	1,1 m
Overall width	0,64 m	0,75 m
Load capacity	140 kg	340 kg
Weight with batteries	70 kg	172 kg
Ground clearance	0,1 m	0,114 m
Climbing slope (pitch-X)	8º	12º

Types of electric powered wheelchairs can mainly be divided into six types or constructs whereby mechanical steering and powered driving wheels placement and actions differ to produce different working area specifications. As for the performance mentioned in Tab. 1 the most common electric wheelchair with rear wheel drive and independent front castor wheels was considered. This research on the motion platform is not limited to the latter type, but can be extended to the other constructs as mentioned in [9].

5 The virtual reality motion platform

A virtual reality simulator for electric wheelchairs consists of different fields of engineering principles integrated into one system. As mentioned in the abstract the design will consist of a mechatronic design. Different scientific, mechanical and electrical properties will exist. The different subsystems can be divided into a user, electric wheelchair, motion platform and graphical human interface. Furthermore the system can be divided into sensors, controllers and actuators working as different sections interconnected between the different subsystems as seen in Fig. 4.

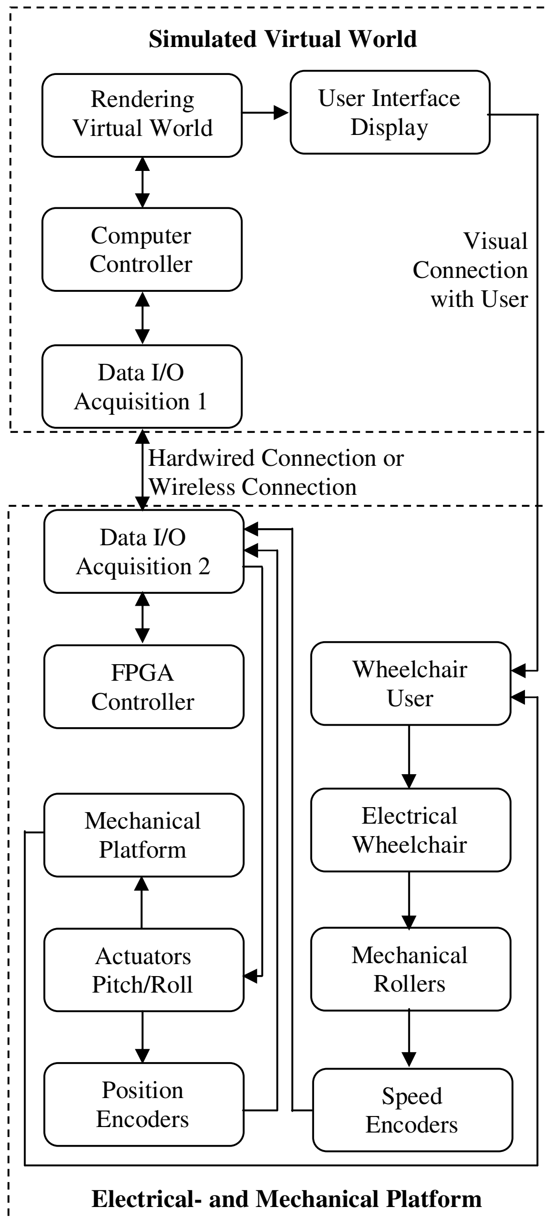

Fig. 4 Virtual reality electric wheelchair simulator block diagram representation.

5.1 The mechanical design

The mechanical design consists of rollers driven by the wheelchairs independently electrically driven wheels. Sensors acquire data of the rotation of the wheelchairs wheels. This is in order to map the intended path of the user onto the virtual world. If ω_L and ω_R represents the left and right angular velocities of the wheelchairs driving wheels respectively. Forward and backward translations can be achieved where $\omega_L = \omega_R$. The rotation of the electric wheelchair is achieved by having $\omega_L < \omega_R$ or $\omega_L > \omega_R$. The wheelchair can rotate around the axis of the wheels if $+\omega_L = -\omega_R$ or $-\omega_L = +\omega_R$ for a sharp turn. Another wheelchair rotation is when the chair rotates around a stationary wheels axis with the other wheel $\omega_{LorR} = +\omega \ or \ -\omega$. A further action is performed by the mechanical platform to convey to the user the feeling of moving on different slopes, over different ground planes or the collision with obstacles. The developed mechanical platform with an electric wheelchair can be seen in Fig 5 positioned in a slight inclined position.

Fig. 5 The mechanical platform.

5.2 The electrical design

The electrical design can be seen as part of the system consisting of the various sensors, actuators and controllers.

5.2.1 The platform sensors

The sensors used in the system are mainly for determining position and velocities. The type of sensors used for the latter is a three channel digital pulse generating rotary encoder.

Position determination is used in a feedback configuration via the controller send by the sensors on the actuators to compare set-points received from the virtual world's desired pitch and roll actions. The rotary encoders used for the wheelchairs independent driven wheel velocities are used to map the intended path to be produced in the virtual world. Hall-effect sensors in conjunction with permanent magnets are used for discrete limit switches on the system. Such limits will be on the actuators linear translations during operation to determine end of travel and zero degree positions. See Fig. 6 with a close-up view of the platforms rollers and the rotary encoder.

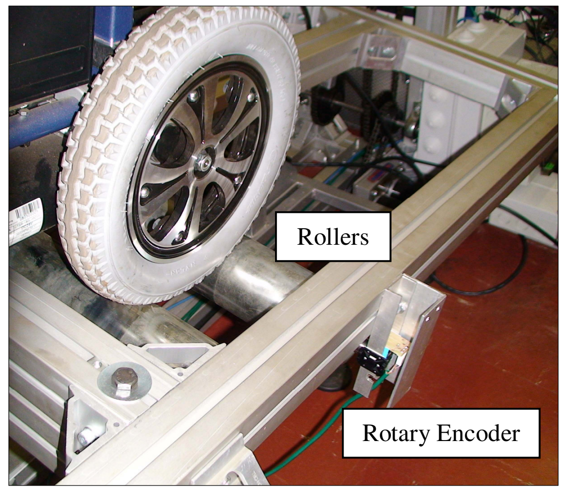

Fig. 6 Platform roller and rotary encoder.

5.2.2 Platform controller and data acquisition unit

The combined controller and data acquisition unit used on the platforms development is National Instruments PXI controller with LABVIEW. All signals are sensed or received on the units data acquisition card and processing are done on the intermediate data by the use of a Field Programmable Gate Array (FPGA) processor to achieve near to real time operations. Multiple analogue and digital inputs and outputs are available for easy expansion and development. FPGA or Windows based operations on calculations and intended algorithms are done on the systems controller on received or send signals to the virtual world as were seen in Fig 4.

The important vector components of a common nonholonomic system in Cartesian inertial spaces associated with the wheelchair is as following

$$\dot{x}_{CG} = v_{CG} \cos\theta_{CG} \tag{1}$$

$$\dot{y}_{CG} = v_{CG} \sin\theta_{CG} \tag{2}$$

$$\dot{\theta}_{CG} = v_{CG} K_{CG} \tag{3}$$

with the coordinates

$$\begin{bmatrix} x_{CG} & y_{CG} & \theta_{CG} \end{bmatrix}^T$$

of the wheelchair with v_{CG} the current speed and K_{CG} the monotonic steering angle.

The nonhlonomic constraint is then

$$-\dot{x}_{CG}\sin\theta_{CG} + \dot{y}_{CG}\cos\theta_{CG} = 0 \qquad (4)$$

Additional constraints due to limited performance of the electric wheelchair can be seen as

$$|K_{CG}| \leq K_{CG}, \max$$

$$|v_{CG}| \leq v_{CG}, \max$$

It is thus relevant that bi-directional data transfers exist between the motion platform driven by the wheelchair and virtual world to ensure correct representation of performed actions. Detailed wheelchair mathematical models can be found in [12,13,14]. Further real time data acquisition is implemented on important parameters of the electric wheelchairs rotations and translations during normal operations to be used in model refinement. Typical gyroscopic pitch, roll and yaw data is collected. Wheel velocity and motor torques is collected that can especially assist in slipping mode control as in [15]. Castor wheel behaviour during normal operations is also used to predict possible movement to be experienced and mapped in a virtual world, as seen in Fig. 7.

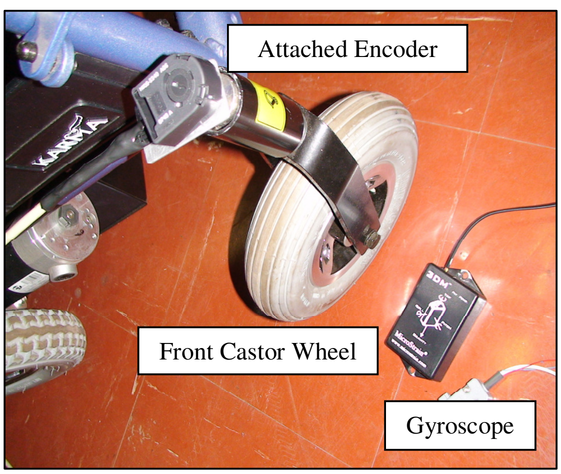

Fig. 7 Wheelchair performance data acquisition.

5.2.3 Platform actuators

The actuators used on the development were designed at the University (TUT). The actuators are electrically driven by two 12 Vdc motors with gear boxes for a higher torque ratio. The actuators mechanical section works on a sprocket chain configuration that proofed to be extremely cost effective solution. The gear and sprocket configuration is constructed to produce the desired velocities and torque outputs as required. The motors are driven by a pulse with modulated (PWM) signal from the PXI controller for easy control. The PWM signal is determined by the intended slope of the virtual world fed to the PXI controller to produce the desired PWM duty cycle to adjust the platforms position accordingly.

5.3 Visual interface

Different methods for conveying visual graphical content to the user on a motion simulator platform is a possibility. The most important factor is that these virtual worlds need to be conveyed to the user in near to real time. The different types of graphical interfaces can be divided into three typical types namely, multiple screens, hemispherical displays or by the use of a head mounted displays (HMD). The latter is chosen for our system since a wide field of view can be achieved and head tracking devices gives a full immersive virtual reality feel. The only disadvantage of HMD on a motion platform is that severe motion sickness can be experienced so a 15 minute period of use is advised. For our development process a simple data projector scheme is used as seen on Fig. 5. The virtual world is still under development with the use of Vizard virtual reality software and scripted in python.

6 Platform performance

Tab. 2 Motion platform performance data

Travel Range X, Y	± 0,25 m
Arc length X, Y	± 0,244 m
Travel Range θ_X , θ_Y	± 14°
Speed X, Y	1,15 m/s
Min Incremental Motion X, Y	735 μm
Min Incremental Motion θ_X , θ_Y	737 μrad
Active roller area	0,3 m (min) 0,8 m (max)
Weight of motion platform	49 kg
Maximum Load capacity in Z	250 kg

From the data in Tab. 2 it can be seen that the motion platform designed is able to map the necessary average performance parameters of the electric wheelchairs as in Tab. 1. The platform will rely on a combination of physical motion and virtual motion to achieve near to real world effective motion transition to the user. The platform is stationed on a pivot point different from a Stewart platform as in [5]. The advantage of using a centered pivot point is that only two actuators exist and lower operating torques is necessary for motion. In such a system the yaw action is not possible. The developing costs are also greatly reduced by only using 2 actuators as in comparison of 6 actuators on the Stewart platform. The motion platform developed is constructed out of aluminium profiles. The use of aluminium profiles reduces motion platform weight and in return increase the maximum load capacity of the motion platform. The aluminum profiles are joined with brackets for flexibility and easy adaptability to other wheelchair constructs.

7 Desired outcomes

Certain criteria need to be met in developing an electrical wheelchair simulator used in a virtual reality environment. Grant M, Harrison C and Conway B from different departments such as architecture, bioengineering at the University of Strathclyde in Glasgow U.K. has compiled a sufficient list of desired outcomes of such a simulator. To accommodate a relevant reasoning of an effective electric wheelchair virtual reality simulator the following is a description of desire outcomes and requirements to be met stated in [6, 7]:

- The ability to accurately feedback intended wheelchair motion where obstacles, different floor coverings or slopes are experienced by the user;
- an interface between the platform and a virtual reality environment in order to provide an immersive virtual feel where intended wheelchair navigation is performed;
- the consideration of different building types to test the performance of both the platform and the system used by wheelchair users;
- the accuracy of the model in order to be dimensionally consistent, visually compelling, and simulate the physical constraints as experienced in real world experiences;
- the ability to interact with the virtual world in a manner that is free from the constraints and abstraction of an artificial control metaphor;
- bidirectional data transfers between the user, platform and virtual environment should be near to real time;
- the accommodation of different wheelchairs as used by wheelchair users;
- the addition of data logging on wheelchair motion in the virtual environment can be beneficial to architectural- and therapist evaluations.

8 Conclusion

This research and development on the virtual reality motion platform for electric wheelchairs is a comprehensive study on different technologies, mathematical modelling of mechanical- and electrical systems. The virtual world together with kinematic and dynamic models on our development still needs refinement and further research are to be conducted to achieve a near to real world virtual motion simulator to be used in an enabled environment. With the platform under development we will be able to address almost all the relevant outcomes mentioned in Section 7.

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