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An Update on International Robotic Wheelchair Development

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ABSTRACT

Disability knows no boarders, so the development of assistive technology is an international effort. This review is a follow up to our previous comprehensive review (Leaman, 2017) and a recent mini-review (Sivakanthan, 2022). The transition from Power Wheelchair to Robotic Wheelchair (RW) with various operating modes like, Docking, Guide Following, and Path Planning for Autonomous Navigation, has become an attainable goal. Thanks to the revolution in maintenance robots and aerial drones for the consumer market, many of the necessary algorithms for the RW software have been developed. The challenge is to put forward a system that will be embraced by the population they are meant to serve. The Human Computer Interface (HCI) will have to be interactive, with all input and output methods depending on the user's physical capabilities. In addition, all operating modes have to be customizable, based on the preferences of each user. Variables like maximum speed, and minimum distance to obstacles, are input conditions for many operating modes that will impact the user's experience. The HCI should be able to explain its decisions in order to increase its trustworthiness over time. This may be in the form of verbal communication or visual feedback projected into the user's field of view like augmented reality. Given the commitment of the international research community, and the growing demand, a commercially viable RW should become reality within the next decade. This will have a positive impact on millions of seniors and people with disabilities, their caregivers, and the governments paying for long-term care programs. The RW will pay for itself by reducing the number of caregiver hours needed to provide the same level of independence. The RW should even positively impact the economy since some users will have the confidence to return to work, and many will be able to participate in social events.

Keywords: Robotic wheelchair, Assistive technology, Human computer interface

INTRODUCTION

The demand for assistive mobility technology is greater than ever, in part because the population of survivors continues to grow, but also because the stigma surrounding disability is getting smaller. Millions of people around the world could benefit from a power wheelchair (PW) to get from one place to another. The first PWs had a seat with two electric motors and a joystick, but many potential PW users find it difficult or dangerous to use a traditional joystick to navigate, so they rely on a companion to use the joystick to propel their chair. A Smart Wheelchair (SW) is a PW that has been upgraded with a collection of environmental sensors, computers, and lights. A Robotic Wheelchair (RW) is one evolutionary step further because it also includes artificial intelligence (AI) to process the sensory data in real-time, and additional motor controllers so that the data can be used for autonomous navigation. The transition to RWs, that cooperate with the user, is at least as important as that from manual to powered wheelchairs. It could be even more important, since it would mark a paradigmatic shift, rather than merely a technological improvement (Pineau, 2011). The RW will help people with severe disabilities today and in the future, lead safer, more independent, productive lives. According to Future Market Insights, the demand for RWs is anticipated to grow significantly in the next decade (2022–32).

Leaman (2017) is a review of the international SW research effort, with multiple groups developing prototypes to test a new input method, or perfect challenging operating modes. Other groups perform human trials to study the best ways to make people feel comfortable to use the new technology. We found that there was still a need for a RW upgrade kit that includes all the technology to convert a standard PW to a RW. The reason we believe an upgrade kit is better than a stand-alone RW is that users would not have to trade in their trusty PW, a platform they have gotten comfortable with.

Our proposed RW upgrade kit is the culmination of 28 years of research by Dr. Leaman (JL), who has been paralyzed from the shoulders down since 1996. The first upgrade was a rear-view camera, and remains a vital safety feature in the 2024 edition. The dash-cam video provides the point of view of the RW user. We encourage users to submit video clips capturing the accessibility of popular destinations and events in their neighborhood. An infrared scanner can be used to build a point-cloud map of the RW's surroundings, however, 3D maps can also be generated from at least 2 video feeds. With the sensors and computers in place, several operating modes become possible (See Table 1).

Following this introduction, Section 2 discusses the background and methods used for our review, Section 3 lays out the future of RWs, and finally, Section 4 is the conclusion.

BACKGROUND & METHODS

We pick up our review where the mini-review of Sivakanthan et al., 2022 (S22) left off. In particular, the RW taxonomy in S22 was very useful for organizing RW research into groups. After conducting a simple Google search for the key phrase "robotic wheelchair" we found that 19 of 34 references were webpages. The biggest difference between our review covering 2005–15 and the current review is that a larger fraction of the references are now websites. Two of those are online stores and four are online news magazines. The rest are web pages dedicated to RW research groups, including years of research and often multiple prototypes.

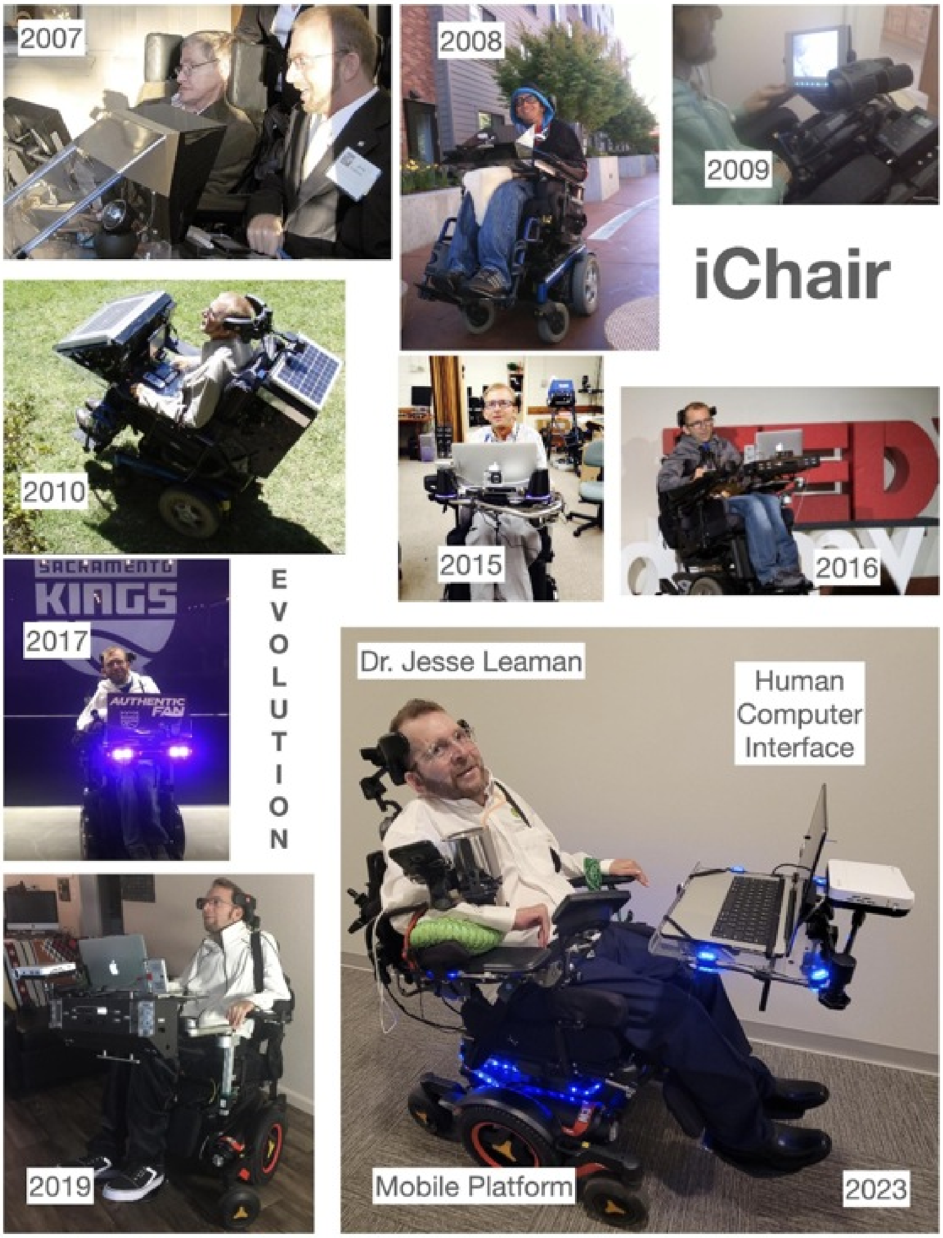

Figure 1: Evolution of Dr. Leaman's smart wheelchair.

See Figure 2 for images of the latest RW prototypes and concepts. The first row features: 1) the University of Pittsburgh's MEBot; 2) the Adventus, a collaboration between the University of Toronto and the University of Washington, 3) a RW from Saudi Arabia, and 4) the latest RW from Switzerland. The second row features: 1) an autonomous RW by MIT, 2) the BallBot by the University of Illinois developed with a $1.5 Mil. NSF Grant; 3) the Centaur a SW designed for the masses by former Ford executives, and 4) the Mobius a follow-up to the iBot. The third row features: 1) a concept model of a RW for toddlers by Cornell, 2) a Romanian RW, 3) a RW by Northwestern University, and University of Michigan's RW, called the Vulcan. The fourth row of Figure 2 features: 1) a RW by Spanish researchers; 2) a Japanese RW, 3) a RW designed to play tennis, and 4) a RW with a robotic arm for assisting with daily living activities.

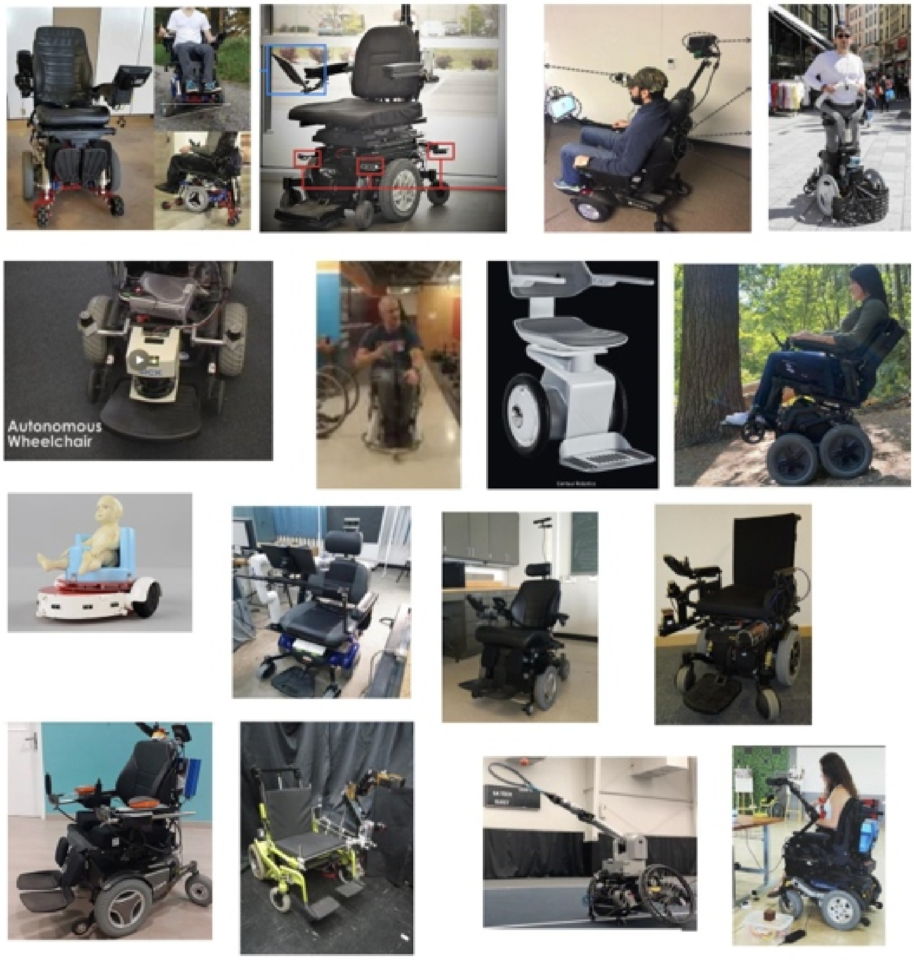

Figure 2: Examples of robotic wheelchairs from around the world.

RW Upgrade Kit

The RW is a combination of hardware electronics and custom software. The PW Platform is the foundation on which various sensors and input/output methods are mounted. Dr. Leaman has been upgrading his PW since 1998 when he was a NASA intern. See Fig. 1 for pictures of the evolution of his PW to SW.

Platform

The specific configuration of the seat, arm/foot rests, lateral supports, headrest, and recliner should be chosen by the user's physical therapist. We find that PW users prefer to use the platform best suited for their particular capabilities. A robotic arm mounted on the PW can even help open doors and play tennis. If combined with an Exoskeleton, the robotic arm can help with upright mobility (Hernandez-Ramos, 2022).

Wheels: The number of wheels and their location varies from one PW make/model to another. Front wheel drive and Center wheel drive are most popular, but there are also Stair climbers and even Tracks. Center wheel drive allows for a very small turning radius but will start by turning first. The Front wheel drive on the other hand starts by going straight, but has a larger turning radius.

Input Methods: When a joystick is not an option, the RW user can activate single switch controls via sip & puff, or head tracking. There is also voice command, but that doesn't work very well in noisy environments. Vision-Language-Action AI research is an important input modality. The 'holy grail' of input methods remains the brain computer interface (BCI), but current electroencephalograph (EEG) technology is not yet accurate enough to safely operate a vehicle like a PW, however the folks at Neuralink are currently conducting human trials of an implanted BCI that shows a lot of promise.

Output Methods: There have to be some electronics included in the kit for the RW to communicate with its user and the rest of the world. This includes speakers and lights, plus a computer monitor with or without touchscreen. Finally, there are wearable monitors for an augmented reality or full virtual reality experience.

Human Computer Interface

The Human Computer Interface (HCI) software should be more than just a collection of individual operating modes, even if they are fully customizable by the user (See Tab. 1). The ideal HCI is simple and elegant, with a drop down menu and fillable pop up windows. Not long after customization the user should feel like the RW fits like a glove. The HCI will have several operating modes that have to be developed and tested in human trials. We had to adapt various algorithms related to autonomous navigation, localization, and mapping by mobile robots to the PW platform (Hung, 2017). There are many researchers taking up the challenge, Alonso (2021), Bakouri (2022), and Kutbi (2023). The future of the HCI is explainable augmented reality projection in the field of view.

Mobile Office: Arguably, the most practical mode is as a mobile work station. The combination of mount-n-mover and laptop/tablet gives the PW user a level playing field with their able-bodied peers. In fact, some might say that not having to worry about the weight of the computer is actually an advantage. JL uses his laptop for Command Line Coding; Charts, Tables and Spreadsheets; Letters, Resumes, and Contracts; Typesetting for Conference Proceedings, Grant Applications, and Business Plans; as well as Capturing and Editing Video.

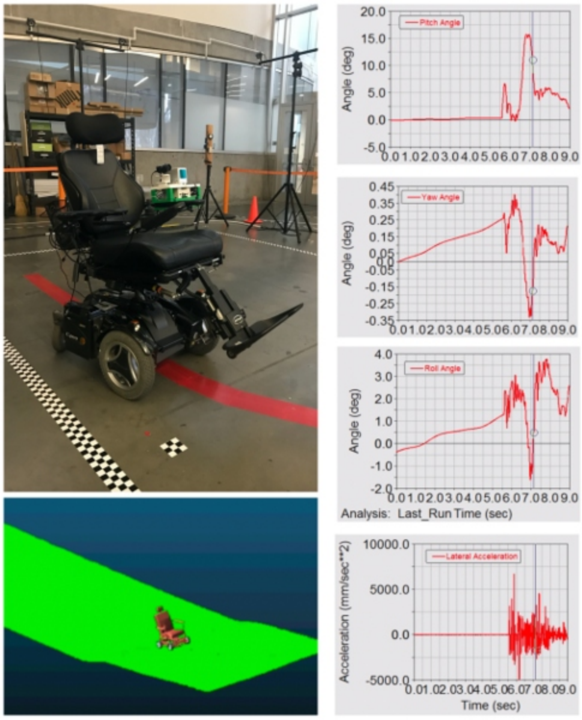

Figure 3: Situational awareness algorithm builds a 3D map of the RW's environment.

Emergency Signaling: In case of an emergency the RW will send a message, blink lights, and broadcast a distress call. This basic mode can detect emergencies, like tipping back, or falling over, by monitoring the inertial measurement unit (IMU) data. Future upgrades will use bio-sensors like pulse, blood oxygen, blood pressure, and forehead temperature to detect user stress levels. This mode should be standard, running behind the scenes at all times.

Mapping: Maps should begin with a 2D representation of the PW's immediate surroundings in order to achieve situational awareness. By combining data from an IMU, and wheel encoders, with the point cloud from an infrared scanner, we can perform EKF localization, (See Fig. 3) [Hung, 2013; Lim, 2014; and Nguyen, 2016]. Then we use object detection to locate all the static objects in the environment to build up an increasingly accurate map. These serve as reference points for previously discovered mobile objects, and makes it much easier to detect and track multiple new objects (Pereira, 2022). This works adequately well for one room at a time, but for larger spaces the memory, and processing requirements are quite high. One solution is to stream the data to the cloud for processing and storage, but that requires a strong internet signal, which is hard to guarantee anywhere in the world. One thing you can do with an accurate 3D map is to model the stability and comfortability of the RW user if they try to navigate a particular location The maximum tilt angle tolerable should be adjustable. The scanners and object recognition can be used for other applications as well. A person with a visual impairment can potentially navigate their environment more efficiently than a traditional cane. A series of clicks or beeps conveys range information, and the camera can identify street signs to aid in navigation.

Collision Avoidance: Some tasks are at odds with the behavior expected from a more general collision-avoidance mode. While passing through a doorway the system must allow the wheelchair to come close to objects to pass through narrow door frames, at the expense of travel speed. It is important to have a robust system, but it must be adjustable to each user's individual comfort level. Minimum distance, beep amplitude, and beep frequency are all adjustable.

Guide Following: When this mode is engaged, the RW locks its gaze on a person or another RW, and follows them until receiving a command to stop. The guide should wear something distinctive so the RW is less likely to lose track of them. Adjustable parameters in this mode include the minimum and maximum distance to the guide, as well as the default guide and their recognizable features.

Docking: In this mode the RW takes the latest environmental data and knowledge of user preferences, to find the best parking spots inside their homes, office, or on public transportation. This mode can be customized by choosing favorite parking spots and the maximum speed to use on approach.

Path Planning: All of the aforementioned operating modes can work with, or without, a motor controller, but all are needed for safe autonomous navigation. The HCI has Object Tracking and Situational Awareness that rapidly builds 3D maps of its surroundings. New RW users interested in autonomous navigation should register their system, and take a wheelchair skills test to certify their ability to safely operate the RW. Users should have the ability to switch between modes and choose from destinations on a map. Variables like maximum speed and acceleration should be adjustable.

Table 1. Human computer interface.

Operating Mode	Variable	Symbol
Mobile Office	Applications	App_1, …, App_i
	Input Method, Output Method	Joy, Head, Eye, EEG, Audible, AR, VR
Emergency Signaling	Contacts	tel_1, …, tel_k
	Color/Pattern Frequency & Magnitude	col_1, …, col_j, freq_es, mag_es
Mapping	Maximum Distance	d_max
	Mode	2D, 3D, Explore
Collision Avoidance	Frequency & Magnitude	freq_ca, mag_ca
	Min. Distance, Mode	d_min, Warn, Auto
Guide Following	Min. & Max. Separation	sep_min, sep_max
	Formation	Line, Pair, Diagonal
Docking	Favorites	Fav_1, …, Fav_l
	Mode	Directions, Auto
Path Planning	Max. Velocity & Accel.	v_max, a_max
	Map Mode	Home, Work, Guide, Auto

CONCLUSION

In this paper we review the international Robotic Wheelchair (RW) research and development effort up until 2024. The ideal RW is intuitive, upgradable, and easy to maintain. We have been testing the hardware and software functionality of the Human Computer Interface part of our RW upgrade kit, making sure that sensors are in the right locations, providing the quality of data needed for situational awareness and 3D mapping. The RW should become a standard PW upgrade, so that users can lead safer, more efficient, independent lives.

RWs are supposed to benefit the greatest possible population, so PW users should be able to upgrade their own chair, and not have to buy a brand new wheelchair platform. There are dozens of groups around the world working on their unique RW prototype, but there are in our view only two RWs that are close to being commercially viable, the Adventus and the Mobius. There are as of yet no complete RW upgrade kits. Given the enthusiasm of the assistive technology community, we are optimistic that a commercially viable RW is only a few years away.

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