

The Importance of Participatory Design for the Development of Assistive Robotic Arms. Initial Approaches and Experiences in the Research Projects MobILe and DoF-Adaptiv

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DOI: 10.48718/8p7x-cw14

Abstract

This Article introduces two research projects towards assistive robotic arms for people with severe body impairments. Both projects aim to develop new control and interaction designs to promote accessibility and a better performance for people with functional losses in all four extremities, e.g. due to quadriplegic or multiple sclerosis. The project MobILe concentrates on using a robotic arm as drinking aid and controlling it with smart glasses, eye-tracking and augmented reality. A user oriented development process with participatory methods were pursued which brought new knowledge about the life and care situation of the future target group and the requirements a robotic drinking aid needs to meet. As a consequence the new project DoF-Adaptiv follows an even more participatory approach, including the future target group, their family and professional caregivers from the beginning into decision making and development processes within the project. DoF-Adaptiv aims to simplify the control modalities of assistive robotic arms to enhance the usability of the robotic arm for activities of daily living. To decide on exemplary activities, like eating or open a door, the future target group, their family and professional caregivers are included in the decision making process. Furthermore all relevant stakeholders will be included in the investigation of ethical, legal and social implications as well as the identification of potential risks. This article will show the importance of the participatory design for the development and research process in MobILe and DoF-Adaptiv.

Keywords: Assistive robotics, Assisted Living Technologies, Participatory Design, Human-centered Design, User Acceptance, Risk Management

Assistive Robotic Arms for a Self-determined Life

At the end of 2019, the German Federal Statistical Office counted 7.9 million people with disabilities. Thereof 11.2% had functional losses in arms and/or legs and 10.4% in spine and torso. 7.6 million people with severe disabilities lived in private households with their families, partners or alone (Statistisches Bundesamt, 2020a + 2020b). As part of the German Spinal Cord Injury Survey (GerSCI) in 2017, 1,479 people with spinal cord injuries were questioned about their life situation, how they experiences living with a spinal cord injury and what

kind of issues they were dealing with. Results towards daily activities and mobility showed that running an own household was viewed as extremely problematic by 40.7% of the respondents. Rated as very or extremely problematic were picking up small objects or opening containers (31.2%) and completing everyday tasks (29.1%). Furthermore, 41% of the respondents said that they could open heavy doors only with some or great difficulties and 18.3% were unable to open heavy doors at all. The authors state that the descriptive statistical re-

sults will be followed by qualitative studies and in-depth analyses (Bökel et al., 2019, 22f.; 41).

Assistive robotic arms could be a solution to enable people with severe body impairment to perform activities of daily living independently. Currently, the online-Portal "rehadat-Hilfsmittel.de" lists three assistive robotic arms on the German market, JACO from Kinova inc., iArm from Assistive Innovations bv. and BATEO from EXXOMOVE UG. All robotic arms are mounted on an electric wheelchair and steered with the wheelchair controller. However, there are still some challenges. In case of functional losses in hands and arms, steering with a special controller is possible, but has its limits. Operating a robotic arm with a chin or mouth controller and thus eating or drinking, for example, are mutually exclusive. Another difficulty is the necessity to constantly switch between different modes of movement of the robotic arm, like up/down and left/right, while performing a task.

The research projects MoblLe and DoF-Adaptiv presented in this article deal with new approaches to the above-mentioned challenges. Furthermore, ethical, social and legal implications (ELSI) and

questions of risk and quality management are investigated. In the spirit of Responsible Research and Innovation (see Owen, Stilgoe et al., 2013), the participation of the future target group was or is being pursued in both projects. Against this backdrop, this article is intended to clarify the importance of participatory approaches or participation in the research process and technology development for research in the field of assistive robotic arms for people with severe physical limitations.

Investigating the Needs and Wishes of the User in MoblLe

How could it be feasible to control and use a semi-autonomous robotic arm as a drinking aid, if using a joystick is not an option, due to functional losses in all four extremities? The aim of the MoblLe project was to research and implement basic skills with and without direct physical contact between robots and humans. For robot control in a three-dimensional space, the use of head and eye movements as well as a combination of motion sensors and glasses with an eye tracker and electrooculography was investigated. For the interaction between the robot and the human, augmented reality

MoblLe – Physical Human-Robot-Interaction	
Announcement BMBF:	Autonome Roboter für Assistenzfunktionen: Interaktive Grundfertigkeiten
Research funding:	VDI/VDE Innovation + Technik GmbH
Grand agreement ID:	16SV7868
Project coordination:	Prof. Dr. Marion Gebhard, Westfälische Hochschule
Project leadership Frankfurt UAS:	Prof. Dr. Barbara Klein
Joint project partners:	Friedrich Wilhelm Bessel Institut Forschungsgesellschaft m. b. H., Bremen Hidrex GmbH, Heiligenhaus Pi4 robotics GmbH, Berlin
Duration:	07.2017-06.2020, extended 06.2021
Website:	https://www.interaktive-technologien.de/projekte/mobile

Table 1: Fact sheet MoblLe (authors figure)

(e.g., in the form of visual representations of intended actions by the robot) and a visual concept were developed. A safety system with redundancies ensures functional reliability. To ensure that the development of the control and interaction modalities meet the future users' needs and acceptance, a user-centred design strategy was implemented throughout the research and development process.

An Ethnographic/Small Data Analysis

At the beginning of the project an ethnographic/small data analysis with 15 persons of the future target group was conducted in Germany. Eleven male and four females took part in the survey. The diagnoses were spinal cord injury (10), locked-in-syndrome (2), multiple sclerosis (1), inclusion body myositis (1) and arthrogryposis (1). Participants were visited at home, where in-terviews and participatory observations of food and beverage intake took place.

The observations were documented with videos and photos. The interviews and videos were transcribed and the transcripts, videos and photos were analysed following the qualitative content analysis approach by Mayring (2015), the qualitative hermeneutical approach from social sciences by Reichertz & Englert (2011) and the photo analysis by Pilarczyk & Mietzner (2000). The aim was to gain a deeper insight into the life situation of the participants in order to work out aspects that promote acceptance and to develop user-centred recommendations for the technical development.

Demographic Data, Life and Care Situation

The age of the participants varied between 18 and 62 years and was distributed relatively evenly. The diagnoses or the accident events ranged from 2 to 35 years ago at the time of the survey. The only exception was in a case with congenital physical

impairment. Around two-thirds of the participants have been living with a physical impairment for at least ten years or longer. However, no significant differences can be derived from the response behaviour in the interviews between participants who have been living with their impairment for decades and those who have obtained their physical impairment more recently. Experiences with assistive robots or technologies seem to be less dependent on the duration of the impairment than much more on one's own interests or accessibility.

All participants stated that they are active and like to go out as much as possible. Some have converted cars that the caregivers drive. Most of the participants use an electric wheelchair (ten participants). Others prefer active wheelchairs (three participants) or use push wheelchairs (three participants). The participants live in accessible houses (six participants) and in accessible or partially accessible apartments (nine participants). Seven participants live alone, three live with their parents, three with a wife/husband or partner (in one case with a child under 18 years) and one participant lives with one child over 18 years. Caregiving relatives exist in eight cases in which the participants live with their relatives, whereby the extent of the care provided varies. In seven of the eight cases, nursing services take on certain aspects of nursing (e.g., catheters or showers). In one case, assistants also support the participant and his relatives. Participants who are not cared for by relatives often use both nursing services and assistants (five participants). Only in two cases are participants supported exclusively by a nursing service or assistants.

The daily structure is characterized by fixed times of basic care (e.g., the morning toilet), relatively fixed/regular mealtimes, regular therapies and times of relief (pressure ulcer prophylaxis). Most of the time is spent in the bedroom (bed) and li-

ving room (wheelchair). The amount of time spent in the wheelchair varies between 8 and 14 hours a day. Participants said that they eat and drink in bed or while sitting in a wheelchair in the living room or in the kitchen at a dining table. Drinking has a special significance, as both the type of beverage (still water, tea) and the amount consumed are particularly important for health and general well-being. The participants often drink large quantities in a row and preferably from large glasses or drinking bottles. For all participants, drinking is linked to the aspects of autonomy and privacy. If they did not have to ask for help for every sip, but could drink independently, they would be able to spend several hours a day alone again. Always having to have someone around for assistance is perceived as exhausting.

The Users Perspective Towards an Assistive Robotic Arm as Drinking Aid

The analysis of the interviews and observations showed certain aspects that can influence the acceptance and use of a robotic arm as a drinking aid. Currently, the above mentioned assistive robotic arms can only be used while mounted on an electric wheelchair. However, some participants cannot or do not want to use an electric wheelchair. Participants would also like to use the robot while lying in their bed and would prefer a solution that enables them to use the robot independently. Most participants are cared for 24/7 by a mix of caregiving relatives, nursing services and assistants, which means, that different people are interacting directly or indirectly with the robot. Therefore, participants wish for an easy and intuitive control and interaction design that does not require too much explaining or a long training period. It should also be safe to use, even if other people are around and interacting with the participant. Furthermore, the robot should be robust, sturdy and

show a high operating safety. Teething problems or safety issues would prevent participants to use the robot at all. How the robotic arm could be perceived by others is important to most participants. If it is too big and "showy" and/or looks too much like a medical device, participants do not feel comfortable and fear stigmatization. Instead, they wish for an unobtrusive and elegant design, like a lifestyle product and as space-saving as possible. If the robotic arm promotes independency and privacy, meaning that it enables the participants to drink without additional help from others, the participants stated that they would use it regularly and would like to spend more time on their own. On the other hand, participants would like to enjoy mealtimes with family and friends where everyone can eat and drink at the same time and communication is not disturbed while someone takes care of the participant. A robotic aid is seen as a possible solution as long as it is not the cause for new distraction. These findings lead to recommendations for the development of robotic drinking and eating aids, which are currently published at INTERACT 2021 (see Pascher/Baumeister 2021).

New Insights Through Including Caregivers

To discuss ethical and social implications of a robotic drinking aid, three workshops with all stakeholders were conducted in 2019. A total of 11 people with a disability, 2 caregiving parents, 4 assistants, 2 physiotherapists and 3 industry representatives took part. In addition, all project partners joined the first workshop, too. The MEESTAR model for the ethical evaluation of socio-technological arrangements was adapted and used to evaluate ethical issues. All workshops were transcribed and qualitatively analysed following the thematic analysis by Tuckett (2005, 75ff.).

Caregiving parents and assistants brought a new perspective towards the topics safety and independence. Both participating groups viewed an assistive robot as positive if they feel assured that the person they care for can be safely left alone to perform a task with it. If the robot promotes a higher independency, it would be a relief for caregivers. Assistants could use their time more efficiently and caregiving relatives would gain more time for themselves. However, it also became clear during the discussions that it is an issue to trust in the safety of an assistive robot and leave the person being cared for alone with it. Especially assistants said that they don't trust the robot and asked what would happen, when a problem occurs? They do not want to risk that the person being cared for comes to any harm or that they cannot help them (fast enough), if needed. Participants with a disability, on the other hand, were much more inclined to take risks, if only they could regain more privacy. Whilst participants with a disability say that safety standards in Germany are very high and they could call the caregivers with a mobile phone if necessary, the caregivers prefer them to be in another room/close by and quickly available when needed. So there is a profound conflict of interest between caregivers and the person being cared for about gaining more privacy and autonomy.

Lesson Learned for Further Research

During the visits of the participants, some asked why MobilLe focused on drinking and how the decision was made. Although drinking was viewed as important, participants and caregivers mentioned further activities a robotic arm could help with. Participants mostly wished to pick up and manipulate objects or open doors. Again, in the context of the workshops, people with a disability, parents and assistants suggested more different activities, like support for dressing. It seems that people with severe body impairments do have several unmet needs that an assistive robotic arm could help with and that it is important to include the future target group into the decision-making before deciding what activity the assistive robotic arm should support. The inclusion of caregiving relatives and assistants in the workshop made clear that it is necessary to recognize the whole social system of people with severe body impairments and to include caregiving relatives, nurses and assistants into the research project as well. The conclusion was to pursue a more participatory approach in the succession project DoF-Adaptiv.

DoF-Adaptiv - Adaptive mapping of degrees of freedom as user interface for an assistive robot	
Announcement BMBF:	Adaptive Freiheitsgradeinbettung als kooperatives Userinterface für einen Assistenzroboter
Research funding:	VDI/VDE Innovation + Technik GmbH
Grand agreement ID:	16SV8564
Project coordination:	Prof. Dr. Udo Frese, DFKI, Bremen
Project leadership Frankfurt UAS:	Prof. Dr. Barbara Klein, Prof. Dr. Patrizia Tolle
Joint project partners:	Westfälische Hochschule, Gelsenkirchen Munevo GmbH, München
Duration:	02.2021-01.2024
Website:	https://www.interaktive-technologien.de/projekte/dof-adaptiv

Table 2: Fact sheet DoF-Adaptiv (authors figure)

Including All Stakeholders in the Research and Development Process of an Assistive Robotic Arm

The ongoing research project DoF-Adaptiv aims to simplify the use of assistive robotic arms, i.e. releasing the users from the necessity to switch between the various modes of degrees of freedom while performing a task. A combination of machine learning and artificial intelligence (AI) will be developed in order to improve the control system. In contrast to automatic control, humans remain in control. In a user-centred design process, possibilities of displaying feedback are explored using data glasses. In a participatory approach, the requirements are raised and the system is evaluated with those affected.

Participative Research, Participatory Approaches

DoF-Adaptiv is conducted as research with people, rather than as research about or for them. This course of action is a characteristic feature of participatory research (Bergold/Thomas, 2010, 333). The DoF-Adaptiv project is guided by fundamental principles of participatory research. The following section focuses on two areas: the concept of „safe space“ for all participants during the research process and the roles of all participants in decision-making processes (von Unger, 2014, 39ff.; Bergold/Thomas, 2012, 6).

Participatory research can be understood as a research style in which professional researchers and co-researchers are equally involved in the process of knowledge construction (Bergold/Thomas, 2012, 2). In DoF-Adaptiv, two groups, the primary and secondary users of assistive technologies, form the group of co-researchers. People with disabilities (primary users), family caregivers, nurses, assistants (secondary users) collectively contribute their unique perspectives. Expressing and sharing their own opinions and experiences in institutional

settings or with strangers requires a “safe space“ (Bergold/Thomas, 2012, 5). The “safe space“ allows, for example, to have and express different opinions or to resolve conflicts in a constructive manner (Bergold/Thomas, 2012, 7). In addition, a “safe space“ creates an opportunity for all members of the research group to experience that each opinion will be heard, but will not be judged or even devalued by others. The “safe space“ is also dynamic. It has to be reestablished over and over again via opening communicative spaces throughout the entire research process (Bergold/Thomas 2010, 338).

To determine whether a project fulfills the basic criterion for classification as participatory research, it is necessary to ask who is controlling the research in which phase of the project (Bergold/Thomas, 2012a, 9). These questions allow to determine which group of researchers (professional researcher or co-researcher) is involved in which decisions, whether the various actors are involved in decision-making-processes with equal rights in order to control and monitor the research and the course of the project (Bergold/Thomas, 2012, 10f.).

The research process in DoF-Adaptiv is designed in cycles. These cycles are based on the process of “Progressive Problem Solving with Action Research“ (Riel quoted in Wright et al., 2013, 147). Each cycle describes the reflecting on practice, the actions taken, reflecting and taking further action (Riel n.d.)

In the following, the concept of “safe space“ and decision-making processes used to control and monitor the research process at DoF-Adaptiv are explained with a focus on the scenario development.

Including the Future Users Early on

Based on the experiences in MobilLe, the future target group in DoF-Adaptiv includes not only people with a disability, but their caregiving relatives, nurses and assistants, too. Furthermore, the project aims for a more participatory approach that involves the future target group in the research and development process from the beginning and is iterative throughout the project. Starting with the development of application scenarios for the assistive robotic arm, workshops and interviews were held. It was decided which activities the robotic arm should support and which scenarios should be described great importance was attached to the fact that participants and researchers meet on an equal footing. Researches were in the role of listening and documenting the participant's thoughts and wishes, accepting them as experts in their own rights. Protocols, findings and work-in-process documents were shared with all participants throughout the development process. When deciding on application scenarios, the opinion of the participants was decisive for the decision-making. Furthermore, participants were given the opportunity to discuss the details of the scenarios design with all researchers during a project meeting. Those who couldn't attend the meeting were asked to give their view via e-mail or a one-to-one call with a researcher, making sure that every participant who wanted to be part of the development process and decision-making could participate. The transcripts, notes and protocols of the workshops, interviews and the project meeting are currently being analysed and the participative approach will be evaluated.

Impact of Participatory Approaches for Risk and Quality Management

In the field of medical technology, there is a separate standard for managing risks. DIN EN ISO 14971

describes requirements and possible procedures with a focus on risk analysis. Risks have to be identified and assessed to determine whether they are justifiable. Remaining residual risks must be set in relation to the benefits. In 2019, a revision of the risk management standard DIN EN ISO 14971 for medical devices was published: ISO 14971: 2019. The procedure has basically remained unchanged. However, some additions and explanations have been introduced. Among other things, the information for training option was discussed as a risk control measure. In addition, the concept of benefit for the patient was further specified. The standard has thus moved the issue of risk-benefit ratio even more into focus. In the area of risk management, the EU directives and EU regulations for medical devices such as the MDR (Medical Device Regulation (MDR)) have to be taken into account too. The risk analysis must factor in, inter alia, the effects of software errors, framework conditions and safety-relevant functions.

As part of a project on „Systemic risk management for the holistic consideration of entrepreneurial risks using the example of medical technology“ at RWTH Aachen University, some weaknesses in the current procedures and methods in the field of risk management in medical technology were discussed and described (SysRisk). Among other things, the current methods are seen insufficient in scope and depth to identify and assess residual risks as comprehensively as is necessary for risk-sensitive products. In order to minimise these weak points in the current project, risk management is being expanded to include methods and procedures that go beyond the mandatory standards and regulations.

For this reason, the current project (DoF-Adaptiv) puts a lot of emphasis on identifying as many risks as possible at an early stage and introducing ap-

appropriate measures in a timely manner. The following procedures and methods are used:

- Users are involved in the risk identification process from the beginning of the project.
- FMEA (Failure Mode and Effect Analysis) is used in the risk analysis to analyse the individual components of the product, in particular the resulting hazards.
- The scenario technique or scenario-based risk analysis is used for the investigation and evaluation of the influencing factors and simulated scenarios.
- Practical conclusions for the intended area of application of the product are derived from the action-oriented error taxonomy. The action-oriented error taxonomy is based on an error term that can be traced back to action-oriented error research (Freud, 1941, 25f.; Frese, Zapf, 1991, 11f.).

Conclusions

The early involvement of the future target group in the research project *MobILe* had a deep impact on the further development of human-robot interaction modalities. The insight into the life and care situation of people with severe body impairments brought findings towards aspects that promote a higher acceptance of assistive robotic arms, allowed a user-centred development and new input for further research was gained. In the ongoing project *DoF-Adaptiv*, the inclusion of the future target group into development and decision-making processes ensures that the research project meets the future target group needs and will increase their independence and autonomy in the future. In this way, both projects seek to contribute to a more independent living for people with severe body impairments in the future.

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