Smart Wheelchairs or Not: Lessons Learned From Discovery Interviews

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***Abstract*— Our team has been selected as an Innovation Corps (I-Corps) Team by the National Science Foundation to pursue customer discovery research to explore the commercial viability of smart wheelchairs. Through the process, our team has performed more than 110 interviews with electric wheelchair users, manufacturers, therapists, policy makers, and non-profit organization directors. Our findings revealed that the acceptability of fully autonomous systems by the users is still challenging and highly-dependent on the severity of the disability. Furthermore, the cost, ease-of-use and personalization are the most important factors in commercializing assistive robotic technologies.**

I. Introduction

As with any durable medical device, wheelchair use worldwide is driven by a number of factors including injury and illness rates, economics, and rehabilitation goals. Our initial research in the development of semi-autonomous control systems for wheelchairs was driven by a need in a particular population, those suffering from a condition known as Locked-in Syndrome [1], [2]. During our work to build functional prototypes, the broad application, and acceptance of these technologies by individuals using electric wheelchairs seemed obvious. We initially assumed individuals dealing with the effects of aging, spinal cord injuries (SCI), and Amyotrophic Lateral Sclerosis (ALS) would also benefit, and accept new semi-autonomous electric wheelchairs. Based on these assumptions we examined the populations dealing with the effects of aging, SCI, and ALS in addition to those suffering from Locked-in Syndrome (LIS).

It is well documented in the literature that aging in place improves the overall health and well-being of patients, and that falls are the leading cause of mortality, and a need for mobility assistance in older adults[1] [3]. 31.7 million[2] older adults are living in the community [4]. Further, 30% of those living in the community are living independently [5]. Of those living independently, 30%, as well as 50% of those living in long-term care, will fall at least once each year [5]. Increased morbidity is due to the association between falls and higher anxiety, depression, loss of confidence, and the onset of post-fall syndrome [6]. Any fall can lead to serious injury, but falls also commonly lead to long-term care placement, functional decline, or even death. Additionally, the prevalence of falls among older adults, lead many to develop a fear of falling [7].

It is projected that in 2030, there will be 4 people for each person over the age of 65. Among these four people, one will be a child, one will be sick, and one will be at a distant geographical location relative to the individual who needs care [8]. This implies that the ratio of available caregivers to older adults will approach 1-to-1 in 2030. Furthermore, it takes approximately 6.5 hours per day to care for a frail older adult. The care requirements are not sustainable for a family member while maintaining full-time employment [9]. The increased need for independent mobility solutions in this population seems clear.

SCI, ALS, and LIS are all degenerative conditions which lead individuals to an increased dependence on caregivers. In the case of LIS, the individual will lose all mobility including eye movement control. For ALS patients, the degeneration of mobility approaches that of LIC as the individual ages with the disease. Patients recovering from SCI have a variable degree of mobility which depends on the injury site, and other co-morbidities. In all of these cases, the rehabilitation goals can be very similar depending mostly on the age group of a particular patient. For the sake of brevity, we will focus on SCI rehabilitation here.

In order to determine treatment goals with the highest impact on the patient, clinicians attempt to take a client-centered approach [10]–[14]. For patients recovering from SCIs, the top three categories of rehabilitation goals (ranked in order of most to least important) tend to be self-care, productivity, and lastly leisure. The self-care goal category is well documented throughout the rehabilitation literature as the highest rated goal by patients. In terms of self-care, the three specific tasks rated as most important by SCI patients were functional mobility, dressing, and grooming [12]. The meaning of functional mobility is highly dependent on the patient. In many cases, functional mobility can simply be maneuvering inside one's own home. In other cases, functional mobility may require the patient to be able to enter, and possibly drive, their own vehicle. The need for customizable control systems seems clear based on this populations continuously changing needs.

Robotics technologies, *the integration of sensing, computation and actuation in the physical world*, can be used to enhance the capabilities of a person with a disability, and possibly allow that person to perform activities of daily

[1]Older adults are defined as those 65 years old and older.
[2]http://www.wolframalpha.com/ (search: people over 65 in the US)

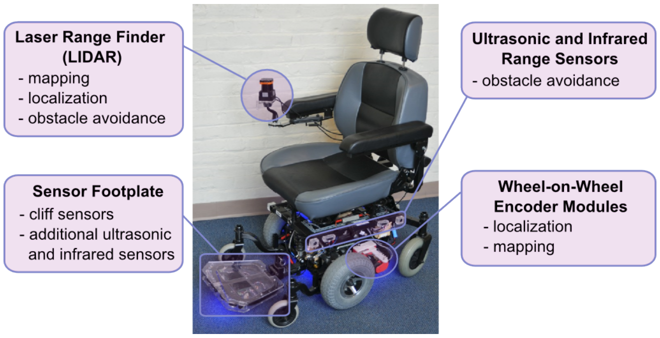

Fig. 1: A commercial powered wheelchair transformed into an assisted mobility platform.

living (ADLs) which the disability might otherwise prevent the individual from doing independently [15]. While robots will not completely replace human caregivers, robotics technologies can help to extend the time in which an individual can spend in independent living situations, particularly for older adults.

Semi-autonomous wheelchairs are an example of a robotics technology that may enhance the quality of life for older adults, as well as for individuals with physical, or cognitive disabilities. The research on (semi-)autonomous wheelchairs has been on-going for more than 20 years however, there are no commercially available systems in the market.

Based on our assumptions for the need of a commercial implementation of a semi-autonomous wheelchair system, our research team applied to, and has been selected, as a result of a competitive process, for a relatively new National Science Foundation (NSF) program called Innovation Corps (I-Corps) Teams [16]. The I-Corps program is designed to extend the focus of NSF funded scientific research projects beyond the laboratory and into commercial applications. The I-Corps Teams receive training from a network of entrepreneurs, and mentors. The goal of this training is to help researchers to identify valuable product opportunities that can emerge from funded research projects.

Our I-Corps Team investigated the commercial viability of a family of products including stand-alone sensor modules (encoder, cameras, range finders) as well as controllers (low-cost embedded systems running navigation and control algorithms) and control interfaces (tablets, smart phones) that will convert an existing motorized wheelchair into a semi-autonomous mobility platform. Figure 1 shows WPI's intelligent wheelchair which formed the basis for our translational research project.

In this paper, we share the details of our approach to customer discovery, and our lessons learned about whether motorized wheelchair users are ready for *self-driving* wheelchairs.

II. Motivation

Our work is highly motivated by user needs. Prior to our I-Corps participation, we focused on a literature based understanding of user needs. In particular we decided to focus our design efforts on systems that would improve the safety, and accessibility of a wheelchair. This is primarily due to the adverse affects on individuals due to wheelchair breakdowns, and key causes of injuries due to wheelchair use (tipping and rolls due to ramps and terrain) [14], [17]. Additionally, we have focused on user groups who had a prognosis that included continued degeneration, and the eventual lack of motor skills required to operate a traditional wheelchair. Our focus resulted in a suite of sensors and control interfaces which were coupled with mapping, localization and navigation algorithms [1], [18], [19].

Based on our research results, and our assumptions of need in the populations previously discussed, we began working toward understanding how the products could be brought to market. We estimated a profitable market opportunity, and included our estimates in a proposal to the NSF I-Corps program.

> Given market research reports projecting that global power wheelchair market will reach $3.9 billion by 2018, the potential commercial impact of the proposed commercialization effort is significant... We believe, through our shared control techniques that incorporate the context information in human-robot teams and demonstrated technologies for realizing smart wheelchairs, we can provide reliable and personalized means for assisted navigation. We estimate that potential customers (individuals, care providers, caring facilities) will pay on a sliding scale from $1,000 for basic functionality to $10,000 for more advanced capabilities such as modular robot arms. This is comparable to the market price for a powered wheelchair.

Based on our proposal, and prior work, we were accepted to the I-Corps program, and began the process of determining commercial viability of our designs.

III. Approach

We will describe the I-Corps Teams training program here for the sake of completeness. As part of the program, our team has participated in several activities.

A. Kickoff Workshop

We attended a 3-day kickoff workshop which was aimed at setting the standards and expectations from the teams. Each of the 21 I-Corps Teams were composed of an Entrepreneurial Lead (EL), the Principal Investigator (PI), and the I-Corps mentor (IM). The EL is typically a PhD student, or a postdoctoral researcher working under the direction of the PI. The expectation is that the EL will eventually lead the commercialization effort if a viable product is identified. The role of the IM is to continuously mentor the EL, and PI, and provide feedback on interpreting the outcomes of the customer interviews.

B. I-Corps Course:

Teams participated in an online class on *how to build a startup*, and met with the teaching team to present their findings and receive feedback. Each week's activities were summarized in the *business model canvas* introduced by Osterwalder [20]. The canvas included nine sections including value propositions, customer segments, key resources, cost structure and revenue streams.

C. Discovery Interviews:

These interviews are at the core of the program, and they provided our team with great insight not only on our exploration for a path to commercialization but also about our research focus and activities on assistive technologies. Each week, our team conducted discovery interviews with individuals who can provide insight on our product ideas and updated the business canvas accordingly. Over the course of the program, we interviewed more than 110 individuals. The participants included wheelchair users, care providers, family members, policy makers such as the disability commissioners of New York City and Worcester, non-profit organization workers such as the ALS Residence in Boston and National Education for Assistance Dog Services, occupational therapists, wheelchair manufacturers and distributors, other researchers, assisted living facility directors, and disability advocates. Each team member spent more than 15 hours every week outside the lab to conduct these interviews. The interviews were informal as each week we were trying to gain more insight about our hypotheses. However, we kept detailed logs of our conversations and analyzed them weekly.

During the course, and through iterative review processes led by the IM, hypotheses were generated to guide the discovery interviews. This process is best described by example. As a team, we initially assumed that any individual suffering from age related mobility loss, ALS, SCI, or LIS would benefit and be willing and able to purchase add on hardware for their motorized wheelchairs. As a result, our early interviews included open-ended questions that would determine if this hypothesis was accurate. Example questions included:

1) What kind of add-on equipment has been purchased for your wheelchair?
2) Who purchases equipment related to your recovery?
3) What are the usual costs for something you might purchase for your wheelchair?

Based on the responses we received, our hypothesis would have to be refined. In the case of who our potential customers would be, we discovered a subclass of users most likely to purchase the equipment we had designed which we called "performance first wheelchair users". These were the users who adopted technology early, and were more interested in a high performing wheelchair in terms of their own personal productivity improvement. We found that many classes of users had simpler requirements, and would not be as likely to purchase semi-autonomous controls. However, no user indicated to us that the system would be undesirable, but many expressed acceptability concerns. These concerns would lead us to adapt our questions to determine which of our technologies were most acceptable to as many users as possible. The iterations in question-response-refinement continued rapidly throughout the interview process.

D. Closing Workshop:

The I-Corps program concluded with a workshop where each team reported their findings, and more importantly their decision on moving forward, or not with commercializing their technology. Our team identified a valuable product to assist individuals with disabilities who are using motorized wheelchairs. We are now in the process of refining the systems and establishing partnerships. We also continue to get out of the building and talk to users.

IV. LESSONS LEARNED

The most valuable aspect of our team's I-Corps experience was the lessons learned from the discovery interviews. We report the following as a summary of our findings:

I DON'T WANT MORE DRAMA IN MY LIFE. Users see their wheelchairs as part of their bodies. They are challenged daily to carry out ADLs, and live ordinary lives. Any technology solutions should be seamless to integrate, and easy to use. Users who are accustomed to their wheelchairs have little to no tolerance to failures of "new features". As a result, full autonomy or "more autonomy than user desires" in a wheelchair will pose acceptability challenges.

THEY WANT IT ALL. The open-mindedness towards a self-driving wheelchair is dependent on the severity of the individual's disability. For example, as a person with ALS (pALS) progressively loses his or her ability to control their environment, they are open to using new technologies that will provide them with independent mobility. In addition to our performance-first users, we identify individuals with aggressive degeneration in motor skills as the early evangelists of our semi-autonomous wheelchair technologies. There are many well-established not-for-profit organizations in support of pALS, and working with these organizations is an essential business channel.

USER CO-CREATION IS ESSENTIAL. Not all disabilities are the same, not one individual with a physical disability is the same from day to day. Therefore, one solution cannot fit all. Co-designing assistive technology with the users is essential in its acceptability and usability. The challenge is to maintain the technology in a personalized manner as the user's abilities often change over time. Modular and reconfigurable design principles must be adopted.

HOW MUCH IS EXPENSIVE? Interview responses indicated that it takes 8-16 weeks, and costs approximately $25,000 to train Labrador retrievers as companions for individuals in wheelchairs. Most of the costs are covered by non-profits. Our team is now convinced that a system that can provide safety and more situational awareness to a wheelchair user, for example while backing up into a transit van, will be affordable for most if the cost does not exceed the price of a high-end personal computer ($2,000).

SHORT-TERM, SHORT-DISTANCE AUTONOMY IS FINE. Most users will be open to the use of technology to cross doors, to traverse narrow hallways, and get on and off of vans using short-term autonomous behaviors. The term *autonomy* is still very disturbing to most, but short-term, short-distance assisted control features will be acceptable.

ASSISTIVE TECHNOLOGY BETTER LET ME KNOW WHAT IT IS UP TO. A personalized channel of feedback from the semi-autonomous wheelchair to the user is an important feature in order for the technology to be acceptable to users. Individuals do not want to be surprised by the actions of their robotic wheelchair. Since each person's ability is different, this aspect needs to be accounted for at the co-design process.

HOW TO INNOVATE IN THE CURRENT HEALTHCARE SYSTEM? It is a well-known fact that it is very difficult to introduce new hardware systems within the current healthcare system. Hospitals for example can be the perfect playground for autonomous wheelchairs, yet the liability concerns are forbidding. On the other hand, assisted living places, and user-centered non-profit organizations are open to new ideas to improve the quality of life for individuals. Therefore, they are the part of the ecosystem for introducing new innovative technologies. Our interviews indicated that the supply chain for users simply has too many voices. The design and deployment of wheelchair systems to users include input from manufacturers, distributors, installers, and of course users. Additionally, most of these sources are not decision makers in terms of what hardware will be funded. Unfortunately, it appears that the wheelchair users are least likely to affect change in this ecosystem. This difficulty will prove to be a significant challenge for product adoption of any durable medical device.

V. CONCLUSION

Even if the reliable autonomous wheelchair technology is available, are the users ready for it? The short answer is *it depends*. It depends on the severity of the disability, it depends on the individual's overall morale and attitude towards his or her condition. It also depends on how quickly and completely we can put support systems, trained technicians, and services in place. In conclusion, there is a substantial group of early evangelists who are ready to invest in smart wheelchair technologies to improve their mobility and as a result productivity. More work is required to determine the best methods to bring this technology to them.

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