Powered wheelchair platform for assistive technology development

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***Abstract*—Literature shows that numerous wheelchair platforms, of various complexities, have been developed and evaluated for Assistive Technology purposes. However there has been little consideration to providing researchers with an embedded system which is fully compatible, and communicates seamlessly with current manufacturer's wheelchair systems. We present our powered wheelchair platform which allows researchers to mount various inertial and environment sensors, and run guidance and navigation algorithms which can modify the human desired joystick trajectory, so as to assist users with negotiating obstacles, and moving from room to room. We are also able to directly access other currently manufactured human input devices and integrate new and novel input devices into the powered wheelchair platform for clinical and research assessment.**

Keywords—component; Assistive Technology; robotic platform; powered wheelchair; obstacle avoidance; research to market.

I. INTRODUCTION

An extensive review of intelligent and assistive wheelchair technology was undertaken in 2005 [1]; another independent review of the technology was undertaken in 2014 [2]. Some of the research projects mentioned in 2005 have continued to influence research [3-6], while other new platforms have emerged [7-9], and some 4,018 papers have been published between 2005 and 2013.

Despite this significant research, little has been done to bring smart wheelchairs to the market [6]. There is a clear need to produce a platform which bridges the gap between academic researchers, the manufacturers, and the end users [10], although one project, IntellWheels [9], has evolved to move closer towards a possible product [11]. The state-of-the-art still lacks a full integration with manufacturers systems; this is a requirement wholly necessary to bring research to the market place.

Our platform was designed for the SYSIASS project [12], with the aim of reducing the technical barrier to perform research on collision avoidance and Assistive Technologies for powered wheelchairs, while providing a simple route to commercializing research, through integrating new systems with existing, commercially available powered wheelchairs.

II. METHODOLOGY

To support a wide range of research projects, the powered wheelchair platform functionality is broken down into a modular system. Communication between each module is fed over a common system RS485 bus configured into a single master and multi-slave topology shown in Fig. 1. The system provides limited processing power within the Communications Module, which is sufficient to run efficiently coded assistance algorithms. If required, additional processing can be made available via a USB-connected PC, or an SPI-connected co-processor, or by simply upgrading the embedded boards used for the nodes and the communication module.

The modular nature of the system thus allows processing work to be shared. Utilizing smart sensor nodes that process their own data, and send only relevant information to the Communication Module when requested, is a method that provides the facility for the addition of many different sensors such as laser ranging and wheel encoders each with localized processing to readily be attached or removed from the platform as desired by the experimental researchers.

To simplify the transition from research to market, the system uses a general purpose communication module supplied by Dynamic Controls to communicate with the DX and DX2 drive systems present on a wide range of commercially available powered wheelchairs.

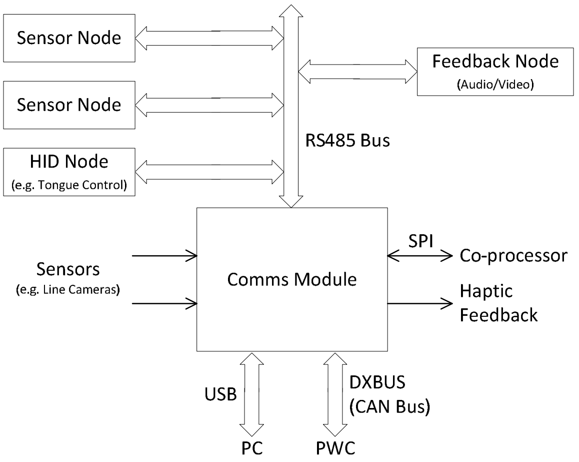

Figure 1- Wheelchair Platform Topology

A. *Sensor Nodes*

Two types of ranging sensors, ultrasonic (US) and infrared (IR) are paired so that they mutually cover a sensor field or zone numbered as 1 to 13 in Fig. 3. These sensor fields on the wheelchair are grouped together by location such that each sensor group (sensor zones 1, 2, 3 are one such group shown in Fig. 2 labelled as the front corner mounted sonar and infrared sensors) is controlled by a dedicated ATmega328 microprocessor board (Arduino Mini). These sensor groups are referred to as Sensor Nodes. These Sensor Nodes are slaves on the RS485 bus; each Sensor Node has a group of 6 attached sensors. For example the node covering sensor zones 1, 2, 3 has 3 Sharp IR rangers, one GP2Y0A02YK0F with a 0.2-1.2M range positioned parallel to the direction of motion, and two GP2Y0A21YK (0.1-0.8M range) sensors, one orthogonal to the direction of travel and the other between them at 45 degrees. 3 HY- SRF05 (0-5M range) US sensors are mounted one above each of the IR sensors.

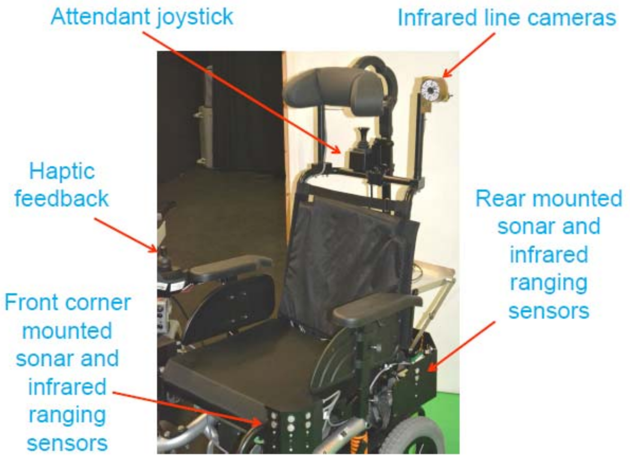

Figure 2 - Wheelchair Inputs and Sensors

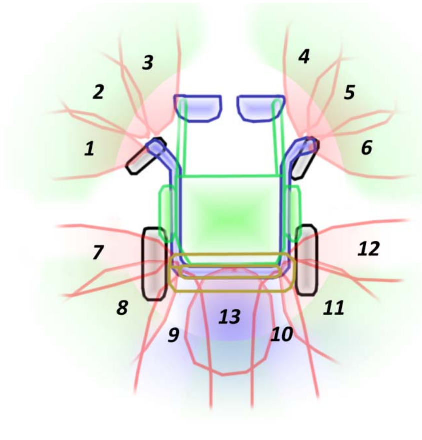

Figure 3- Wheelchair Sensor Zones

The responsibilities of the Sensor Node, schematic shown in Fig. 5, are to enumerate, configure, and synchronize the 6 sensors, fuse the range data of each ultrasound-infrared pair and to send, if called for, the current distance to the closest object in each sensor field to the Communication Module. Additionally, a digital signal can be sent if an object in any sensor field passes a threshold range.

The modular nature of the Sensor Nodes and method of implementation allows new arrangements and different types of sensors to be added to the system transparently; several different models of US and IR sensors were tested on the system without any major issues arising.

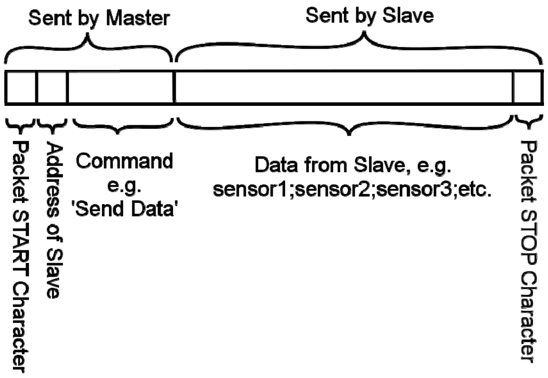

Figure 1 - Communication packet format

B. *Master Module*

The main board or Master Module, schematic shown in Fig. 6, contains the microprocessor board, the Sensor Nodes communications control board, and the General Purpose Serial Board for interfacing with the Dynamics Controls standard wheelchair control system. In our implementation, an Atmel SAM3X8E ARM Cortex-M3 CPU based Arduino DUE was the microprocessor board chosen to run the main system program.

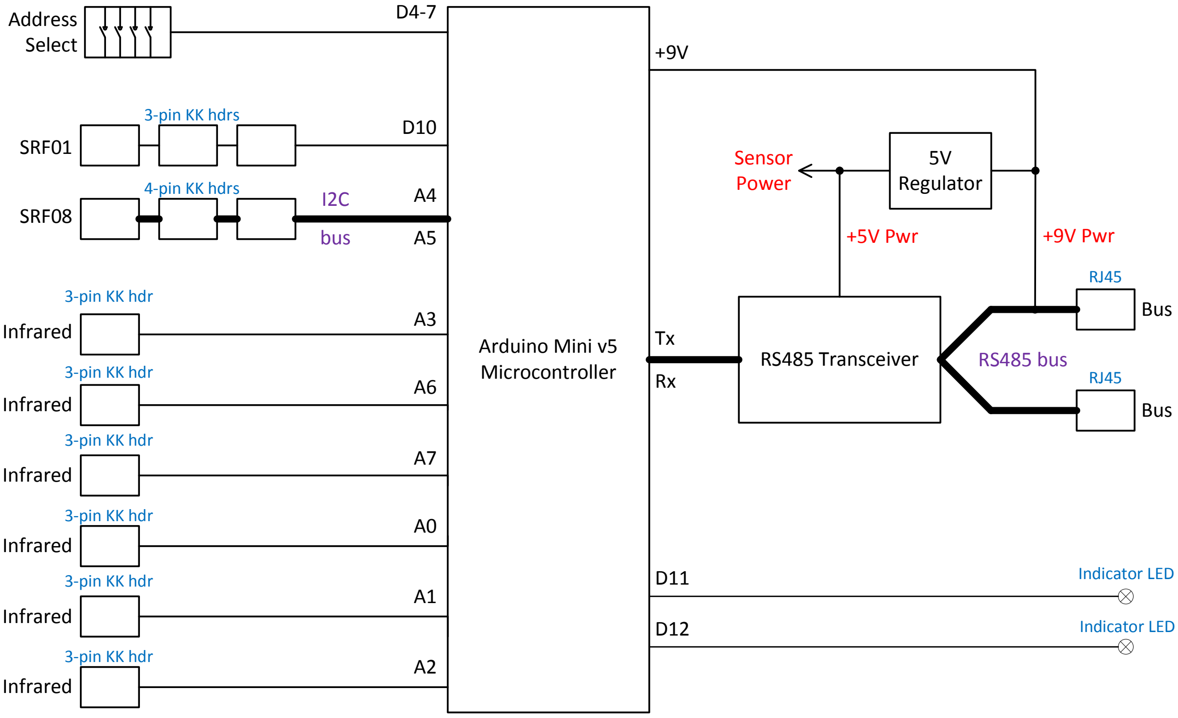

Figure 5 - Arduino Mini Sensor Cluster breakdown schematic

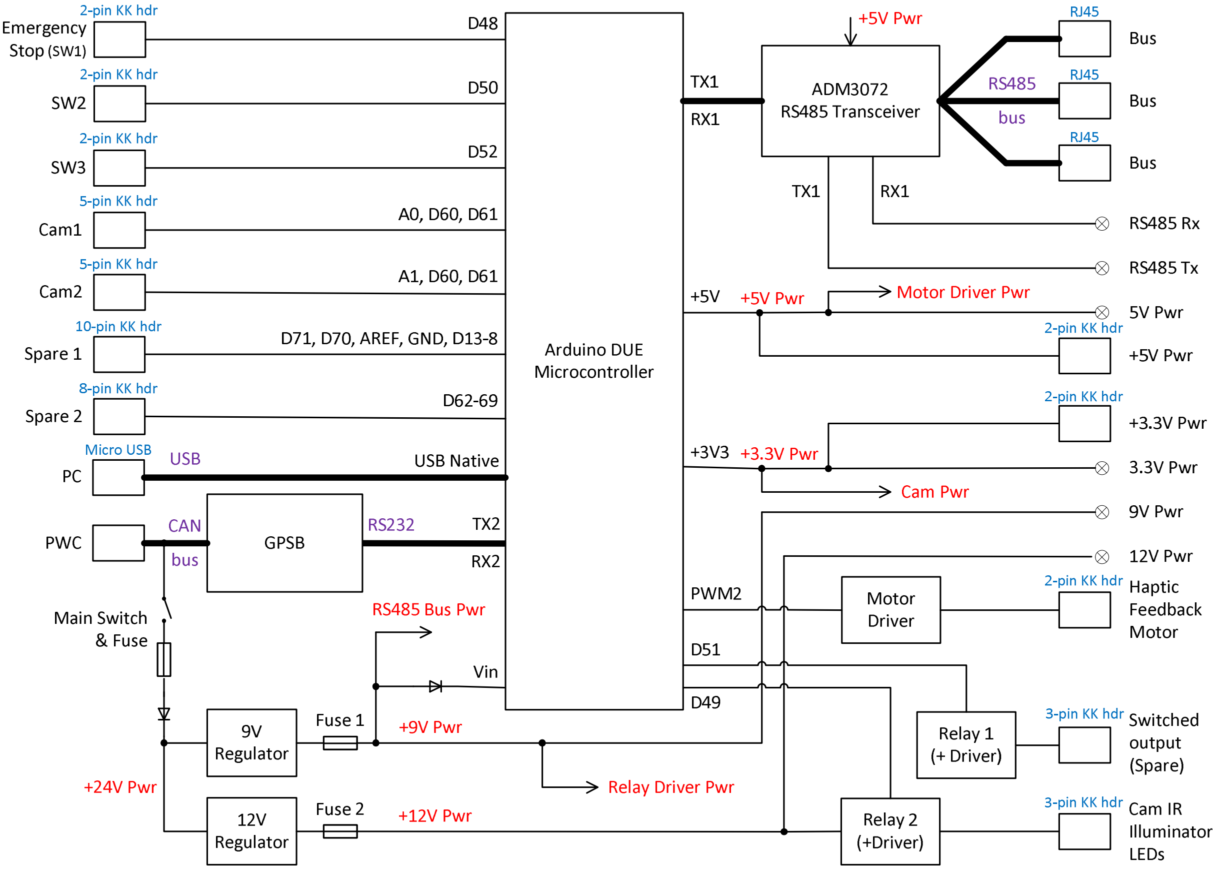

Figure 6 – Arduino DUE main communication board schematic

C. Communications Bus

RS-485 was used for the physical layer of the protocol, as it is robust over long distances, safe (low power), and makes future connection of any additional modules straightforward. Communication over the physical layer was sent in the form of data packets, which consist of a string of ASCII characters, the formatting of a data packet is illustrated in Fig. 4.

The application layer of the communication protocol was designed to minimize latency of sensor data, while maximizing the flexibility of the system in terms of adding and removing sensors. To meet these goals, the system had to allow connection of an arbitrary number of sensors, which are detected on startup, and then the shortest data format which includes all the data from each node was dynamically chosen. The data section of communication packets are therefore of flexible width.

D. System Feedback to Users

A small vibration motor—of the same class used in mobile phones—was implanted into the wheelchair joystick and is directly actuated from the Master Module. This allows a number of vibratory patterns to be used to provide feedback to the user, either warning the user about an obstacle or informing the user about an assistive action being taken by the intelligent component of the system. Additional feedback such as Colour LCD depicitng the user desired and system altered trajectories, or an audible warning, can be easily added to the system either directly connected into the Master Module or through the RS485 bus.

E. Other devices

Additional sensors or Human Input devices can be connected into the system in the same fashion as the system feedback devices. One such device we fitted to provide a better angular resolution for doorway passing were a pair of infrared line cameras using the Parallax TSL1401-DB single, 128 pixel, row imaging device [13] shown attached to the platform in Fig. 2. Another such device developed as a Human Input Device for use on this powered wheelchair hardware platform was the Tongue Palatal Control which utilizes a new and novel method called Resistopalatography [14].

III. EXPERIMENTS

Testing the wheelchair platform system's suitability for use in assistive technology development requires experimentation; a simple test using the ultrasonic ranging sensors was devised to test haptic feedback, and platform dynamic response. We employed a simple threshold stop value to the ranging sensor data, zeroing the joystick input of the user to the Dynamic Controls powered wheelchair controller if an obstacle was detected less than that threshold range of 0.4m and sending a signal to the haptic feedback to inform the user. We then tested the platform response to a series of common obstacles. The wheelchair was set to a maximum velocity of approximately 0.5m/s and the obstacles driven at from several random approach angles between 0 and 90 degrees. We made 100 passes at 9 classes of obstacle and the platform stopped 91% successfully, Table. 1, before collision with the obstacle occurred; warning was given to the user in all cases. The system was able to provide fresh ranging data from all the sensor nodes over the RS485 every 170ms, the total time from joystick sample taken off the GPSB, to the modified returned to GPSB signal, was 181ms. The joystick can be sampled and the signal can be returned in 21ms if the Sensor Nodes are not sampled and instead sensors are directly connected to the Master Module, devices such as the infrared line cameras.

TABLE 1. INITIAL COLLISION AVOIDANCE EXPERIMENT

Class of Obstacle	**Number of obstacles**	**Number of Collisions**	**Reason for Performance**
Walking Stick (2cm diameter)	10	1	Narrow.
Road Cone (0.3m high)	10	2	Small size and low.
Square Metal Bin (0.3m x 0.3m x 0.3m)	10	3	Small size, low, and smooth metal sides.
Secretary's chair	20	0	Complex shape, seat and back had large area.
Person Walking	10	0	Large irregular area and low velocity.
Person Standing	10	0	Large irregular area.
Wall	10	0	Large flat area (rough) and angled array of sensors.
Railings	10	3	Complex shape, very low reflective area to free space ratio.
Cardboard tube (1m high x 0.5m wide)	10	0	Large object with no smooth surfaces.

IV. DISCUSSION

The results from our experimentation show that the zonal coverage, Fig. 3, functions well, ultrasound is slow to update and hence the Sensor Nodes can only update data every 80ms or so although other sensors can be attached either directly to the Master Module or over the RS485 bus as a new node. Fig. 7 shows a figure of eight trajectory obtained from using the Tongue Palatal Control, where that device was used as the human input, directly sent to the Master Module, to drive the wheelchair. They found the trajectory to be comparable in smoothness to the standard powered wheelchair joystick [15]. Another paper presented an obstacle avoidance algorithm using this platform, joystick drive signals were modified according to obstacle distances thereby adjusting the user's trajectory [16].

Our results and other work show that the platform we have developed is able to use new and existing methodologies and algorithms seamlessly within a fully commercial product. Our platform bridges a gap in the assistive powered wheelchair between the standard market hardware and the researcher's requirements; therefore this importantly increases the possibility of users benefiting from future research work because of manufacturer take-up.

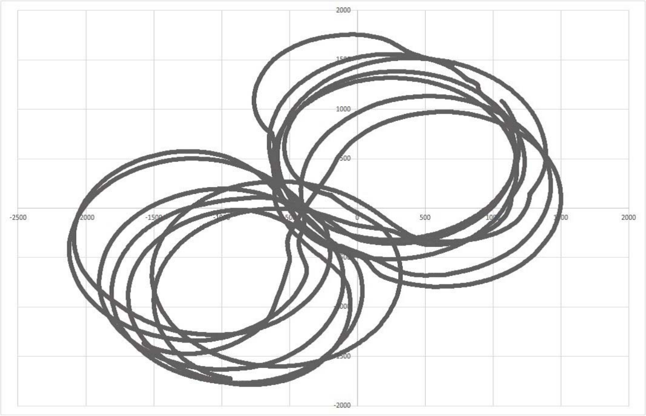

Figure 7 - Trace of wheelchair trajectory, using a Resistopalatography input device, around a figure of eight track

Developing technologies which are suitable for manufacturer take-up require robust algorithms using data from low cost sensors that can be run in a real-time system. This platform is fully capable of integrating previous research and sensors for assisting wheelchair users to safely navigate from room to room through doorways and around obstacles which meet these requirements [17-19].

The platform has been and will be used to conduct research involving university and health care institutions supported by industry collaboration; during which the platform's capacity to implement assistive control algorithms has been and will be demonstrated. Future work will be to expand and further refine this hardware to also allow higher level complex functions such as visual camera based algorithms to be employed for more complex navigation and path planning research.

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