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Nottingham Robotic Mobility Assistant (NoRMA): An Affordable DIY Robotic Wheelchair Platform

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I. Introduction and Motivations

In 2008, the world health organisation estimated that sixty-five million people needed wheelchairs (10% of the disabled population and 1% of the global population at the time) [1]. Wheelchairs help to improve mobility, independence, and dignity of their users, allowing them to partake in work, attend school or college, and engage in social activities with their family and friends. Unfortunately, not all users are able to use a regular manual wheelchair. Powered wheelchairs offer users a significantly more comfortable experience in the hands, arms, and upper body, and have been shown to improve the user's mobility and independence, enabling participation in work and new activities, whilst simultaneously reducing pain and discomfort [2, 3, 4, 5]. Despite being able to accept a much larger userbase, powered wheelchairs still present difficulties such as navigating through crowds and manoeuvring backwards and through confined spaces [6].

A robotic, or smart, wheelchair is a powered wheelchair with additional sensors and processing equipment, which is designed to help individuals who struggle with or are unable to operate standard mobility systems. These individuals typically have difficulties with manoeuvrability and would benefit from additional features such as object avoidance or navigation systems [7].

There is a glaring issue with the adoption of this technology however: commercially available smart wheelchairs are incredibly expensive or still in development, and most published experimental systems being only briefly described in papers where they cannot be easily reproduced. The prohibitive cost of these systems or advanced knowledge required to build one, has created an inaccessible accessibility market. Whilst a significant amount of research and development has gone into creating smart wheelchairs with alternative inputs, control methodology, and processing capability, little has been done to make these features easily accessible to the users that need them the most. Furthermore, people that wish to contribute to this research must often pay large sums of money to gain access to the smart wheelchairs or robotics platforms necessary to complete their research, thus creating a demand for an affordable platform.

In this work, we discuss the development of the Nottingham Robotic Mobility Assistant (NoRMA) and present our effort to develop a publicly available and easy-to-follow DIY (do it yourself) guide for wheelchair users and researchers to build their own smart mobility devices using affordable components. The focus is less on any innovative control mechanisms and more on accessibility of components, the ease of implementation and quality of the overall solution. The DIY guide for NoRMA can be found here[1].

II. Related Work

In [7], Leaman and La undertook a systematic review of existing smart wheelchair research. Out of the one hundred and fifty-five references, fifty-four looked at interaction methodologies, forty-one looked at the human aspect while using smart wheelchairs and the remainder looked at environmental sensing. This raised two key observations: The published work is predominantly looking at input methodologies with few attempts being made to make any reference available to consumers, and there has been no noted attempt in academia to publish a guide on how to build any of the referenced systems.

One example was found [8] in which Torres et al. created an affordable smart wheelchair designed as a cheap and accessible competitor to commercial solutions. This wheelchair is ROS powered with a bimodal voice control and joystick interface, stereo camera, 2D lidar, IMU (inertial measurement unit), TOF (time of flight) sensors and wheel encoders. This paper is insightful and proposes a cheap, easy to implement control system. Whilst the system proposed in this paper is the insightful, the paper fails to discuss details of the hardware and physical design of the system short of the components used making reproducibility challenging.

III. Design

A. Motivation and description of work

The aim of this work is to develop an affordable research platform for smart wheelchairs that could be easily constructed to fit the user's needs. This platform is designed to use common components, which can be easily retrofitted to an off-the-shelf powered wheelchair to allow for easy construction. An accompanying easy-to-follow DIY guide is created to allow for easy installation and reproduction. The guide details the modifications to create the NoRMA (Nottingham Robotic Mobility Assistant) platform, however it is written in a way to enable conversion of any powered wheelchair platform into a robotic mobility assistant.

The defining tenet of this project is *off-the-shelf*, where we exclusively selected components that are easy to use and commercially available at affordable prices. In addition, any requirement for advanced knowledge or an understanding of complex techniques are abstracted away. Restricting the wheelchair specifications in this manner ensures that the platform is as accessible as possible by reducing the cost of components and the required knowledge for self-assembly.

[1] https://github.com/HCRLabRepo/NoRMA

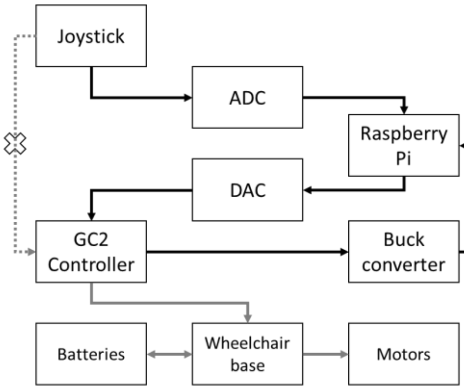

Figure 1. System diagram with original connections shown in grey and new connections in black. Severed connections shown with dashed line and a cross.

B. Implementation

NoRMA platform consists of two parts as shown in Figure 1: a hacked PG (Penny and Giles) GC2 joystick controller that interfaces with a powered wheelchair and a Raspberry Pi with easy to assemble hardware that acts as the brains of the platform. The wheelchair base used in NoRMA is Jazzy Select 6 from Pride Mobility.

The GC2 controller is a joystick commonly found on powered wheelchairs and contains four hall-effect sensors linked together in pairs of two in a same-ramp configuration. This configuration is designed to detect faults in the joystick as the rate of increase for each sensor in a pair should be the same, with the difference between the sensors also being the same. To enable control of a wheelchair, these sensors are emulated by passing them through to Raspberry Pi. Whilst it is possible to directly control the motors of a wheelchair, the high current and battery management required to do this adds an unnecessary level of complexity and cost. Modifying only the joystick is cheaper, easier, and safer than directly interfacing with the motors and batteries.

As the GC2's hall-effect sensors are analogue, a four-channel analogue to digital converter (ADC) is used to interface them with the Raspberry Pi. A four-channel digital to analogue converter (DAC) is added to allow the Pi to output control signals back to the GC2. The ADC, DAC, and a buck converter power supply are mounted on the shared circuit board to power the Raspberry Pi and send signals to and from the GC2 independently of any other circuitry or power. Two ethernet cables are used to link the joystick hall-effect sensors with the Raspberry Pi. These cables carry four control signals to the Pi, four overriding control signals back to the GC2, and power using the GC2's power supply. All modifications are explained in detail in the DIY guide[1].

C. Affordability and customisablility

To build NoRMA, costs are incurred only to buy the DAC, ADC, Raspberry Pi, circuit boards, connecting cables and their enclosure. Including the cost of the powered wheelchair (£1500), the entire system can be constructed for under £2000. The system can then be easily tailored to the needs of the user by adding additional sensors and/or computing, as necessary. This modularity ensures spending is limited to what is necessary for the user. The closest alternative commercial solution is a smart add-on for a powered wheelchair and is significantly more expensive costing at least $8,000 [9]

IV. Summary and Implications

This work took significant efforts to complete as the assumption was that a common piece of equipment, such as a powered wheelchair, would have substantial documentation to aid maintenance and customisation for a user's needs. Unfortunately, the documentation available to end users was limited and components had to be reverse engineered to enable customised robotic functionality. This unfortunately supports the gap between academic research and its translation to end-users, especially regarding assistive technologies, which are generally too expensive to be gain widespread use. In this sense, DIY guide is expected to significantly benefit researchers and end-users by creating capacity to build customised systems in an easy and affordable way.

NoRMA and the accompanying DIY guide is designed as a research platform and verified for functionality in the lab. Whilst being made of off-the shelf components means at a base level, the circuitry is not entirely novel, however, its application is. The DIY guide enables customisation and modification for most powered wheelchairs in the market, with the only restriction being the compatibility with a PG joystick. It creates a standard to unleash the potential for exploring custom control systems, interface methods, and AI algorithms for mobility support for future generations of robotic wheelchairs. The affordability of the platform allows for the creation of multiple research systems for the price of a single commercial one and the standard input range means that researchers can easily and cheaply verify, challenge, and build-upon work that uses the same system.

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