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 the world population ages, functional independent mobility becomes more essential for the well-being of older adults. To demonstrate the impact that practical assistive robotics technologies can have on our society, it is sufficient to look at the current population statistics. Today, there are 7 individuals in the United States for each person over the age of 65. Moreover, 23% of the younger adult population in the U.S. declare themselves as informal caregivers for an individual [1]. 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 [2]. This implies that the ratio of younger adults as caregivers to older adults as individuals in need of care will be 1-to-1 in 2030. According to National Institute of Aging [3], it takes approximately 6.5 hours per day to care for a frail older adult and this is not sustainable for a caregiver while maintaining full-time employment. Furthermore, 75% of the seniors prefer to age-in-place [4].

Robotics technologies, the integration of sensing, computation and actuation in the physical world, can be used to transform the capabilities of a person with a disability in performing the activities of daily living [5]. Robots will not replace a human caregiver in near future, however they can provide an extended independent living for older adults or individuals with physical and mental disabilities, and hence, improve the quality of life for humans. Semi-autonomous wheelchairs will dramatically enhance the quality of life for elderly as well as for individuals with physical and 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. Motivated by these facts, 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 [6]. The I-Corps program is aimed at extending the focus of NSF funded scientific research projects beyond the laboratory to broaden the impact. The I-Corps Teams receive training from a network of entrepreneurs and mentors to identify valuable product opportunities that can emerge from research findings.

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 perform an extensive customer discovery research study in less than two months and report on our lessons learned about whether motorized wheelchair users are ready for self-driving wheelchairs.

II. MOTIVATION

We summarized our motivation for potential commercial impact of smart wheelchairs as follows in our proposal to NSF:

Our proposed innovation is the development of
tightly integrated yet customizable hardware and software systems to enable individuals with mobility. Our typical customer is an individual who already has a powered wheelchair and is in need of assisted navigation in the home. Currently, such individuals rely on the presence of a caregiver to move in their homes. Our vision is that with our products, it will be possible to convert an existing wheelchair into an autonomous mobile platform in less than one-hour. 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. Our ongoing research on human-in-the-loop cyber-physical systems resulted in our modular and reconfigurable designs which motivated the formation of the WPI I-Corps Team. 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.

This statement summarizes well how we envisioned to convert our academic research into a valuable product before we participated in the I-Corps Program.

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. i.

1) Kickoff Workshop: We attended a 3-day kickoff workshop which was aimed at setting the standards and expectations from the teams. Our cohort included 21 teams. Each I-Corps Team is composed of an Entrepreneurial Lead (EL), the Principal Investigator (PI), and the I-Corps mentor (IM). 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. The kickoff workshop was organized and run by NSF Program Managers and a teaching team consisting of entrepreneurs, and academicians. The main message at the workshop was to get out of the building and talk to potential customers to identify a minimum viable product.

2) I-Corps Course: Teams took an online class on how to build a startup and met with the teaching team to present their findings and get feedback. The goal was to populate the business canvas model introduced by Osterwalder [7] with hypotheses and validate or invalidate through interviews. The canvas included 9 sections including value propositions, customer segments, key resources, cost structure and revenue streams. Each week ELs presented their current state of the canvas and plans to continue to test their hypotheses.

3) 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. Our team attended the European Seating Symposium, Medtrade Home Medical Equipment Expo, Chicago Health Technology and Health 2.0 conference, and the Abilities Expo. 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.

4) 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. The I-Corps Program for our team spanned from October-November 2013.

IV. LESSONS LEARNED

The most valuable aspect of our team’s I-Corps experience was the lessons learned from the discovery interviews. Figure 2 presents the final business canvas for commercialization of semi-autonomous wheelchair technologies. It captures what we hypothesized and what we learned from our 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. As is they are challenged in carrying out simple tasks and live ordinary lives. Any technology solutions should be seamless to integrate and easy
to use as 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. We identify such individuals 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 channel for the assistive technology to reach to the users.

**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. Given most wheelchairs are customized in size, add-ons, etc., for each user this goal is realizable. The challenge is to maintain the technology in a personalized manner as the user’s abilities can change in time. Modular and reconfigurable design principles must be adopted.

**How Much is Expensive?** We found out 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 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 Lets Me Know What It Is Up To.** A personalized channel of feedback from the semi-autonomous wheelchair to the user is an important feature of the interaction. Users 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 nearly impossible to introduce new innovative solutions 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.

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 de-
pends 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 earlyvangelists who are ready to invest in smart wheelchair technologies to improve their mobility and as a result productivity.

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