Field-based AT Innovation Methodology and Development of an Information Assistance Robot System for Older People with Cognitive Decline

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Abstract This chapter describes the methodology for the development of assistive technologies with the user and the use fields at its core, which is called Field-based Assistive Technology Innovation (FATI). Furthermore, as a case study, the development of a communication robot that provides important information in the daily lives of older adults, such as dates and schedules, is presented. In devising the FATI methodology, a comprehensive framework for promoting AT innovation was developed. Then, based on existing user-centred design methods, etc., a methodology focusing on AT concept planning was developed. As a result, a concept planning guideline consisting of seven items was developed, and a concept planning sheet was created to visualise the process.

In the case study of the development of an information assistance robot for older adults with memory loss, in which FATI was applied, the needs of older persons with cognitive decline were accurately identified, many stakeholders in the robot's use were identified, and a concept was compiled for the intended use scenario.

This methodology may also hold promise for the appropriate integration of rapidly advancing recent technology into the AT space.

Feldbasierte AT-Innovationsmethodik und Entwicklung eines informationsunterstützenden Robotersystems für ältere Menschen mit Abbau der kognitiven Fähigkeiten

Zusammenfassung. In diesem Kapitel wird die Methodik für die Entwicklung von Assistiven Technologien (AT), mit Nutzer*innen und den Anwendungsfeldern im Mittelpunkt, beschrieben, die auch als Feldbasierte Assistive Technologie-Innovation (FATI) bezeichnet wird. Als Fallbeispiel wird die Entwicklung eines Kommunikationsroboters, der wichtige Informationen im täglichen Leben älterer Menschen, wie z.B. Termine und Zeitpläne bereitstellt, vorgestellt.

Mit der FATI-Methodik wurde ein umfassender Rahmen zur Förderung von AT-Innovationen entwickelt. Anschließend wurde auf der Grundlage bestehender nutzungszentrierter Designmethoden etc. eine Methodik entwickelt, die sich auf die Planung von AT-Konzepten konzentriert. Das Ergebnis ist ein Leitfaden für die Konzeptplanung, bestehend aus sieben Elementen, sowie ein Konzeptplanungsblatt zur Visualisierung des Prozesses.

In der Fallstudie zur Entwicklung eines Informationsunterstützungsroboters für ältere Erwachsene mit Gedächtnisverlust, bei der FATI angewandt wurde, wurden die Bedürfnisse älterer Menschen mit kognitiven Einschränkungen genau ermittelt, verschiedene potentielle Nutzer*innengruppen für den Einsatz des Roboters identifiziert und ein Konzept für das geplante Einsatzszenario erstellt.

Diese Methodik erscheint vielversprechend für die angemessene Integration von schnell fortschreitender neuer Technologie in den AT-Bereich.

1 Introduction

Users of assistive technologies (ATs) can participate in daily life and social activities by utilising their functions, even if their physical and mental functions are impaired. AT plays a critical role as one of the environmental factors for this purpose. However, the needs of persons with disabilities are highly individualised, and customisation according to their characteristics is always required.

AT professionals play a crucial role in the personalised needs of persons with disabilities, which they address with individual adaptations that make use of existing technology and expertise, for example, adapting cushions and postural support devices to maintain the sitting position in a wheelchair and devising switches for the use of communication support devices. However, even with such specialist support, there are still persons with severe disabilities who are unable to use current ATs, and it is expected that advanced technology will be applied to these users' unmet needs.

Installing new technology in new products is sometimes fraught with potential risks, even for general products other than ATs. For example, the introduction of autopilot technology for aeroplanes has led to new human errors, which might result in serious accidents. Hence, developing novel products using these technologies should be cautiously pursued. Advanced technology is often applied to toy spaces at an early stage, owing to the possibility that the market will accept the technology even if it does not perform adequately and because it is a relatively lower-risk area for withdrawal from the market. By contrast, ATs require a high level of perfection in technology. They are a higher-risk area for developing new products because of the highly individualised functions of users and unknown characteristics. In many cases, even if development is initiated, it does not reach the field-testing stage with the target user groups. For example, Suzurikawa et al. (2012) have shown that among 71 development cases of intelligent wheelchairs for 42 models, only seven cases made it to field testing with target users with disabilities, according to a review by Simpson (2005). Moreover, the performance tests encountered some challenges. Although mechanical or electrical performance confirmation can proceed as with other conventional products, user field tests are often limited to qualitative evaluation because of the lack of indicators and other reasons.

As described previously, while the development of ATs requires the application of new technologies, problems remain, such as high risks and difficulties in product development and field tests for persons with disabilities. Therefore, methodologies to promote development based on these characteristics are required.

Another feature is the involvement of many related stakeholders in the use and utilisation process. Once these points are accurately considered and the concept of AT is determined, subsequent development can be handled by utilising existing design methods for conventional products. Therefore, clarifying and addressing the considerations specific to AT development will enable effective and efficient development.

The use of user-centred design methods is a promising strategy; however, various conditions specific to AT should be considered, such as disabilities, living environments, and social systems, and a framework and methodology that can organise and share these conditions should be established. Additionally, prototyping and testing indicated in design thinking often offer tests in workshops. However, in the development of ATs, evaluation in the actual usage environment is required, and it is crucial to construct a design process that considers these factors. Thus, this study aimed to

develop a framework and methodology for information sharing in developing ATs against the background of these issues.
This chapter proposes a comprehensive framework that includes factors of the social environment to facilitate the development of ATs and a methodology that includes a process and guidelines for envisioning the complex user and usage situations of ATs in the concept-planning stage.

2 Comprehensive Framework to Promote AT Innovation

Inoue et al. (2003) extracted bottlenecks in AT development and their solutions by analysing the development process of 10 types of ATs that have been developed at the Research Institute of National Rehabilitation Centre for Persons with Disabilities in Japan:

1) Head-controlled powered wheelchair
2) Prevention system for forgetting to apply the brakes of the wheelchair
3) Scan-pen for augmentative and alternative communication
4) Light spot keyboard
5) Eye gaze communication system
6) Bed separable to wheelchair
7) Wheelchair for older persons
8) Powered wheelchair for office use
9) Impact detection switch for persons with cerebral palsy
10) Gyro mouse

On this basis, they proposed a framework for promoting AT development, as shown in Figure 1. Here, not only the AT development process (Paradigm one) but also the approach to society (Paradigm two) is shown as an important perspective. In the AT development process, it is important to grasp the users' needs, characteristics, and environments, which are more difficult to understand than for ordinary products and which are fully taken into account at the concept planning stage. For this purpose, the participation of the target user groups in the AT development process and the development of ATs closely connected to the field of use are effective methods. In the second paradigm, outcome measurement of ATs, fitting and assessment system improvement, standardisation and enlightenment toward stakeholders are important.
In this way, it is essential to innovate truly useful ATs in a context where social change and technological development are closely intertwined.

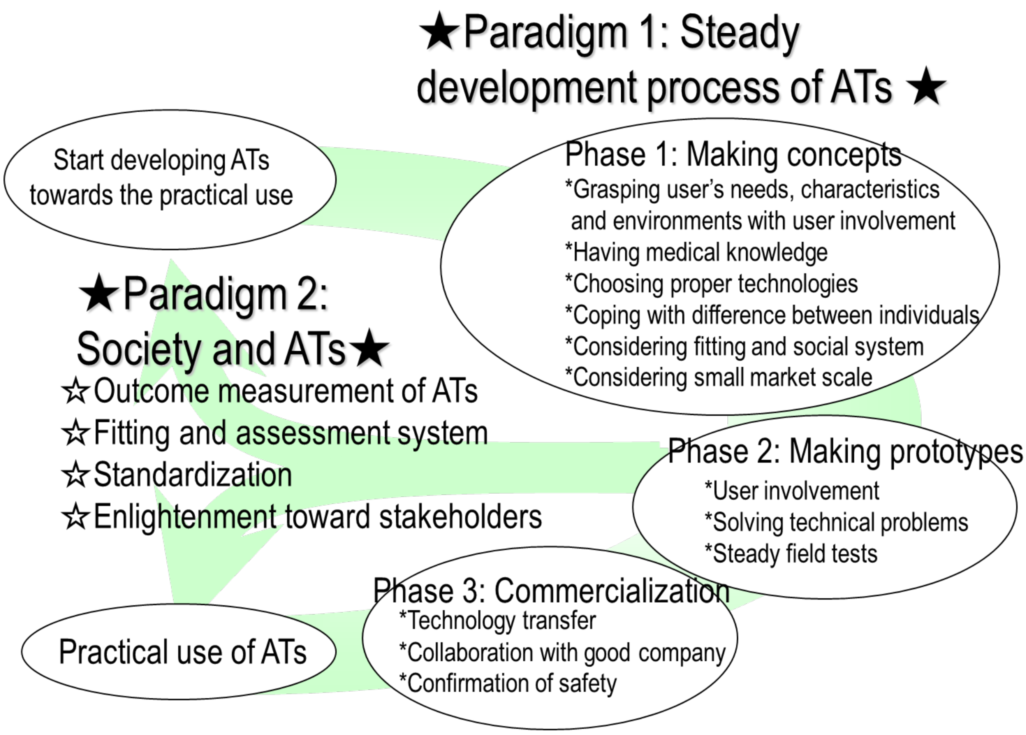

Figure 1 Comprehensive framework to promote AT innovation

3 Development Methodology for ATs

The development methodology of ATs is based on a user-centred approach owing to its characteristics. This methodology has been advocated in fields other than ATs and can be considered by following those development methodologies. These include the user scenario method, user-centred design, participatory design, and user-driven innovation. In addition, a method that includes systems thinking has been proposed considering the AT innovation framework mentioned previously (Figure 1). Moreover, this approach corresponds to the 5Ps proposed by WHO in its GATE (Global Cooperation on Assistive Technology) initiative (World Health Organization/Unicef 2022).
This chapter focuses on recent trends in design thinking, Systems Design Management (SDM).

3.1 Design Thinking

In Japan, the term 'design' is often understood as meaning to devise various shapes, colours, and patterns for arts, crafts, and industrial products. In contrast, in the English language, 'design' includes a plan or drawing produced to show the look and function or workings of a building or industrial products. In the 1980s, discussions on scientific design arose in the engineering design field, where the three phases of design engineer's thinking – analysis, creation, and execution – were clearly articulated (Cross 2000). This trend also relates to design thinking. Design thinking is defined as "a human-centred approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success" (IDEO Design Thinking n.d.). The Stanford d.school and the consulting firm IDEO explained design thinking as a problem-solving approach, bringing it to people's attention worldwide. IDEO defines the three conditions above based on the following four mindsets (T. Kelley and D. Kelley 2013).

- Inspiration: Go outside the world and actively seek experiences that ignite creative thinking. As catalysts for novel ideas, we understand and empathise with human needs, desires, and motivations.
- Synthesis: Tackle the complex task of 'making sense'. Shift perspective from concrete observations to more abstract facts across the entire population, organising results and categorising types of solutions.
- Ideation and experimentation: Generate ideas to explore new possibilities, giving form to ideas through rapid prototyping and experiment while repeatedly adapting, improving, and redirecting ideas by receiving feedback from end users.
- Implementation: Refine the design and prepare a roadmap for the market before developing a new idea. Consider the product and service as an integral part of verifying demand marketability, including repeated feedback and improvement, while introducing them to the field.

Although not specific to AT, examples of similar methods have been used and are useful for development in this field. Suzurikawa (2014) is developing toilet-support devices for people with disabilities based on participatory design, practising observation, workshops, imagining ideas using mock-ups, etc.

3.2 System and Design Thinking

System and Design Thinking has been proposed as a methodology that crosses Design Thinking and System Thinking (Graduate School of System Design and Management 2015). System Thinking, although central to the aforementioned discussions at WHO, was originally the thinking about underlying systems engineering and referred to a way of thinking that takes a bird's-eye view and a systematic approach. As the motto 'seeing the forest for the trees' suggests, this method aims to accurately design complex systems by repeatedly understanding the structure as a whole and the precise details of the structure and by attempting to understand the structure from multiple perspectives (Maeno et al. 2014). SDM (System Design Management) combines the systematic and logical aspects of System Thinking with Design Thinking, emphasising ideas and sensitivity, and aims to create innovative value through a holistic view by repeating ideation, fieldwork, and prototyping based on divergence and convergence. Additionally, it is critical for diverse people to think together – a methodology that goes well with assistive technology development.

4 Field-based Assistive Technology Innovation

Field-based Assistive Technology Innovation (FATI) was proposed as a development methodology for AT based on Design Thinking and SDM (Inoue et al. 2012; Inoue and Kamata 2019). The aim is to develop new ATs by considering the users and stakeholders involved in their use and the sites where they are used. FATI focuses on the concept planning of ATs, particularly in the pre-commercialisation stage, which is intended to lead to subsequent commercialisation by companies. It consists of a concept planning process, a concept planning guideline composed of seven items, and a concept planning sheet incorporating these items.

4.1 Concept Planning Process

In the conventional design process, gathering information based on development goals and concept planning based on the analysis results form the core of the process, which the developer carries out. It is characterised by incorporating the concepts of Design Thinking and the SDM into this process, based on the participation of persons with disabilities and stakeholders throughout the entire process, measuring physical and mental functions, collecting information in the usage environment, and adding field tests and improvement processes for persons with disabilities. These could enhance matching with users and usage situations and could promote the development of ATs if this part of the process was conducted efficiently. In conventional product development, field tests are often conducted on products close to final prototypes. Thus, improvements based on field tests increase waste because they are implemented after several processes. Regarding the aforementioned Design Thinking methods, there are cases where evaluation is conducted using mock-ups or simple prototypes in the concept planning phase; however, in the case of ATs, a certain degree of perfection is required because the evaluation is conducted on a trial basis by users with disabilities. This is a major difference between the development processes of general products and ATs.
Based on the above, we decided to include the aforementioned field tests in the concept planning process and create a process that includes creating prototypes for this purpose. In addition, the clinical evaluation results can be fed back into concept planning or prototype creation, and a pathway for repeated modifications can be clearly defined. Refining this concept and deriving a final proposal by repeating these loops is possible. Figure 2 illustrates the proposed concept-planning process.

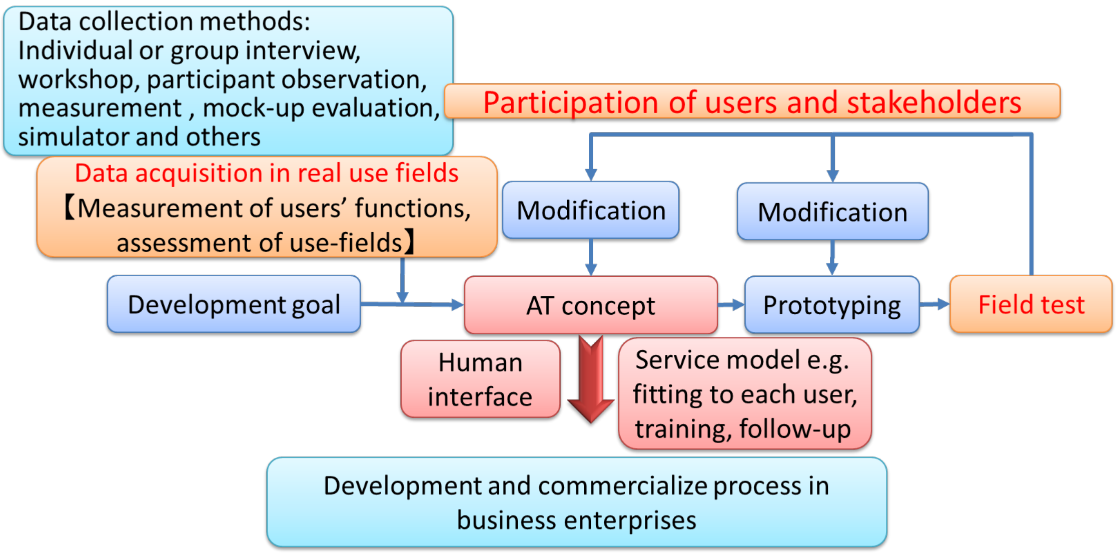

Figure 2 FATI concept-planning process

Because the target users are those with disabilities, one challenge is that less information is available to the public than in the development of conventional products. Therefore, individual and group interviews, workshops, participant observations, and

measurements of mental and physical functions should be conducted. Understanding users' needs while presenting mock-ups and utilising tools such as simulators is useful.
The developed concept clearly states that it includes requirements related to the human interface and service requirements in terms of methods and systems for adapting and operating to the characteristics of individual users as considerations for use by persons with disabilities.

4.2 Concept-Planning Guidelines

The following seven guidelines were established for the implementation of the concept-planning process.

1) Based on the development goals, establish the type and degree of disability of the users.
2) Collect information regarding users' living conditions and establish stakeholders involved in the usage scenarios and usage of the developed ATs.
3) Participate in the development process of the set parties with disabilities. In cases where it is difficult for them to participate in all processes, key stakeholders should be involved.
4) Depending on the type and degree of the subject's disability that has been set, the technology to be used in the human interface is determined. If required, measurements should be taken to match the technology with the mental and physical functions of the users. It is desirable to conduct the measurement in the assumed daily life situations of the target users. Additionally, the following non-functional requirements should be considered:
    a. Add technology to realise functions, such as the modularisation of the human interface and parameter adjustment, to respond to the individuality of target persons and changes in their physical and mental functions.
    b. Identify the risks of secondary disorders associated with the use of the developed equipment based on the type and degree of disability of the established target persons and take measures to prevent them.
5) The concept was developed based on envisioned usage scenarios. At that time, the following non-functional requirements should be considered:
    a. Collect information, such as benefit plans, related to the developed ATs and determine whether it is included in its scope.
    b. Collect information on market size and review selected technologies and concepts as appropriate to accommodate smaller market sizes.
6) Create a prototype and modify the concept by field test.
7) Based on the findings from the field test, the methods of individually fitting services and introducing training for users and the methods and systems for operation should be considered in the concept planning stage. If necessary, service delivery models using the developed ATs were considered.

4.3 Concept-Planning Sheet

Figure 3 shows the concept planning sheet with the FATI. In this sheet, starting from the development goal, information gathering, determination of each requirement, and determination of concept of the ATs, fitting methods, and service delivery models are visually represented along the items of the concept-planning guidelines shown in the blue section. In the figure, the area framed in blue describes the information warranted for concept planning, such as the conditions of use, non-functional requirements, and field test. The green area indicates the method used to collect information. In the orange box, requirements such as technologies and measures determined from the information obtained should be described. The orange areas represent the concepts obtained and adapted methods and service delivery models. By filling this sheet, it is possible to consider all required items without omission, and it can be used as a support tool for concept planning of ATs. Furthermore, it is possible to accumulate items obtained through user participation, measurement in usage situations, and information gathering; extracting new non-functional requirements and creating a detailed list could also be helpful in the future.

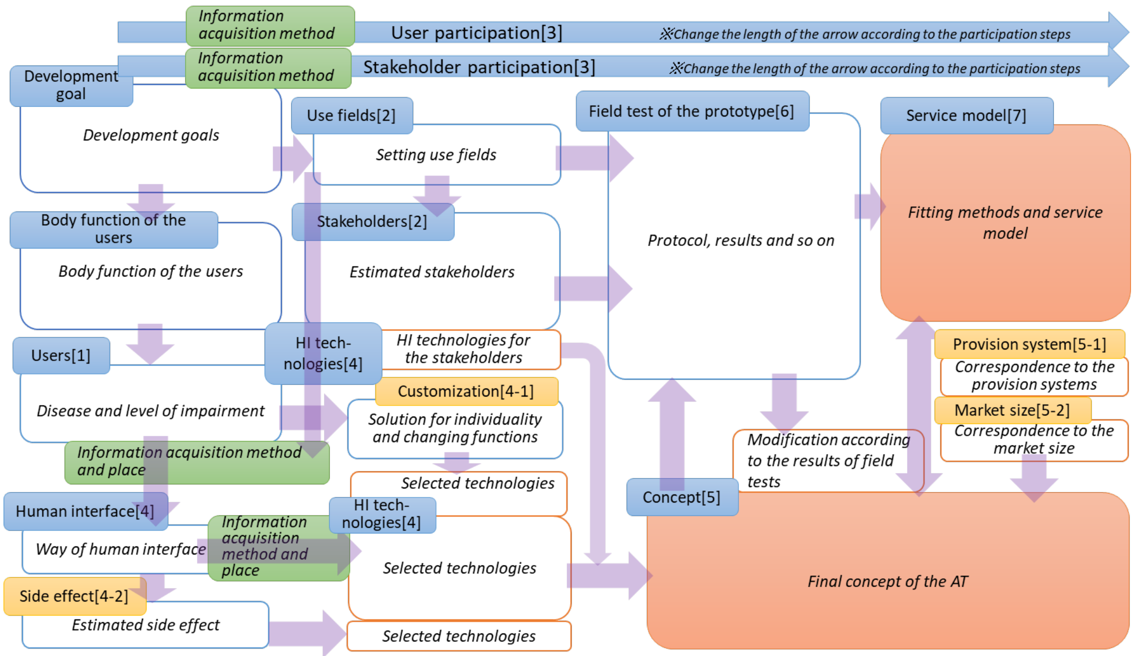

Figure 3 FATI concept-planning sheet

5 A case study in the development of an information assistance robot system for older adults with cognitive decline

A robot system was developed for older adults with cognitive decline due to mild dementia or Mild Cognitive Impairment (MCI), the preliminary stage of dementia, to present basic information necessary for daily living, such as dates and schedules, through conversations. The entire development project lasted nine years and three months, with the first two years and three months spent on system concept development (Stage I), the next four years on system construction (Stage II), and the last three years on social experiments (Stage III). This chapter focuses on Stage I of the project and shows the progress leading up to concept development.

The development team consisted of a company that operates more than 30 nursing homes nationwide, a robot system development company, a company that operates nationwide AT rental services, the University of Tokyo, the National Institute of Advanced Industrial Science and Technology, and the Research Institute of the National Rehabilitation Centre for Persons with Disabilities.

The robot system used in this project was PaPeRo i® produces by NEC, and was an ICT-based system. The stakeholders are not only family members but also a wide range of community resources, such as local comprehensive support centres, senior citizen associations, and neighbourhood associations. Information gathering for concept-planning included measurement experiments on the cognitive functions of older adults and the human interface between the robot and its users, participant observation of information transfer methods between staff and users at an independent nursing home, needs identification through group interviews with elderly people, and the development of an operational framework for the system through workshops targeting local resources. A mock-up of a communication robot with basic functions was fabricated and used in group interviews and workshops. Figure 4 shows the concept-planning sheet.

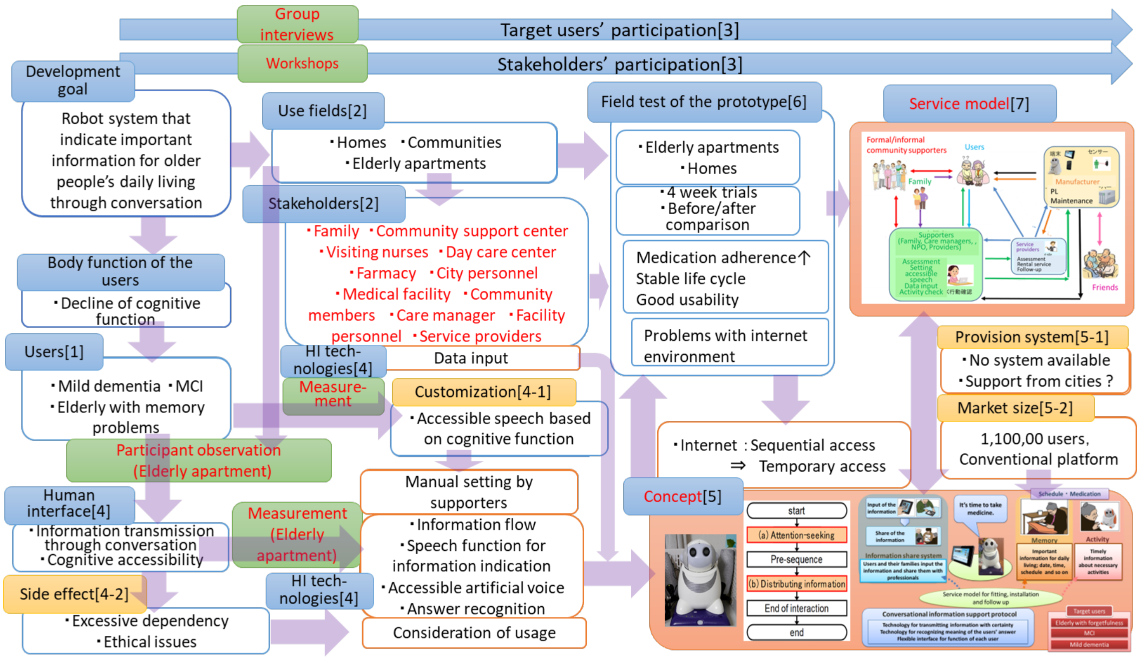

Figure 4 FATI concept-planning sheet with development of information assistance robot

The resulting concept of the information assistance robot system is shown in Figure 5 and summarised as follows:

1. It targets older adults with mild dementia and MCI and those who are neither of the above but have memory loss and problems with scheduling, etc.
2. It presents information critical for daily life to the users through conversation with the robot, mainly supporting schedule confirmation and health management, such as medication administration.
3. It presents information by voice from the robot based on the information transfer flow in conversations.
4. It enables supporters to present information according to the user's cognitive function using an easy-to-understand synthetic voice and technology that extracts the intent of older adults' responses.
5. Input information to the robot system via the cloud.
6. It accesses the cloud depending on the transmission status, considering its dependence on the Internet environment.
7. It highlights excessive reliance on this system and ethical issues including privacy, and addresses them by considering how to use the system.

8. In implementing this system, establish a service delivery model with family members, community comprehensive support centres, home-visit nursing stations, day-care facilities, pharmacies, city departments, medical institutions, neighbourhood residents, care managers, manufacturers of equipment and systems, and service providers who introduce and operate the system.
9. The following points were noted as non-functional requirements:
   a) Selection of appropriate presentation methods as a response to individuality and change in cognitive function
   b) Consideration of usage methods to deal with excessive dependence as a secondary disorder and ethical issues
   c) Use of a general-purpose platform assuming 1.1 million users
   d) Measures to cope with an unstable internet environment

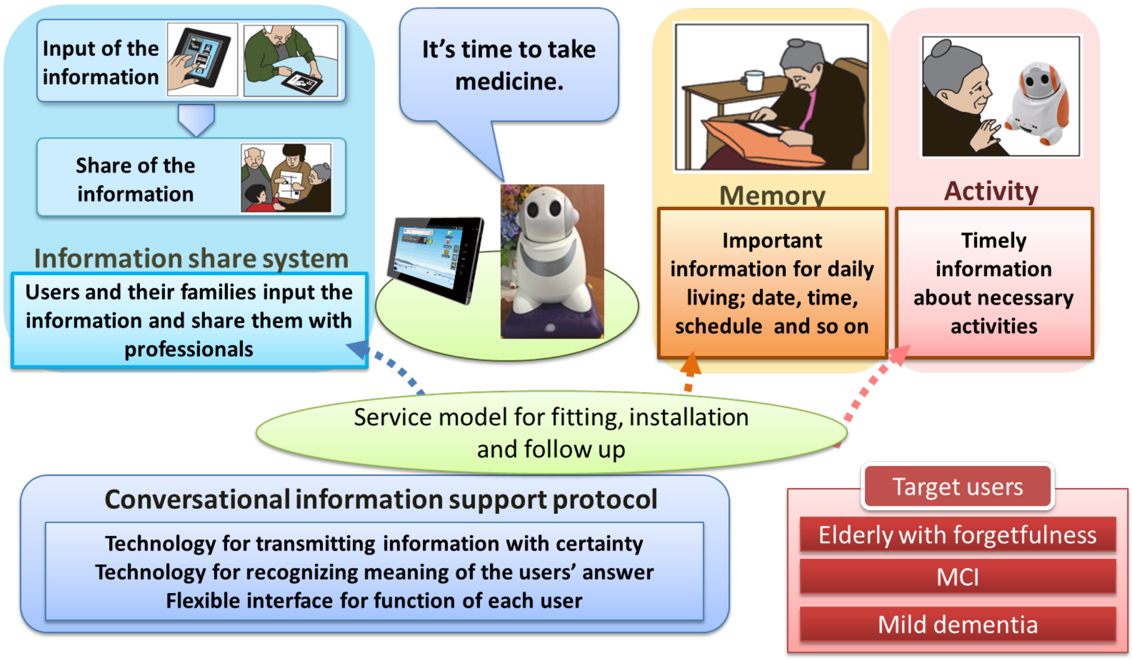

Figure 5 The final concept of the information assistance robot system

In this case study, four-week field tests were conducted with six older adults, which showed some efficacy. A social experiment is planned for the future, and the results of future evaluations will determine the program's effectiveness in the community. However, previous field tests have shown that the program is effective in maintaining and improving the lives of individuals. In this respect, the concept of the system to be developed was validated.
Further, it is possible to derive a concept for an information assistance system that can be used in daily life, targeting elderly people with cognitive decline whose needs are difficult to capture. Although other communication robots with conversational functions have been developed, most are mainly used in exercises and recreation at facilities and for conversational functions with users, and few have been proposed for home use. Therefore, the usefulness of this method was demonstrated.

Furthermore, several stakeholders are involved in the operation of such a system, and the research team has been able to combine the crucial functions of the robot system by assuming this point early in the development process, as well as by gathering information at the sites where the system is expected to be used. In a study of concepts specific to human interfaces, experiments and observations were conducted to determine the functions required for information assistance systems in an independent private nursing home, which falls between a home and an institution, and to construct a human interface matching users' declining cognitive functions. Information presentation according to cognitive function can also be incorporated into functions based on examining non-functional requirements, which is another useful feature of this method. The results further demonstrate the concept's validity, as it is possible to build an introduction and service delivery model that considers stakeholders.

6 Future Vision of AT innovation

Due to the quick improvement of technology in this era, AT innovation needs to change to create a new image. It is urgent to incorporate current advances into the field as quickly as possible, and these efforts have already begun. The use of Artificial Intelligence (AI) has the potential to become the core of future technological development in this field, such as technologies for monitoring older adults and super-universalization technologies in which ATs automatically adapt their functions to the user's characteristics. Application of 3D technology is also underway. Suzurikawa (2020) have utilised 3D printers to create highly individualised self-help devices and is building a system that includes training and support for rehabilitation professionals for their effective use. In addition, human augmentation engineering, which is defined as "a system to be attached to humans, to enhance and empower human functions" (Mochimaru n.d.), develops the concept of including those with disabilities in the idea of extending human functions rather than capturing the negative aspect of disability. Further matching of technology and people in this way will surely be the future of AT innovation.

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References

Cross, Nigel. 2000. *Engineering Design Methods: Strategies for Product Design.* 3rd ed. Chichester, Weinheim: Wiley. http://www.loc.gov/catdir/description/wiley034/00043339.html.

Graduate School of System Design and Management. 2015. "What Is System Design and Management?" https://www.sdm.keio.ac.jp/en/about/concept.html.

IDEO Design Thinking. n.d. "Design Thinking Defined." Accessed November 23, 2023. https://designthinking.ideo.com/.

Inoue, Takenobu, and Minoru Kamata. 2019. "Filed-Based Innovation Methodology and Its Implementation on Development of an Information Support Robot System for the Elderly." *Technology and Disability* 31 (1): 44–45.

Inoue, Takenobu, Misato Nihei, Takuya Narita, Minoru Onoda, Rina Ishiwata, Ikuko Mamiya, Motoki Shino et al. 2012. "Field-Based Development of an Information Support Robot for Persons with Dementia." *Technology and Disability* 24 (4): 263–71. https://doi.org/10.3233/TAD-120357.

Inoue, Takenobu, Atsushi Tsukada, Takanori Aikawa, Hideyuki Hirose, Toru Tamura, Kazuyuki Itoh, and Koichi Yokota. 2003. "Bottlenecks and Their Solutions for Development of Assistive Technologies." *Assistive Technology Research Series* 11: 732–36.

Kelley, Tom, and David Kelley. 2013. *Creative Confidence: Unleashing the Creative Potential Within Us All.* New York: William Collins.

Maeno, Takashi, Toshiyuki Yasui, Seikou Shirasaka, Yoshikazu Tomita, Ishibashi, Kanenori, Iwata, Toru, and Hiroyuki Yagita. 2014. *Changing the world through systems x design thinking Keio SDM 'How to Create Innovation':* Nikkei BP.

Mochimaru, Masaaki. n.d. "Message from the Director." Accessed November 23, 2023. https://unit.aist.go.jp/harc/en/index.html.

Simpson, Richard C. 2005. "Smart Wheelchairs: A Literature Review." *Journal of rehabilitation research and development* 42 (4): 423–36. https://doi.org/10.1682/JRRD.2004.08.0101.

Suzurikawa, Jun. 2014. "New wave of AT Development process." In *Developing Next-Generation Technologies for Human Locomotion and Mobility – Towards the Widespread Use of User-Friendly Assistive Technologies: NTS, Japan*, edited by Takenobu Inoue.

Suzurikawa, Jun. 2020. "Concept of Novel Production Method for Self-Help Devices Using 3D Printers - Not to Be Drowned in Technology [In Japanese]." *Rehabilitation Engineering* 35: 56.

Suzurikawa, Jun, Takafumi Kinoshita, Mitsuhiro Kamo, Norikazu Iida, Kakuya Iwata, Osamu Matsumoto, and Takenobu Inoue. 2012. "Estimation Model of Joystick Input Changes Induced by a Downhill Turning Prevention Control Mounted on a Powered Manual Wheelchair." *Journal of Life Support Engineering* 24 (3): 128–34. https://doi.org/10.5136/lifesupport.24.128.

World Health Organization/Unicef. 2022. "Global Report on Assistive Technology." https://www.unicef.org/reports/global-report-assistive-technology.

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