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Modelling and design of an augmented reality differential drive mobility aid in an enabled environment

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ABSTRACT

In this paper the authors discuss the modelling and design of an augmented reality platform for disabled wheeled mobility studies. This design consists of a virtual environment with two degrees of freedom motion platform and integrated ground contact force feedback. Differential drive mobility users continue to be in touch with reality on their own mobility aid while interacting with virtual objects. The major domain related to the differential drive mobility of the disabled members of society which coincides with the use of manual wheelchairs, electric wheelchairs and mobility scooters. In order to account for environmental and dynamic effects, the wheeled mobility user needs to map the intended trajectory into the virtual world. Motion and inertia force feedback produced on the augmented simulator give the users a haptic sensory stimulus input regarding spatial movement and ground contact forces. The main objective is to model and design an augmented reality platform with real world kinematic and dynamic properties to place a wheeled mobility user closer to real world encounters. The use of the designed augmented reality platform will be beneficial to disabled wheeled mobility users in need of occupational therapist training and evaluation.

1. Introduction

A physical or cognitive impairment may compromise the ability of a person to walk, whereas wheeled mobility may aid in giving a partial or a total degree of mobility. Mobility difficulties are also strong predictors of the degree of activities of daily living (ADL) [1] which a person is able to achieve, as individuals need to be mobile to accomplish many of these activities. The primary issue of concern to persons with impaired mobility is access to gainful employment, promotion, recreation, socialisation and, the most important, dignity [2–4]. An enabled environment may be defined as the ability to perform necessary actions by a person with certain disabilities. Human disabilities are minimised or eliminated to the best possible extent in an enabled environment with the aid of assistive technology [5–8]. Examples of such assistive devices are mobility aids driven with chest muscle actuators, halo controllers to detect the operator's head movement and sip/puff devices that consist of a straw to detect positive and negative air pressures from an operator's mouth. Recent research developments in the field of brain computer interfaces (BCI) [9,10] allow the translation of the brain's electrical activity into mobility aid control commands.

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Regarding the training aspect in a simulated environment, the user may be safely belted to the augmented reality platform and an occupational therapist can ensure a safe, controlled environment with different training possibilities and intensity levels [11]. The augmented reality platform is able to supply the therapist with real-time mobility information indicating user equipment and assistive technology interaction associated with the limitations, control and stability of the specific interaction [12].

Regulations governing architectural spaces are an important factor in the disabled community. During 2005 in France, a law was instituted that requires public buildings to be in accordance with specific accessibility standards before 2015 [13]. Standard regulations and practices for accessibility guidelines for buildings and facilities in the USA may be found in the Americans with Disabilities Act (ADA) [14], with the relevant SA accessibility guidelines for buildings and facilities may be found in [15]. Augmented reality platforms may mainly be used to determine the accessibility of architectural space and the possibility of training electric wheelchair users in a fictitious environment and may readily be used in multi-functional virtual architectural and therapist evaluations [16] for the generation of obstacles to be encountered in simulation form, such as humans, cars, walls, slopes and different ground conditions.

2. Related work

In the early 1980s, Daimler-Benz in Germany launched a driving simulator [17], which created wide interests throughout the world. Most common motion systems of driving or flight simulators use six degrees of freedom as the Gough-Stewart platform [18]. The Gough-Stewart platform architecture, however, is very complex to control, with additional disadvantages as complicated forward kinematics, singularity, a relatively small size workspace and coupling between different freedoms, which minimises its application in industrial and academic fields. For 15 years, virtual reality based systems have been developed to address cognitive, motor, and behavioural disabilities in the areas of assessment, rehabilitation and training [19]. In [20], an application of the Stewart Platform was used to convey motion to a wheelchair user. The design was done by Mitsubishi for the National Rehabilitation Centre for Persons with Disabilities in Japan. The chair which is designed to represent an electric wheelchair is fixed and is not interchangeable with other electric wheelchair models. The main disadvantage of the system in [20] is that the user will not be able to use their own wheeled mobility on the platform. A further example of a wheelchair simulation platform in virtual reality is reported by Dr. M. Grant [21,22] of the University of Strathclyde. This platform has the ability to generate feedback representing different floor coverings to the user, and the effect of approaching different slopes is visually experienced. The existence of virtual reality wheeled mobility motion platforms, while acknowledged, has been associated with a specific functional property in mind. The use of a user's own wheeled mobility becomes an important factor when wheelchair-user configuration and wheelchair stability is addressed. Various wheelchair constructs exist, their foremost purpose being to give a disabled person the ability to be mobile that forms an integral part into an enabled environment [23,24].

The first wheelchair with adjustable seating and footrests was recorded in the 17th century [4], although as early as in the sixth century C.E. recordings of wheel-based furniture were already made. From the wheelchairs developed in the early 17th century the operation stayed largely the same, with two driving wheels and two caster wheels. Consequent dynamic wheelchair models with two driving wheels and two caster wheels may be found in [25–27,28]. From this general wheelchair construct and operation, the kinematic model [29] and dynamic model will be formulated and implemented on the augmented reality platform, in order to obtain a good representation in a simulated environment.

The research into and consequent design of the Virtual Space-1 (VS-1) augmented reality platform's conceptual design to be found in Fig. 1, address all of these required functional shortfalls that may exist of current simulators. It is important that a proper interface between the virtual reality environment and physical feedback exist in order to provide an accurate model representation, that is dimensionally consistent, visually compelling and simulates the physical constraints as experienced in a real world environment. In this work the design of an augmented reality platform in an enabled environment is based on an open design approach. Utilising such an approach, the various factors determining the most important functionalities of a wheeled mobility simulator, to be used in an enabled environment, were addressed. VS-1 addresses the research objectives set down by the multi-factorial wheelchair-user configuration, wheelchair stability, wheelchair training, assistive technology training and architectural evaluations.

3. Description of the designed VS-1 augmented reality platform

The designed augmented reality platform VS-1 is used as a differential drive simulator for conventional wheelchairs and may be adapted to other drive mobility aids [30,31].

Various mobility aids may be found in Table 1, with a table extension to indicate the ability of the current VS-1 augmented reality platform to host a certain type of mobility aid. The case of possible operation on the VS-1 augmented reality platform is determined by factors such as mobility aid size, weight and driving configuration. The area size of the motion platform is 2 m (length) $\times$ 1 m (width) with a usable mobility aid evaluation area of 1.2 m (length) $\times$ 0.85 m (width) (Fig. 1). The maximum weight to carry is 250 kg including the mobility aid and user. With front steering electric scooters the centre linear velocity in a global reference frame need to be determined by addition of driving angle detecting hardware.