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Proposal for a New Development Methodology for Assistive Technology Based on a Psychological Model of Elderly People

Misato Nihei and Masakatsu G. Fujie
The University of Tokyo, Waseda University
Japan

1. Introduction

Developed countries are all witnessing an increase in the aging of their populations and Japan is no exception to this. In fact, Japan is a pioneer in this respect, and as of 2011 the nation's elderly population stood at 29,440,000, or 23.1% of the total population (The Cabinet Office in Japan, 2011). Social aging has thus triggered research into geriatric assistive technology (AT) as well as a supportive societal infrastructure catering to the elderly and to persons with disabilities. The AT industry in Japan, which has great significance for social and industrial users, has been referred to as a growth industry since legislation on AT was enacted in 1992 (M. Watanabe et al., 2006). Some modifications to the social system and care insurance system were enacted in 2000, and the market has been steadily expanding and currently it is said to have reached maturity (K. Masahiro, 2005). In the past decade, emphasis has been given to developing an AT infrastructure that can readily facilitate the adoption of the advances being made in standardizing AT and to further improve the quality of this service in addition to enhancing the safety and operability of the system (S. Hashimoto,.2007).

Unfortunately, the gap between AT developers and users in understanding the needs involved is a wide one that is just beginning to be addressed, e.g., the development and standardization of databases focusing on the individual physical and psychological profiles of the elderly (Body function Database of elderly persons, 1993); the effectiveness of the systems (Y. Shinomiya, 2001); and the emotional and mental effects of the AT on users in terms of such matters as physical function assistance versus mobility. In this study, we analyzed the AT-user relationship and presented the results in a form that AT developers can understand and apply. Taking an inductive approach, we studied changes in the mental states of AT users and looked at device-oriented lifestyles. To build a useful psychological concept design model, we used psychological analysis methods widely employed in medical science, psychology and sociology. As the focus of our study, we chose the wheelchair as a representative example of AT as an example that is both widely used and widely studied (R. Morales, et al., 2006; Q. Zeng, et al, 2006; J.L. Murray et al., 2003).

The use of ATs can improve the physical and social functioning of persons with disabilities and elderly people (J. Jutai, 1999). When developing ATs, engineers need to take an

inclusive approach that considers user participation and user needs (T. Inoue et.al, 2002). The development process should also emphasize conceptual design, based on the physical and living situations of targeted users. Nonetheless, some persons inevitably feel a conflict with regard to the use of ATs. We hypothesize that, for a number of elderly people, the use of ATs is associated with a degree of psychological resistance (Figure 1). According to some reports, such psychological resistance arises and bears a social stigma (B. Louse et al., 2002), when ATs are selected and introduced by therapists (DJ. Baker et al., 2004). On the other hand, there are certain psychological effects produced as a result of using ATs. Consequently, in this study, we propose a new and effective method of developing ATs. In the proposed method, psychological factors associated with the use of ATs are carefully examined before formulating the concept for a new AT.

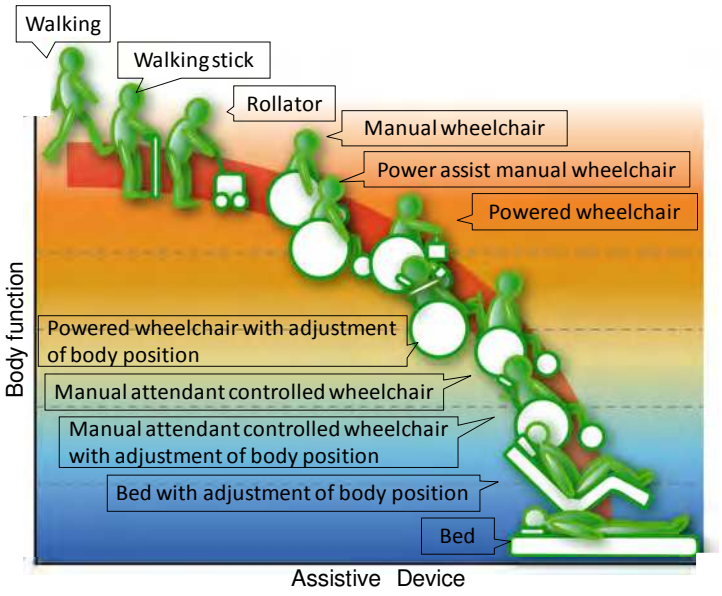


Fig. 1. Relationship between body function and ATs.

In this study, complicated psychological situations are taken into account at the conceptual design stage. The process of developing ATs comprises the following phases:

1. To clarify the process by which psychological conflict with respect to the use of AT is generated, the qualitative research approach was selected.
2. A psychological conceptual model of elderly persons using ATs is developed.
3. The concept of a mobility aid is developed based on the psychological conceptual model and discussions with users.
4. A prototype of a new mobility aid is constructed.

2. The position of a quantitative research approach in design

2.1 The effect of devices on human psychology

In recent years, there have been discussions on what benefits have been seen by using ATs. In particular, it has been made clear in some studies in the practical clinical field that ATs as well as the decrease in daily life activities, and the physical burden on caregivers and that means that the effects on the total evaluation, including psychological. Inoue et al., based on case studies of person with severe disability, state that AT (a powered wheelchair as a case study) has a potential to improve physical health, activity in daily life, social life and, indirectly, spiritual life by using the component QOL (quality of life) model of Lorentsen (T. inoue et al., 2002).

On the other hand, there are several reports of AT not being used in the clinical field. The acceptance of a disability is considered to be one of the causes of this AT non-use. Rosalind et al. describe how physiological and social care became necessary when therapists started to introduce ATs to users in the 1980s (H. Rosalind et al., 1998). In the literature, Krueger's disability acceptance model explains that shock, expectations of recovery, confusion, efforts to adapt, adaptation have a lot to do with why and how users accept the use of a wheelchair.

2.2 ATs for persons with disabilities

ATs help people live their lives in general. So what impression does a wheelchair user make on another person? In a study that examined the awareness of ATs for persons with disabilities, positive aspects such as "(AT) raise awareness of independence," "Give a sense of safety," (M. Roeland, et al., 2002) and "freedom (D.J. Baker, et al., 2004)" were described. On the other hand, negative aspects such as "limits activity (D. J. Baker, et al., 2004)" have been reported. In interviews with persons with disabilities conducted by Lupton et al., positive aspects such as "it is possible to clear various obstacles" were reported (D. Lupton, et al., 2000). On the other hand, negative aspects such as "(assistive devices) to the perceived self-barriers," "really feel that people with disabilities," "difference" and "defect"—indicating a social stigma—have been pointed out as a potential downside to the use of AT.

2.3 Different between the elderly and persons with disability

Based on these reports on persons with disabilities, the particularity and issues were clarified and policy recommendations and medical interventions were proposed. However, in cases that focus on the elderly, the difference in characteristics between the elderly and persons with disability were not clarified. From the few reports related to AT research for elderly person without disabilities, there are statements of opinion or concept regarding the meaning of AT for the individual user. However, these reports did not refer to the development of AT. Therefore, the aim of this study is to investigate the needs of the elderly with respect to AT and also to research the factors and processes behind non-use, and whether it is the same as for persons with disabilities.

3. Assistance for mobility activities (M. Nihei, et al., 2008)

3.1 Research questions regarding assistance for mobility activities

We reviewed the literature and classified prior research into: effects of AT use on QOL, effective AT applications, problems arising in clinical settings, user response to AT

applications in a clinical setting, and the meaning of AT for users and user awareness of AT. In addition, we considered the following in the light of prior research:

- Psychological considerations are related to AT non-use
- It remains unclear whether the disability acceptance model is applicable to the elderly
- Study results must be visualized in relation to AT development

Specifically, we sought to define:

- Factors leading the elderly to like or dislike wheelchairs
- How these factors are related to nonuse of wheelchairs
- How the elderly view wheelchairs when using them
- Factors for differences in views of wheelchairs among elderly users and nonusers

3.2 In-depth interviews

This paper investigates how elderly people feel about ATs. In this study, we examine two types of elderly people: those who have never used mobility aids; and those who are using (or have used) mobility aids in their daily lives (Figure 2). A semi-structured interview approach was selected for analysis. First, profiles of the subjects were constructed through interviews, and their living conditions and physical situation were recorded based on their responses regarding environmental and personal factors. Next, questions concerning 13 items were designed and categorized into: living space, mobility walking experience of wheelchair use, and capability of walking categories. The primary factors were extracted via a recording process, based on a transcript of language data. Consequently, a number of factors were found to impact the subjects' impression of mobility aid use, including the image of mobility aid uses, the impression of mobility aids, comparison with other persons, a new understanding of the walking function, acceptance of their situation, and emphasis of the advantages of mobility aids (shown in Table 1).

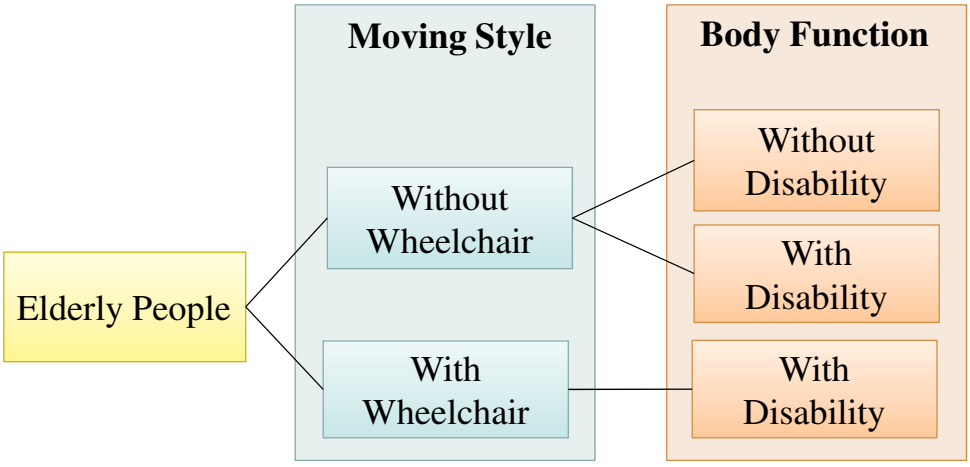


Fig. 2. Classification of survey participants (M. Nihei, et al, 2007).

Mobility Aid	Device Function	Body Function
Walking stick	Walking-aids with one leg and a handle without forearm support.	Person for whom support when walking is necessary. The person grasps the stick to support their weight.
 Rollator	Wheeled frames with handgrips and legs that provide support whilst walking.	Person who needs greater support and stability than that provided by a walking stick.
 Wheelchair	Wheelchairs designed to be propelled by the user, by pushing with both hands on the rear wheels or on the hand rims of the rear wheels.	Person who can walk for short periods.
 Electric motor-driven wheelchairs with manual steering	Wheelchairs powered by electricity that are steered by direct mechanical linkage without power assistance.	Person who cannot walk for long periods.

Table 1. Typical personal mobility aids in daily living in Japan (Association of Technical Aids, 2002).

3.3 Psychological conceptual model for the introduction of mobility aids

The psychological situations of elderly people were clarified by visualization based on the investigation results, and the relationships among these factors were derived through a psychological process based on antinomy. There are two main tradeoffs with respect to ATs, namely that between body function and mobility, and that between body appearance and effortless mobility. For example, if their physical functions decline, persons with disabilities chose to use a mobility aid. Such devices enable them to extend their area of movement. However, a further decline in physical function may occur. This study clarified the psychological states of elderly persons when trying to resolve these dilemmas.

3.4 Assistance with mobility activities

Based on our research findings, we built a conceptual model that AT developers can easily understand. In the model, we paid attention to users and ATs, mobility in daily life, focusing on daily mobility among elderly persons who used/had not used/had experienced using a wheelchair at home. We emphasized two viewpoints: mobility by wheelchair and

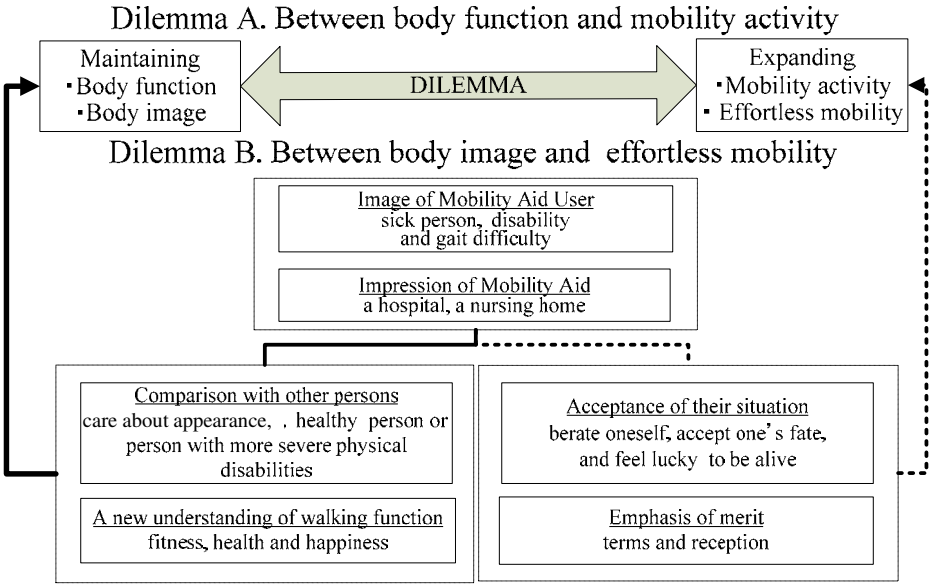


Fig. 3. A dilemma-resolving process model for elderly persons (M. Nihei, 2008).

mobility by walking as viewed by wheelchair users and nonusers. We concluded that: wheelchair users are satisfied with the status quo, but initially had psychological conflicts. Former wheelchair users who are now walking fear physical deterioration, while at the same time recognizing the usefulness of wheelchairs. Acceptance by the elderly of wheelchairs depended on their impressions of and resistance to wheelchairs. These impressions were explained by a disability-acceptance phase model. Wheelchair nonusers clearly harbored some resistance to wheelchairs. We found that the psychological conflicts identified in our survey involved: (a) anxiety about deterioration in physical functions due to AT use, (b) expansion of mobility thanks to AT use, and (c) wheelchair use augmenting an image of physical deterioration and disability. We conceptually diagrammed these psychological states, illustrating the mechanism of psychological resistance and conflicts in a trade-off relationship.

3.5 Assistance of mobility and ICF

What is the best way to resolve these dilemmas? The goal of rehabilitation is the medical viewpoint (medical rehabilitation), such as a disability has to be cured and depression of body function was the only cause for disability for a long period. Therefore, they spend a long rehabilitation time to cure the impaired function. Since 2001, ICF (International Classification of Function), which was established by WHO (World Health Organization), consider the goal of rehabilitation to be body structure and function, activity and participation (WHO, 2001). This representation was an important turning point in stating that rehabilitation is not only a medical issue, but involves but also daily activities and social life.

Here, we discuss the results obtained in Section 3 and the modality of mobility. The idea of selecting physical therapy and non-use of AT to avoid physical depression caused by the use of a wheelchair is an idea based on medical rehabilitation. On the other hand, the idea of selective use of a (powered) wheelchair is an idea based on social rehabilitation. These ideas are poles apart, and it was considered that these ideas were incompatibility. Is that true? In this paper, we propose a new solution to resolve satisfy both medical and social rehabilitation.

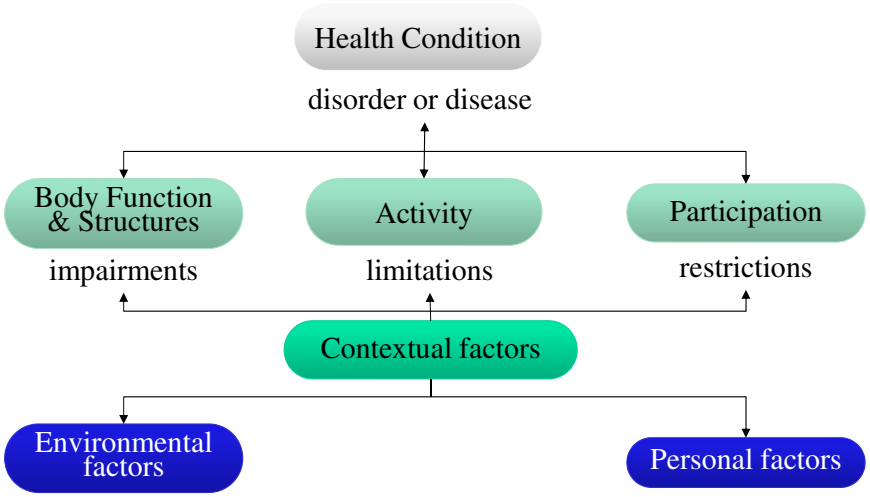


Fig. 4. The International Classification of Functioning, Disability, and Health (WHO, 2001).

4. Concept of a new mobility

4.1 Developmental requirements (M. Nihei et al., 2006-2008)

Our novel concept was created based on the model described above. The cause of psychological conflict of elderly people who have to use a wheelchair: "decline of physical functions," "reduction in mobility activities," "resistance to being a person with a disability," were clarified by a qualitative research approach. Proposing development requirements and introducing their life is needed in order to reduce the psychological conflict and to devise a solution for the situation of elderly people who have to use a wheelchair. To this end, three developmental requirements were proposed and defined.

- Maintain body function: maintain muscles and joints motion for walking.
- Expand mobility activity: expand mobility activity related to daily activities and participation
- Maintain natural walking appearance: maintain a natural walking style and gait

This concept includes the following three functions: enabling natural walking, similar to walking on flat ground; amplifying movement speed and enabling comfortable movement; and maintaining the appearance of being able to walk. Table 2 shows the estimation of the psychological conflict against these mechanical functions of existing products.

The targeted persons have the following characteristics: the ability to walk under their own power, but not quickly; the ability to maintain or expand their mobility area; and the appearance of being able to walk.

Required function	New concept	Walking stick, Rollators	Wheelchair	Powered wheelchair	Trainer
Maintaining body walking function	○	○	×	×	○
Expanding mobility activities	○	Δ	○	○	×
Maintain natural walking appearance	○	○	×	×	×

Table 2. Comparison between new concept and existing products.

4.2 Components of requirements

To decide upon a more concrete mechanical requirement than that listed above, we initially categorized the relationship between the human bodily phase and mechanical phase shown in Fig. 5. Human functions consist of main three factors: the sensory system, the central nervous system, and physical function. These three factors are integrated in body movement and bodily appearance is dictated by movement. Likewise, the mechanical system consists of main three factors: the operation system, the control system, and mechanical function. These three factors are integrated in mechanical design. The interfaces that connect human and mechanical function are the human sensor receptor to recognize the mechanical function (behavior) and the operation system to use the physical function. Therefore, to meet the developmental requirement, amplifying the results of the system's movement for the operation of one's own body movement is one solution.

Second, using a combinational method (H. Yoshikawa, 1985) with keywords and partial functions, solutions were extracted by using the matrix shown in Figure 6. The developmental requirements are shown in the following equation.

$$T = T^1 \bigcap T^2 \bigcap T^3 \tag{1}$$

Here, T is developmental requirement, T^1 is maintain body function, T^2 is expanding mobility activity, T^3 is maintaining a natural walking appearance. First, we extracted a keyword for each factor, e.g. walking, treadmill, training machine, stepping machine in the case of T^1, and the flow of the developed figure. Here, S_1 is the expected duration of product development, S_2 is the feasibility of technical issue.is shown in Figure 6. Based on one example of these solutions, we propose a new mobility aid.

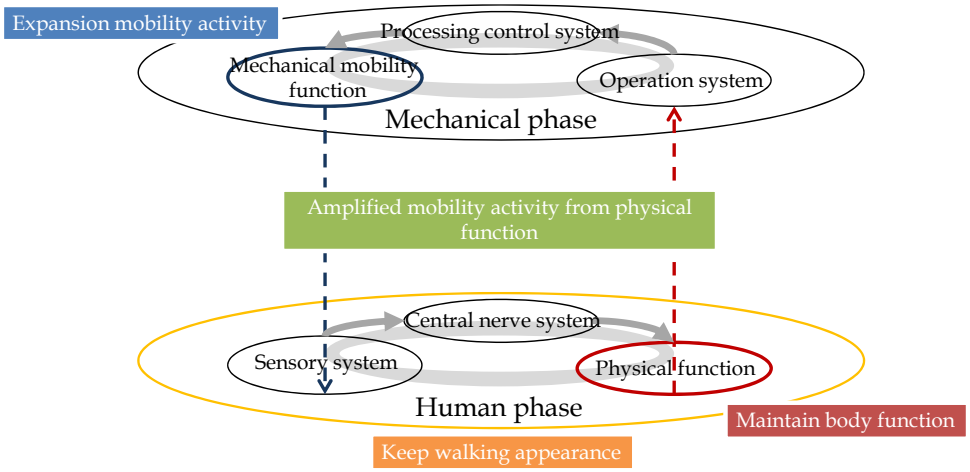


Fig. 5. Development requirements between bodily and mechanical phase.

4.3 New mobility, tread-walk (M. Nihei et al., 2006-)

We have designed and developed a new mobility-aid for the elderly that improves their walking speed, as shown in Figure 7. This device is called Tread-Walk1 (TW-1). It is mobile treadmill-like system that is designed to meet the following three requirements: the maintenance of bodily function; the extension of mobility; and the maintenance of the appearance of a natural gait. Targeted users have the following characteristics: the ability to walk under their own power, but not quickly; the motivation to maintain or expand the geographical area in which they are mobile; and the wish to appear as though they are walking naturally. The control of the system's belt velocity is based on the natural walking velocity of the user. The user's intended walking speed is detected by the kicking and braking forces applied by the user's feet as he or she walks on the treadmill belt, which in turn is connected to a DC motor. These forces are counteracted by the propulsion force of the belt. To control this system more accurately, signals for rotational movement should also be derived directly from the walking motion. In this section, we focus on human rotational movement, and we describe a novel system that uses two belts to derive separate signals from each foot during walking.

Figure 8 shows a moving walkway. The developed system, the TW-1, gives the same feeling as walking on a moving walkway; just imagine the marvelous feeling of acceleration.

4.4 Prototype construction

1. Basic concept

The mobility aid shown in Figure 9 is a four-wheeled vehicle that permits the user to walk naturally, while a servomotor amplifies the natural walking speed of the user. Its main components are a treadmill and two front driving wheels. Sensors in the treadmill detect the acceleration/deceleration forces applied to the surface while walking. The rotational speed of the driving wheel motors is controlled by signals from these sensors. Computer software

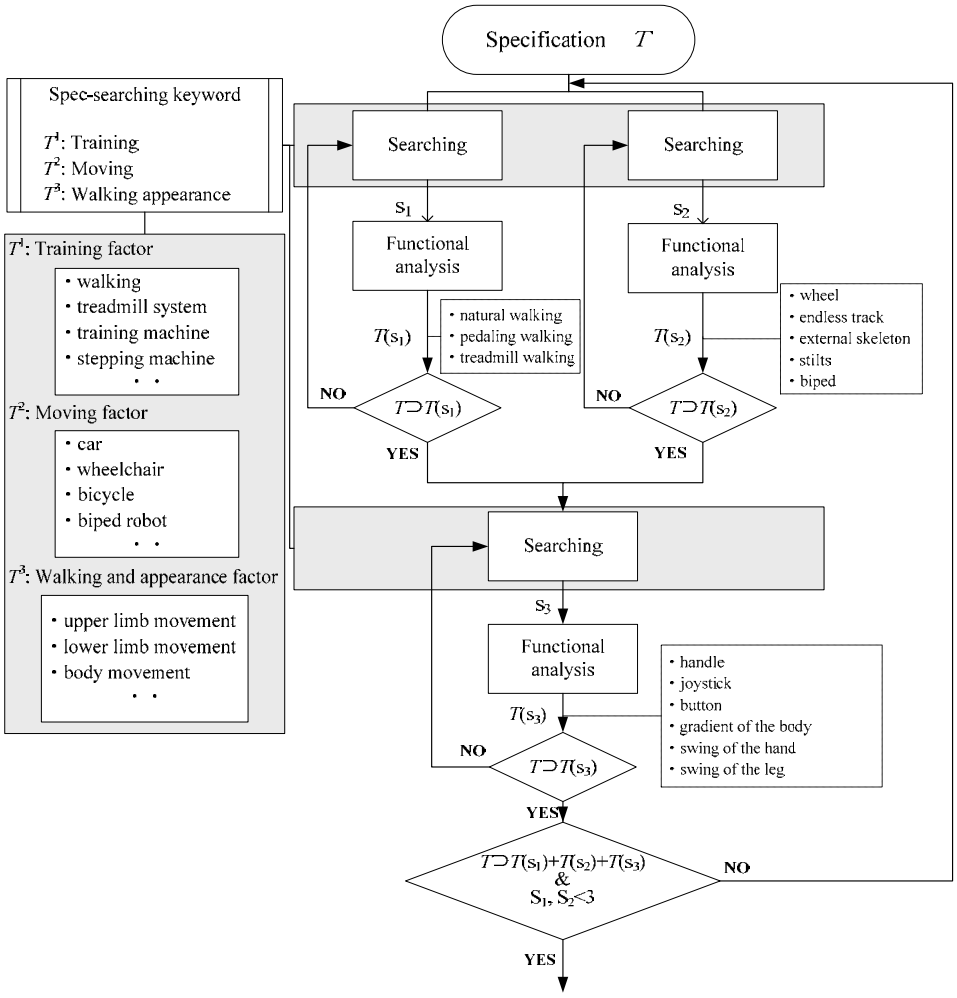


Fig. 6. Development requirements between bodily and mechanical phases.

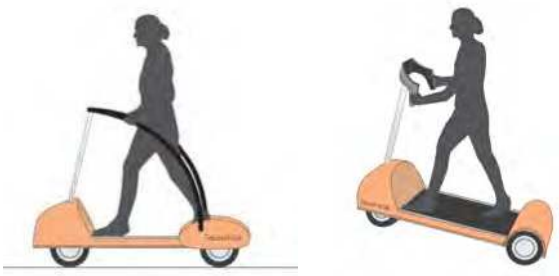


Fig. 7. Artists impression of Tread-Walk1.

Fig. 8. Image showing the pleasant walking feeling of Tread-Walk1.

monitors the walking pattern, as measured by the treadmill motor load, and the steering control detects the angle of the steering wheel and controls the speed ratio of the right and left wheels.

Figure 10 shows the system flow of the functional overview of the treadmill and the driving parts. The treadmill motor actuates the treadmill belt and acts as a sensor device at the same time. The mobility aid drive operates as follows:

i. The kicking force of the user rotates the treadmill belt
ii. The rotation force is directed to the shaft, and the load current is detected as kicking and braking forces while walking
iii. The increase or decrease in the rotation speed is decided in the same manner as the kicking or braking force, based on the current load signal, which is derived by a computer program
iv. The mobility aid operates synchronously with the treadmill belt, but the velocity is increased by driving motors.

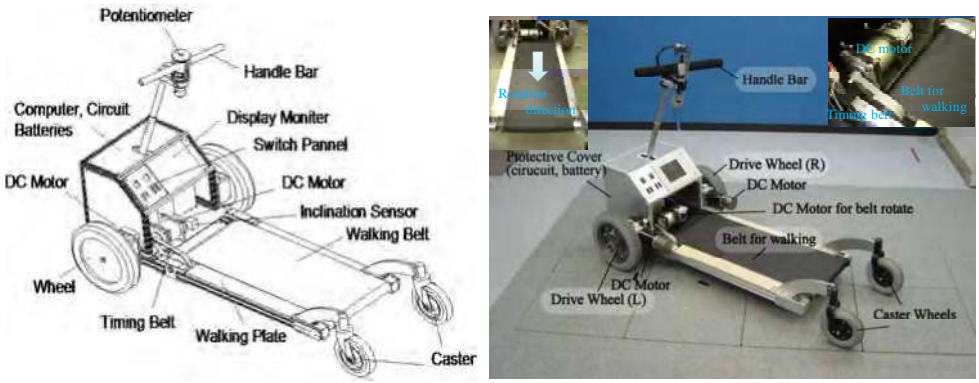


Fig. 9. Prototype of Tread-Walk1.

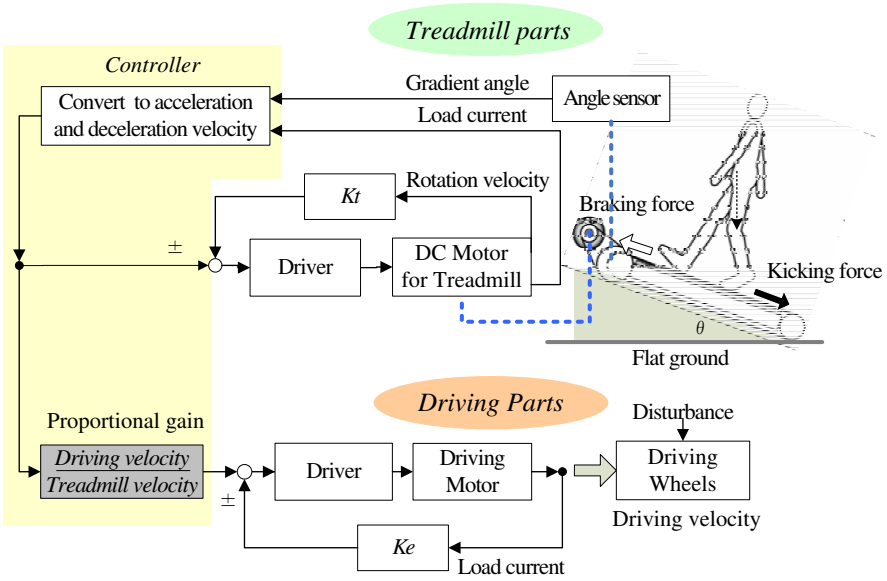


Fig. 10. The system flow of the functional overview of Tread-Walk1.

2. Design for the elderly

The vehicle's external dimensions are 1520 (L)x760 (W)x1120 (H) [mm] and the maximum velocity is 6.0 [km/h], and are reference from JIS (Japanese Industrial Standardization). The size of each component such as platform height, withstanding load, continuous operation time, handle length and height, grip size, rotational resistance of handle, and size of treadmill were determined by consulting a database of human body dimensions and data on the characteristics of the body functions of the elderly (NEDO, 1993) (shown in Figure 11). The specifications were also determined by taking into consideration envisioned risks such as the likelihood of elderly users falling off the vehicle.

3. Walking movement on TW-1 treadmill

Control of the treadmill belt velocity was based on the natural walking velocity of the user. The user's intended walking speed is detected by the kicking and braking forces that are applied by the user's feet as he or she walks along the treadmill belt, which is connected to a DC motor. These forces are counteracted by the propulsion force of the belt as load trque.

4. Vehicle movement and acceleration

The technological opportunity, the walking assist-rate, assist force, slope assistforce and acceleration were extracted. The vehicle control mthodology was designed to be safe, taking into consideration the inertial force resulting from the acceleration of the vehicle. Figure 11 shows the gait pattern during walking on Tread-Walk1 and movement, recorded by video capture every 0.2 [s]. These photographs shows that the gait is a natural pattern including (a) a double-stance phase, (b) push off by the left foot, (c) foot off by the left foot, (d) stance phase of right foot and (e) foot contact of left foot. (T. Ando et al., 2009)

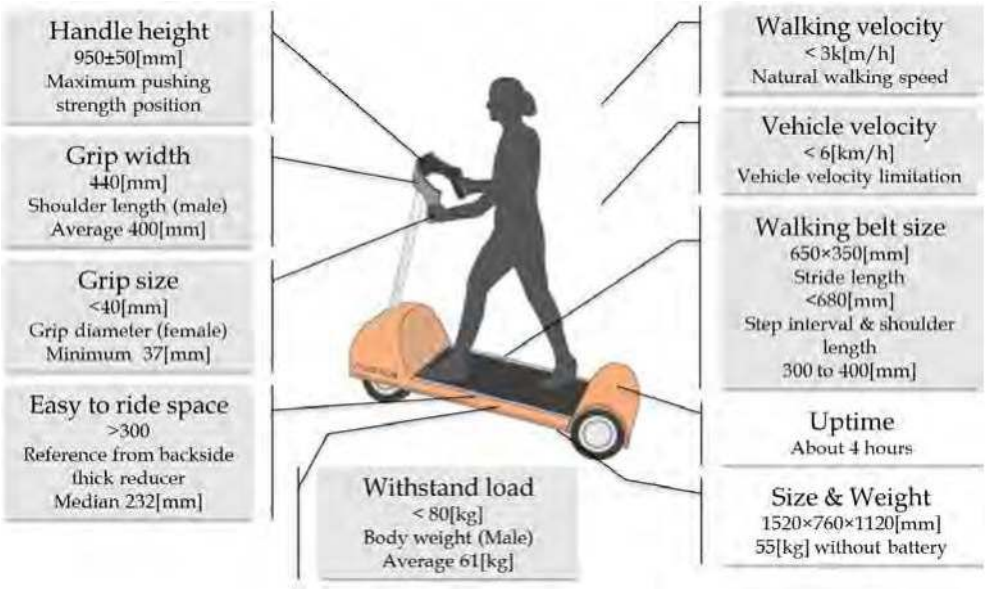
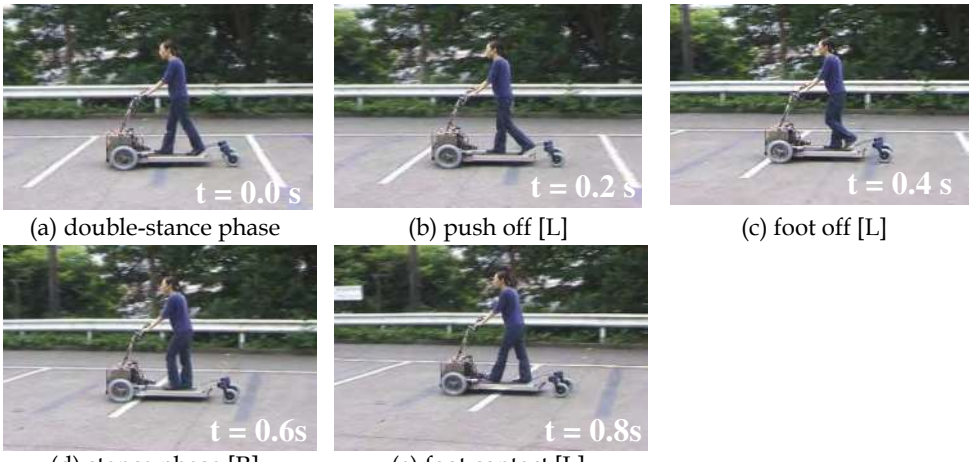


Fig. 11. Specifications and design for the elderly.

5. Vehicle steering

We propose a method for steering control that enables the user to turn the device safely and in a stable manner. The system is designed to allow the user to maintain his or her balance in a standing position during a turning operation. To achieve this, the rotational velocity at which a comfortable balance can be maintained in a standing position when the user is subjected to a centrifugal force was established (T. Ando et al., 2008).



(a) double-stance phase (b) push off [L] (c) foot off [L]

(d) stance phase [R] (e) foot contact [L]

Fig. 12. Gait pattern during walking and driving Tread-Walk1.

4.5 Evaluation of prototype and impression of new mobility aid

Test drive evaluations in an open space suggest that this device is safe and effective for use by middle-aged and older adults. Walking movement on TW-1 was analyzed kinematically by comparing it with the corresponding walking movement on flat ground. To determine whether the two dilemmas between body function and mobility activity, and body appearance and effortless mobility of the mobility aid had been addressed, detailed interviews were conducted to determine the impressions of users regarding the proposed mobility aid. We interviewed 38 healthy adult participants aged over 60. We performed test drives in an open space, and each driver demonstrated their test drive to other participants. The question "How do you feel about using Tread-Walk1?" was asked, and responses were made according to a five-grade evaluation scale. In addition, free comments were also recorded. The results of the interview revealed that 79% of the participants had a positive impression of the proposed mobility aid. Comments such as "interesting," "exciting," "novelty item," "good for health," "exercise," "rehabilitation, " and "increased willingness to go out," were provided by the participants.

(a) Participant A

(b) Participant B

Fig. 13. Test driving and evaluations, subject (healthy elderly persons).

4.6 Proposal for a new development methodology for ATs

Figure 14 shows the development methodology used in this study. The first point was to introduce participant observation (the Cogitation stage) and a qualitative research approach at an early stage (the Analysis stage). This methodology can reveal latent needs that do not rely on the individual experience and thinking of users, key persons, and therapists. The second point was to visualize the qualitative data obtained in the survey of the relationship between ATs and the elderly, and to clarify the developmental requirements (Visualization of the tradeoff relationship stage). The result of the qualitative research was translated to a conceptual model for visualization and the developmental requirements were extracted from the main components of the conceptual model. To decide the shape of the new mobility aid, a components matrix and human-machine system were introduced because there are several solutions for the design.

A new mobility aid, Tread-Walk1, was developed through the proposed methodology that was based on an understanding of the undeclared needs of elderly. In this study, a prototype of Tread-Walk was developed with the goal of resolving conflicts among elderly people regarding the use of AT. According to a survey based on the qualitative research

approach, this conflict was described schematically as a dilemma between a willingness to maintain-improve body function and an extension of the mobility area. To resolve this conflict, we proposed the concept of a new mobility aid. In the result of this study, the impression of the mobility aid was reported by elderly people to be positive. Psychological issues, such as a resistance to the wheelchair, which clearly emerged in this study, is a real and substantive problem. In addition, the development of useful AT will be improved by taking into account a composite observational study of the bodily, living and psychological situation of elderly people. While the model we developed does not apply to all elderly people, it can be treated as a representative case of a realistic situation.

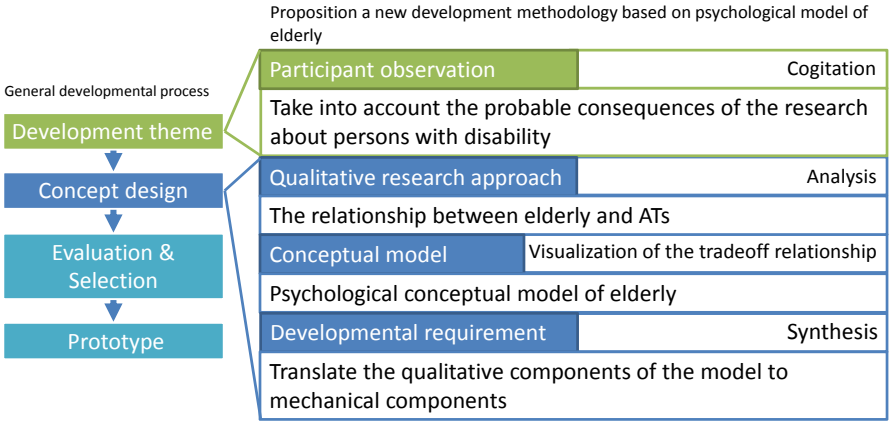


Fig. 14. Development methodology using a qualitative research approach.

5. ATs and an aging society

5.1 Additional issues

As addition issues, we surveyed the elderly and people with disabilities living in nursing homes who routinely use wheelchair as to AT satisfaction and the psychological effects. As a result, the elderly were almost all pleased that more people with disabilities were using ATs and their services. However, lower overall psychological effects were found to be less aggressive, especially "Adaptability" score.

While the elderly are satisfied with the AT that is available; it was shown that there is a potential psychological effect is difficult to obtain due to the AT. Considering these results from a survey, we conducted in-depth interviews at the same time "(Even if I get more advance AT), there is no place to go," and can dilute the purpose of such movement, "I don't feel like a new things now" and lack of purpose in life and found that the presence and movement activities are meaningless. These result are what leads to non-use of AT, to provide a useful instrument for the elderly is truly what we do, a comprehensive approach is necessary for life beyond the framework of the high life and considered.

5.2 The role of technology for an aging society

Here, we discuss how the positioning of the ATs in this study contrast with the background of an aging society and ideology. There are mainly two different ideologies between the

elderly and ATs. One ideology focuses on improving QOL by promoting physical health leading to comfortable life—coincidentally a mainstream social policy. Maintaining physical health reduces medical expenses and lightens the care burden, together with public financial and physical burdens. Extending this ideology too far, however, may lead to excessive "embodiment (L. Cheryl, 2003) " centering on an ideal body image rather than the realities of the aging body itself. This ideology in engineering is the mainstream, as it has been predicted to increase in the number of consumer AT to the increasing number of elderly people, and commercialization has developed various devices entered many enterprises have been promoted.

The other ideology involves an ideal called "empowerment (C.M. Morell 2003)," and is based on the idea that the will to live and a positive mindset will improve QOL, regardless of physical function. This values neither age nor physical function, focusing instead on spontaneous self-motivation, making it easier for individuals to "accept" disability, illness, or death. In the field of engineering, they are powered-wheelchairs and information and communication technologies.

These two ideologies, one focusing on the physical and the other on the mental, both are likely to improve QOL, but their components differ. Most of the elderly thus are finding their own optimum solutions to balancing their lives between "an aged but healthy society" and " a wonderful thought not so healthy life." Our research results show that we can improve the QOL of the elderly by using AT. Instead of suggesting ways of ideology, we propose developing ATs based on the potential needs of elderly people (Figure 15).

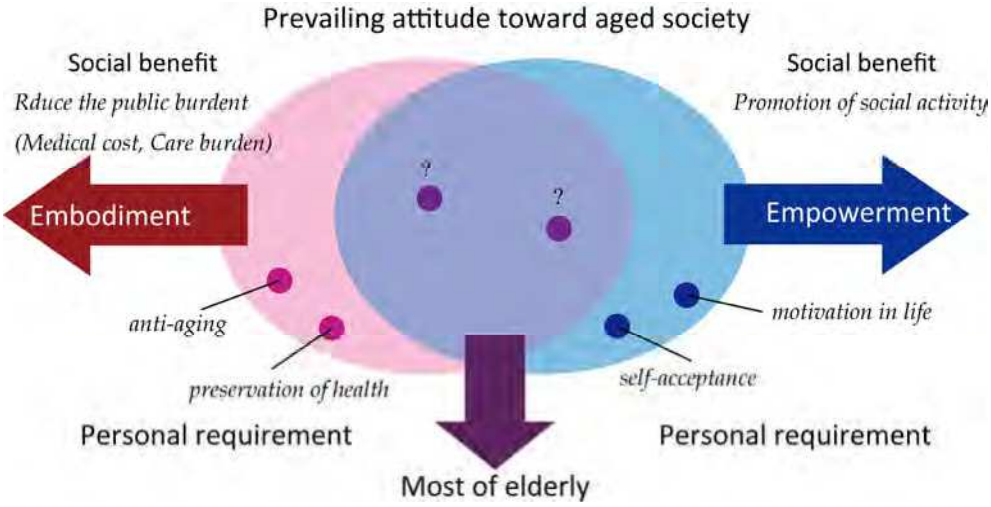


Fig. 15. The elderly and social thought.

6. Conclusion

One of the outcomes of this research is that qualitative research of the psychological trends of individuals who use assistive technologies clearly exists in regard to the relationship between users and assistive technologies, which was clarified by an analysis of this concept,

and these findings are expected to be applied to rehabilitation engineering and clinical fields in the future. In addition, this research can greatly contribute to future progress in rehabilitation engineering by providing a concrete example of device development, by showing the necessity of considering user psychology during development, and by proposing a new methodology for use in development.

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This book offers the reader new achievements within the Assistive Technology field made by worldwide experts, covering aspects such as assistive technology focused on teaching and education, mobility, communication and social interactivity, among others. Each chapter included in this book covers one particular aspect of Assistive Technology that invites the reader to know the recent advances made in order to bridge the gap in accessible technology for disabled or impaired individuals.

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University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821