# A Call for Convergence of Research Directions in Assistive Robotics

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## I. Introduction

Assistive robotics is a unique subfield of robotics because it has a direct impact on enhancing the quality of life for people with diminished physical capabilities, social deficits and motor impairments. Although the field has seen considerable progress in the last 10-15 years, several challenges still remain to be addressed. In this paper, we take the opportunity to reevaluate the current research in assistive robotics based on potential and approach. We hope to summarize the research approaches and propose possible areas of improvement. We also hope that this paper will push forward the debate in the assistive robotics community regarding what approaches might be useful for academic research labs in the future for a successful integration of assistive technologies into people's daily lives with high user satisfaction and acceptance.

For assistive technologies to be successfully adopted, various research components must come together in a seamless manner. These components range from design of software and hardware, human-robot interaction (HRI) schemes and technical aspects such as efficient algorithms, sensor technologies and control interface design.

Research groups focusing on HRI in assistive robotics typically work on innovative ideas which will lead to products and research solutions with high user satisfaction and acceptance. Central to most HRI research is the notion that the success of assistive technologies depends heavily on how well the end users' needs are met and how customizable the products are [18]. Furthermore, it acknowledges that a universal solution is unlikely to meet the needs of different categories of end users (patients, caregivers) [21]. Although numerous design solutions and novel human-robot interaction schemes are proposed by groups conducting HRI research, rigorous testing of the proposed design solutions on real hardware with the targeted user populations is not as common [3]. This is likely due to the challenges associated with building the hardware and a lack of access to subjects in the target population. As a result, many of the design models do not find their way to the real world.

On the other hand, research groups that focus on the technical aspects (robot motion planning, perception, human-robot interaction modeling and sensor technologies) are often inspired by the success of engineering techniques and algorithms in related fields, e.g. machine learning in computer vision, and seek to extend these techniques to the domain of assistive robotics. Contrary to HRI and design-focused groups, these researchers often start with a problem, design their own technology and build systems that will address the problem and then finally run the evaluation experiments on human subjects. While effective in solving the defined problem, in most cases the end user is not involved in the process until the evaluation stage.

Therefore, at one end of the spectrum we have research approaches that start with the users' needs and try to generate solutions that will make sure that the system functionalities are in accordance with what the user requires. At the other end, researchers typically start by assessing what functionalities are implementable in a concrete way on a particular hardware platform (such as smart wheelchairs, assistive robotic arms or socially assistive robots) and try to solve the problem using state-of-the-art sensors, hardware technologies and engineering techniques. This often results in functional modules that can perform a small set of tasks such as reaching tasks and grasp detection [23], obstacle avoidance [20], doorway navigation [8], *et cetera*. Finally, the efficacy of the system is evaluated by end users (with and without impairments) through controlled lab experiments (Figure 1).

The important question is whether these research approaches are complementary. In particular, how often do we see progress on one end benefit research on the other end? Research in assistive technologies is a meaningful pursuit that will have an impact on million of lives. As academic researchers do we have responsibilities to the end user communities? If so, besides contributing to the progress of science itself, research should result in the development of practical and usable assistive technologies that are successfully adopted by end users. Therefore, within academic research it is imperative that a balance is struck.

One can see that the above approaches (HRI-inspired and technology-inspired) are dealing with two different aspects of the same problem. Even though some effort has been undertaken to merge these approaches [4, 5], focusing on reducing the gap between these two approaches will increase the utility of research solutions and products, which then will facilitate the adoption of these technologies by the end user.

By reevaluating current research trends and research outcomes we aim to propose future directions that can possibly bridge this gap.

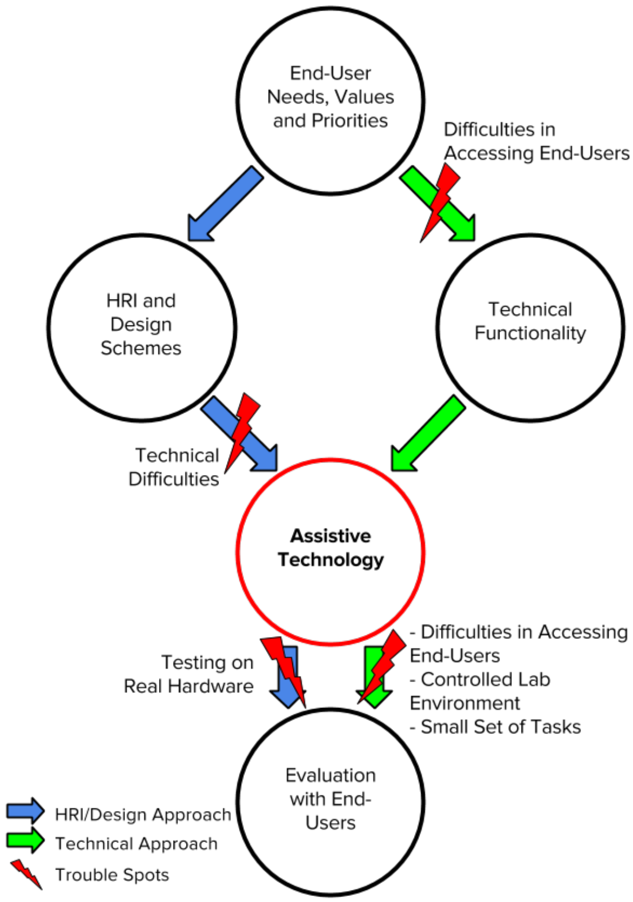


Fig. 1. Typical Approaches and Problem Areas

## II. Current research approaches

In this section we review some of the relevant research approaches in the domain of assistive robotics.

### A. HRI/Design Research

Researchers focusing on HRI agree on user-centered design (UCD) to be the best practice to understand and meet user needs [4, 11, 17]. There are different approaches to user-centered design, but they all consist mainly of the following four steps: identify the needs, specify the requirements, implement an assistive technology and finally evaluate the design [11]. Iterating over these steps leads to a solution that ideally matches the users' needs as accurately as possible. However, it is essential in UCD that the user needs are well-defined, because the entire development process is based upon their definition. A number of studies have investigated user needs through different means such as task priority analysis [24], focus groups, interviews with caregivers and receivers or surveys [21].

Instead of focusing on realizing particular user needs, other design strategies such as *emergent design* focus on improving user values such as individual values (quality of life, independence) and social values (impact on other people). In an immature market such as the one of assistive robotic devices, it is not always straightforward to define user needs. However, the hope is that user needs and priorities will emerge during the design process (therefore, emergent design). The market environment is not stable because insurance policies or legislation may change. Therefore, as the market evolves, user priorities may also change. A key element in emergent design is that the initial product serves only as a starting point for a fast series of product releases. Therefore, it is important not that the product has a big initial impact on resolving the users' needs but rather that it causes a positive change in the users' values and provides useful information about the users' needs, priorities and the environment. The overall outcome from a series of products releases should make a significant impact on realizing the user needs and priorities [17].

The evaluation of assistive technology is crucial for continued development and improvement. Beyond measuring straightforward quantifiable task performance-related metrics such as time taken to accomplish a task or user effort, it is important to measure the overall user satisfaction. User satisfaction measurement [12, 16] is a key factor when assessing the overall quality and usefulness of an assistive device for the end user. Measuring user satisfaction during the design process helps to direct research towards more user-accepted solutions [4]. Different strategies, specifically developed to quantify user satisfaction of assistive devices, such as the *Assistive Technology Device Preposition Assessment* (ATD PA) [22] or the *Quebec User Evaluation of Satisfaction with Assistive Technology* (QUEST) [7], are proven to have a good reliability and validity.

### B. Technical Research

In addition to the social, design and psychological challenges present in assistive technology research, there are various technical challenges as well. Unlike industrial robots which assume a deterministic environment and perform well-defined tasks, assistive robots are required to work in close proximity with humans in uncertain environments, thereby making the human-robot interaction a more complex problem. These robots typically require high-quality sensors to gather information about the environment to take appropriate actions. However, it is also important to keep the cost low so that the device is affordable to the end user and therefore high-cost sensors (which provide more reliable and consistent measurements) are usually not favored.

Fortunately, the shortcomings of low-cost sensors can be compensated through advances in areas such as machine learning and signal processing. Machine learning and artificial intelligence hold great promise for solving various challenges such as predicting human intent [6], identifying optimal grasp poses for pick and place tasks in assistive robotic manipulation [23] or object recognition [25]. Modeling the human-robot interaction using probabilistic tools such as Partially Observable Markov Decision Processes (POMDPs) [13] can support architectures that share control responsibility between the system and the user, helping to select the most optimal action (optimizing some predefined cost function, which may be time or energy) at every step. Learning robot policies from demonstrations also is a viable option to create intuitive and useful robot behaviors [14].

However, many of these techniques are employed to solve only a small set of problems or tasks. In many cases the evaluation of these systems is performed in controlled lab environments (and in some cases on virtual robots or just on subjects without impairments) and it therefore is very hard to predict how beneficial they will be once deployed in the wild. This will necessitate user studies of a much larger scale. Furthermore, it is vital that the evaluation be performed on the actual intended user group (e.g. subjects with motor/cognitive impairments) as the results from evaluation studies performed on subjects without impairments might not always be generalizable. The needs and values of end users with impairments may be significantly different.

Although software provides higher functional flexibility, advances in hardware technology also can be a key factor for the success and quicker adoption of assistive technology. For example, with the ubiquitousness of smartphone technology and embedded systems, researchers have begun to leverage these technologies for various applications such as health monitoring [1], health and medical apps [27] and hearing aids [9]. Improved and low-cost perception systems can play a key role to ensure safe interaction between assistive devices and the environment [26]. Providing haptic feedback to the user while operating assistive devices also can enhance the quality of the interaction [15].

## III. Future directions

Current research trends in assistive robotics reveal that often there exists a dichotomy between the HRI-motivated research and technology-inspired approaches. These approaches seem to progress in parallel to each other. However it is clear that for assistive technologies to become more acceptable there has to be a convergence of these different research approaches (Figure 2).

For example, a conscious effort to build interdisciplinary research teams consisting of roboticists, social scientists, psychologists and clinical care givers may be undertaken so that different aspects of the problem can be addressed in a holistic manner [19][1]. Researchers invested in the technical aspects of the problem will benefit greatly from early collaboration with and feedback from the patients and caregivers in giving a better direction and purpose to their research. This convergence can also help researchers who focus on generating novel design for state-of-the-art technologies, so that they are reachable in the short term, otherwise running the risk of having all the knowledge always remain in the theoretical domain without any practical applications.

Academic research labs also would benefit from collaborations with local hospitals and rehabilitation centers in order to have increased access to patients and caregivers. This will possibly increase the frequency of iteration cycles, and through continuous feedback from the users and caregivers there is higher promise that the outcome of the research will be useful for the user. Although including the patient in the design process from day one might not be feasible for logistical reasons, or always necessary as there are various studies documenting the general needs of the community, collaborating directly with the end user eventually is likely to lead to more user acceptable solutions.

[1]For example, the EU Framework Program for Research and Innovation, HORIZON 2020 (https://ec.europa.eu/programmes/horizon2020/), focuses on large interdisciplinary research teams to achieve breakthroughs in various fields; including in assistive robotics [2, 10].

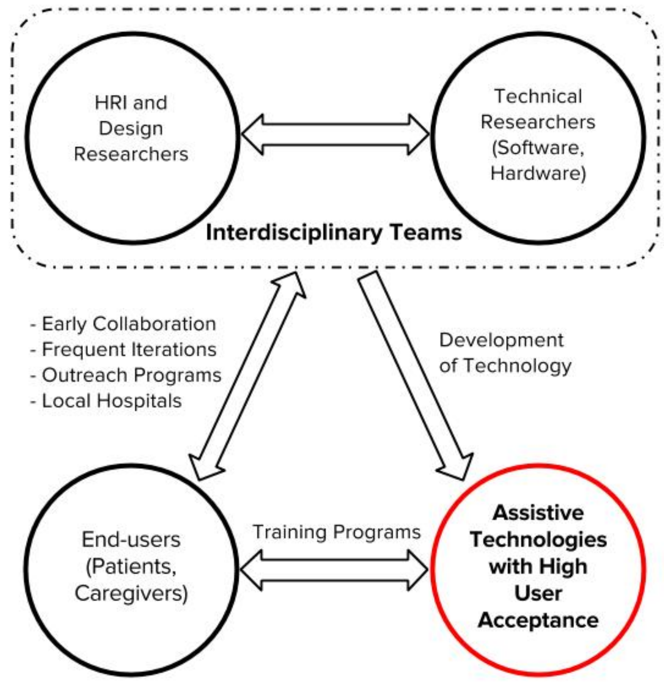


Fig. 2. Collaboration Scheme

Outreach programs in the community can help to reduce the social stigma of such technologies in the general population, and also to raise awareness. Training programs will help in giving the potential users a clear idea of the practical gains that result from the use of such systems. Otherwise, it is possible that the intended end user might not always be aware of the functional possibilities of assistive robotic systems, and therefore be limited in their vision of possible use scenarios.

The future holds great promise for the field of assistive technology. This future will become even brighter if there is successful crossover between different knowledge domains.

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