2011 IEEE International Conference on Rehabilitation Robotics
Rehab Week Zurich, ETH Zurich Science City, Switzerland, June 29 - July 1, 2011

A Concept of Needs-Oriented Design and Evaluation of Assistive Robots Based on ICF

Yoshio Matsumoto, Yoshifumi Nishida, Yoichi Motomura, and Yayoi Okawa, Non-*Member, IEEE*

Abstract— **In the robotics community, a great number of assistive robots for elderly and handicapped people have been developed in the past few decades. However, very few of them became commercially available. It is often claimed that the major problems for the commercialization of robotic technologies are the "cost" and the "safety." However we believe that the mismatch of "needs in daily lives" and "seeds in the technologies" is also a major problem. In this paper, we describe our novel ideas on the development of assistive robots which fit the real needs of users based on ICF (International Classification of Functioning, Disability and Health), which is a part of the WHO Family of International Classifications for describing whole activities of a person in daily lives. By utilizing ICF, the development process of assistive robots - analyzing and discovering needs in daily lives, designing robots and evaluating the products - will be achieved in an objective manner.**

I. INTRODUCTION

IN the robotics community, a great number of assistive robots as well as assistive technologies for elderly and handicapped people have been developed in the past few decades. However, very few of them became commercially available, and even fewer have been continuously supplied for lengthy periods of time.

It is often claimed that the biggest problem for the dissemination is the "cost" of assistive robots. It is true that assistive robots tend to be very expensive because they are usually composed of a large number of electrical and mechanical devices such as sensors, actuators and processors for intelligent and sophisticated control. They tend to be even expensive since they are ill-suited to mass production.

Another big problem is the "safety" issue of the service robots which need to co-exist and interact with human. It is not yet clear who takes the responsibility for accidents caused by / with such robots, and thus many large companies are reluctant to do business with service robots. Considering the successful framework in the current automobile industry, it will be necessary for the service robot industry to involve casualty insurance companies to insure such risks. Also standards for safety test methods and safety certification organization for service robot should be established, which is being conducted in a project promoted by NEDO (New Energy and Industrial Technology Development Organization) in Japan.

However, even if two problems described above are solved in some way, we think another big problem still remains - "benefit" of assistive robots. Benefit means what kind of functional assistance in quality and quantity a user can get from a robot. People who need assistance will utilize assistive robots if the cost and risk is lower than the benefit. Therefore we must clarify both cost-benefit and risk-benefit relations. The definition of benefits is also important because it clearly indicates which functions in the daily lives can be assisted and realized. Excess functions of assistive robots and inappropriate use of them may result in disuse syndrome[9], which is another kind of risk aside from mechanical and electrical risks. Thus clear definition of function of assistive robot is necessary for determining "indication and contraindication" (who should utilize and who should not utilize) of assistive robots. If the benefit can be described as functions in an objective manner, the needs of a user can be also described in the same framework by analyzing the functioning of a user in daily lives. This will help developing assistive robots based on the real needs.

In this manuscript, we propose a framework towards describing the "benefit of a robot" and "needs of a user" based on ICF[1]. It is a common language for describing the whole state and functions of a person with more than 1,500 elements. We believe that this framework will be helpful for developing and evaluating assistive robots which are truly beneficial to elderly and handicapped people.

The rest of the paper is organized as follows. Section II describes related conventional works on describing functions of a robot and a person. ICF, approved by WHO, is then introduced as a new description language. In Section III, novel ideas on how to apply ICF to the development of assistive robot are indicated. Four examples of the processes, the analysis of functions in daily lives, the description of needs for assistive robots, the description of the specifications of robots, and the evaluation of assistive robots, are to be described.

Yoshio Matsumoto, Yoshifumi Nishida, and Yoichi Motomura are with the National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568 Japan. (corresponding author to provide phone: +81-29-861-5201; fax: +81-29-861-5989; e-mail: yoshio.matsumoto@aist.go.jp). Yayoi Okawa is with the National Center for Geriatrics and Gerontology.

II. Related Works

A. Classification of Behaviors of Human and Robots

Considerable efforts have been taken for standardization of behaviors of robots or agents as follows:

- RAC (Robot Action Commands)[2]
- RSi (Robot Service Initiative) Protocol [3]
- BML (Behavior Markup Language)

RAC is a set of generalized motion commands defined as an extension of ORiN (Open Robot Interface for the Network)[4] which operates on different robotic platforms such as manufacturing robots and pet robots.

RSi Protocol is a communication protocol specification for robotic services that uses the network. It promotes realization of service robots which provide physical services and information services at home and in the office.

BML is meant to be a general mark-up language to express multimodal behavior of conversational agents. It provides a framework for defining multimodal gestures (including the face, the head, the hands, and the body) and defining timing synchronization. The language is to describe behavior in an abstract way, independent of the agent model or the actual engine realizing the behavior.

These three description methods were invented in order to generalize and standardize the behaviors of robots independent of the platforms. However such frameworks seem to have something to do with the description of the specification of an assistive robot as well as the needs of a person to be assisted.

On the other hand, several methods for describing human activities are proposed and utilized mainly in the medical and healthcare fields as follows:

- MET (Metabolic Equivalent of Task)
- ADL (Activities of Daily Living)
- IADL (Instrumental Activities of Daily Living)
- ICF (International Classification of Functioning, Disability and Health)

MET is a unit used to compare the working metabolic rate (the amount of oxygen used by the body during physical activity) to the resting metabolic rate[5]. It is a way to compare the amount of exertion required for different activities. At rest, the body uses one MET for basic functions such as breathing. Moderate physical activity requires 3 to 6 METs, and vigorous physical activity requires more than 6 METs.

ADLs represent the things we normally do in daily living including any daily activity we perform for self-care (such as feeding ourselves, bathing, dressing, and grooming), work, homemaking, and leisure. The ability or inability to perform ADLs can be used as a very practical measure of ability/disability in many disorders[6]. Health professionals refer to the ability or inability to perform ADLs as a measurement of the functional status of a person. This measurement is useful for assessing the elderly, the mentally ill, and those with chronic diseases, to evaluate what type of health care services an individual may need.

IADL stands for six daily tasks (light housework, preparing meals, taking medications, shopping for groceries or clothes, using the telephone, and managing money) that enable the patient to live independently in the community.

These three description methods can indicate how actively a person is living, and what type of assistance a person may need in some aspects. However they are rather rough to find out the detailed needs of a person. ICF is another way of describing the activities of an individual with finer description capability, which is explained in the following section.

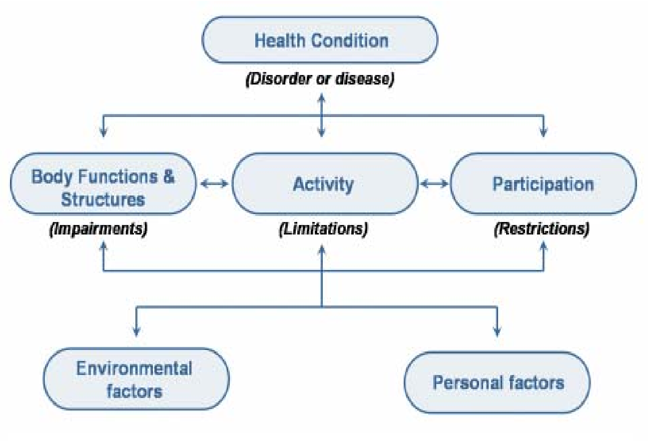

Fig. 1: The overview of ICF

B. ICF: International Classification of Functioning, Disability and Health

International Classification of Functioning, Disability and Health, also known as ICF, is a classification of the health components of functioning and disability[1]. It was approved by the World Health Organization (WHO) in 2001. The ICF complements WHO's International Classification of Diseases (ICD), which contains information on diagnosis and health condition, but not on functional status. The ICD and ICF constitute the core classifications in the WHO Family of International Classifications (WHO-FIC). The ICF is structured around the following broad components as shown in Fig.1:

- Body Functions and Structure
- Activities (related to tasks and actions by an individual) and Participation (involvement in a life situation)
- Additional information on severity and environmental factors

Functioning and disability are viewed as a complex interaction between the health condition of the individual and the contextual factors of the environment as well as personal factors. The picture produced by this combination of factors and dimensions is of "the person in his or her world". The classification treats these dimensions as interactive and dynamic rather than linear or static. It allows for an assessment of the degree of disability, although it is not a measurement instrument. It is applicable to all people, whatever their health condition. The language of the ICF is neutral as to etiology, placing the emphasis on function rather than condition or disease. It also is carefully designed to be relevant across cultures as well as age groups and genders, making it highly appropriate for heterogeneous populations.

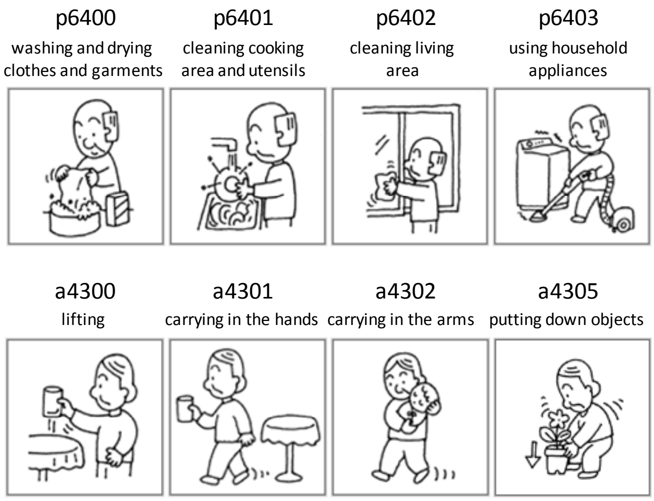

Fig. 2: Examples of participation-level (upper) and task-level (lower) activities and corresponding codes

The outline of the classification in the Activities and Participation is described as follows:

a1: learning and applying knowledge
a2: general tasks and demands
a3: communication
a4: mobility
a5: self-care
a6/p6: domestic life
a7/p7: interpersonal interactions and relationships
a8/p8: major life areas
a9/p9: community, social and civic life

In this list, the prefix character "a" indicates task-level activity, and "p" indicates participation-level activity as shown in Fig.2. These categories in total consist of all kinds of actions and behaviors in daily living. For instance, the part of "mobility (a4)" is further classified as follows:

- changing and maintaining body position (a410-a429)

a410: changing basic body position
a415: maintaining a body position
a420: transferring oneself
a429: changing and maintaining body position, other specified and unspecified

- carrying, moving and handling objects (a430-a449)

a430: lifting and carrying objects
a435: moving objects with lower extremities
a440: fine hand use
a445: hand and arm use
a449: carrying, moving and handling objects, other specified and unspecified

- walking and moving (a450-a469)

a450: walking
a455: moving around
a460: moving around in different locations
a465: moving around using equipment
a469: walking and moving, other specified and unspecified

- moving around using transportation (a470-a489)

a470: using transportation
a475: driving
a480: riding animals for transportation
a489: moving around using transportation, other specified and unspecified
a498: mobility, other specified
a499: mobility, unspecified

Lastly, all categories shown above are further categorized with detailed basic motions with four digits. For example, "fine hand use (a440)" is categorized as follows:

a4400: picking up
a4401: grasping
a4402: manipulating
a4403: releasing
a4450: pulling
a4451: pushing
a4452: reaching
a4453: turning or twisting the hands or arms
a4454: throwing

In total, 1,424 functions and factors are coded in the ICF. Seeing these categories, we came up with an idea to utilize the ICF in the development process of assistive robots for analyzing and finding out the needs in daily lives, designing robots and evaluating the products objectively. The important point is that the ICF includes all activities, and it is an internationally standardized classification.

III. Application of ICF to Assistive robot

In this section, the ideas on how to utilize the ICF in the development process of assistive robots - analyzing and discovering needs in daily lives, designing robots and evaluating the products - are described. Fig.3 shows the concept of life design with various assistive methods based on ICF. If the status of current life and desired life are described based on ICF, and the effect of various assistive methods are defined by ICF, the combinational usage of assistive method to fill the gap will be analytically obtained. Of course, it won't be as easy as solving combinational simultaneous linear equations, as each assistive method is not independent of others such as side effects.

In the following sections, examples of the usage of ICF in developing assistive robots to realize the concept of life design such as (A) analysis of functions in daily lives, (B) description of needs for assistive robots, (C) description of specifications of robots and (D) evaluation of assistive robots, are to be shown.

A. Analysis of Functions in Daily Lives

It is important to analyze the functions conducted in our daily lives in order to understand the structure of the life, because it is not clear what kinds of task-level activities should be assisted for achieving a certain participation-level activity. Supposing that we need to build a cooking assistant robot for a handicapped person, then the conc rete contents of assistance as well as the specification of a robot should be determined first. It is actually very difficult to achieve this in an objective and quantitative manner. In addition, it should be also noted that excess functions of assistive robots may result in disuse syndrome[9]. Too much spoils, too little does not satisfy. Therefore the design of assistance should be performed to avoid the excess and the deficiency.

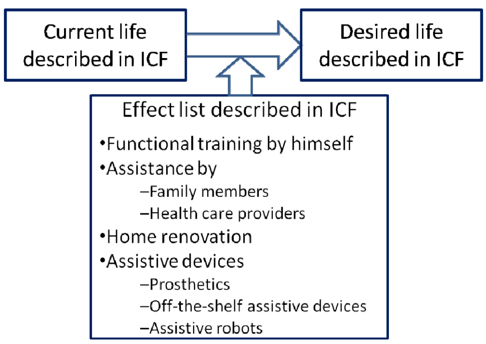

Fig.3: Concept of life design based on ICF

We recorded a life-log of a healthy person and analyzed it based on the ICF. Action, time, duration, place, target object, and purpose were recorded by voice recorder every time when an action was taken, and 3964 activities were recorded for five days. Fig.4 indicates the histogram of all recorded activities. It can be seen that "pick and place," which are the very basic motion of the robot studied for decades are the most frequent activities performed in the daily lives. Fig.5 indicates the task-level activities that "cooking" includes.

B. Description of Needs for Assistive Robots

By analyzing the life-log data described above, it was found out that "lifting (a4300)" is included in 43% of participation-level behaviors. By further analyzing them, it was found out that approximately 90% of the objects of "lifting (a4300)" activities were less than 300g. The exceptions were, for instance, a kettle filled with water (1kg) for "preparing complex meals (p6301)" and a vacuum cleaner (3.8kg) for cleaning (p6402). This kind of information is very useful for finding out the needs of the assistive robot based on the evidence of the real life.

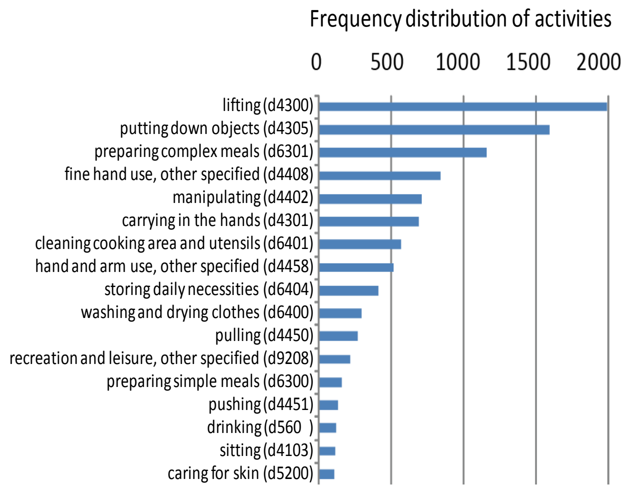

Fig. 4: Frequency of distribution of activities

The ICF can also be utilized describing the current status of daily living and desired one. The gap between them is the needs of assistance. The more concretely the description of the status of daily living is, the more clearly we can see the needs of assistance, therefore the utilization of the ICF will be of great help.

There are many ways to fill in the gap as follows:

- functional training
- support from family
- support from home helper
- house renovations
- conventional assistive devices
- assistive robots

The robotics researchers and developers should notice that robotics technology is not the only way to realize the assistance, but the combination of above mentioned ways is the assistance. It should also be noticed that the less functions an assistive robot has, the less cost and time is necessary to realize it.

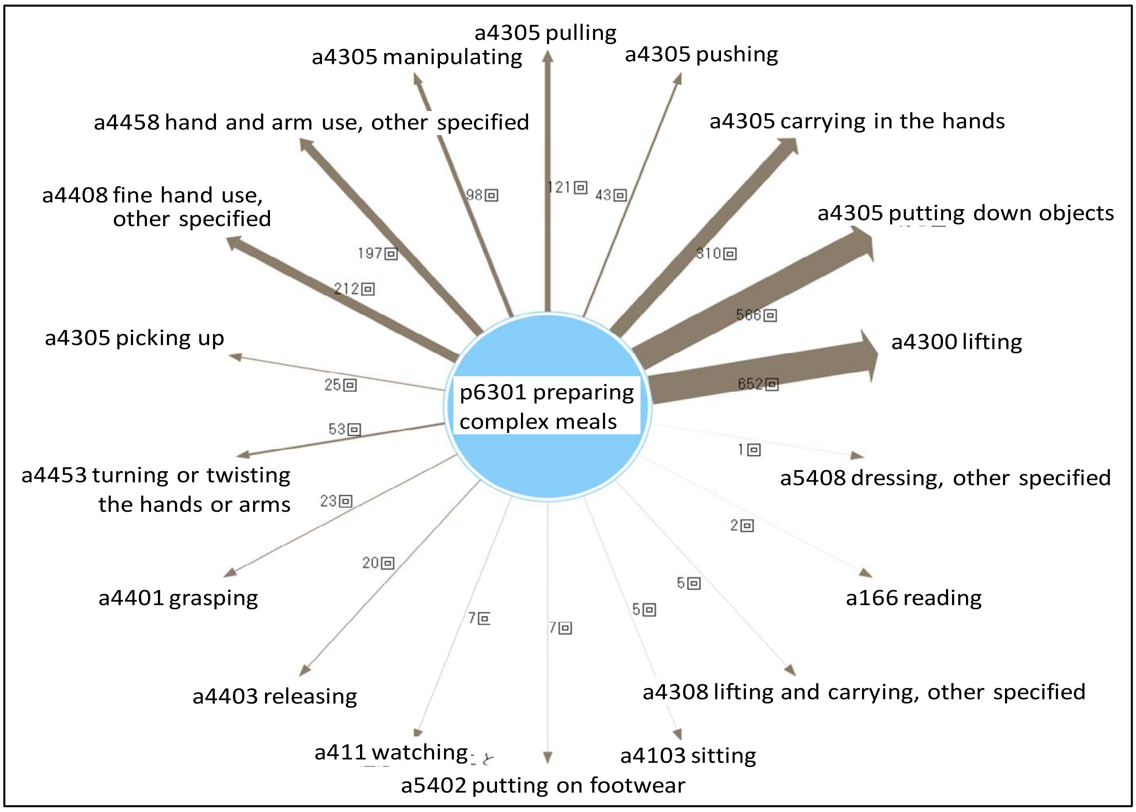

Fig.5: Activities included related with "preparing complex meals"

C. Description of Specifications of Robots

In order to indicate the objective performance of an assistive robot, it should have information including following items:

A) Tasks that the robot can perform
B) Objects that the robot can handle
C) Environments where the robot can work
D) Indication and contraindication of users

The ICF can be utilized for describing A) and D). The qualitative and quantitative description of the specification of a robot is especially important when comparing a robot with another. Fig.6 indicates two robotic arms for persons with disabilities in upper-limb. The iARM is an off-the-shelf robotic arm from ExactDynamics, and the RAPUDA (Robotic Arm for Persons with Upper-limb DisAbilities) is a novel robotic arm with linear mechanism developed at AIST. By utilizing the RAPUDA, we have demonstrated that a bottle of water can be picked up from a table and taken to the mouth using a simple joystick or single-button interfaces. However, the representation of the specification such as "RAPUDA is capable of bringing a bottle of water from a table to a mouth. Maximum weight is 0.5kg" is not sufficient. This is because a potential user cannot know the difference between the two robots as to what tasks can be performed, and what tasks cannot. It is further difficult to imagine how the whole life will change when a user introduces the robot in his/her daily lives.

Fig. 6: Robotic arms for persons with disabilities in upper-limb (top: iARM, bottom: RAPUDA)

There has been efforts in the community to determine a "benchmark task" for assistive robots[7,8]. It will also be beneficial for a user to clearly indicate what activities can be performed in terms of the ICF. As a preliminary trial, we described the tasks that the RAPUDA can perform as follows:

- a430: lifting and carrying object
  - a4300: lifting
  - a4301: carrying in the hands
  - a4305: putting down objects
- a440: find hand use
  - a4400: picking up
  - a4401: grasping
  - a4402: manipulating
  - a4403: releasing
- a445: hand and arm use
  - a4450: pulling
  - a4451: pushing
  - a4452: reaching
  - a4453: turning or twisting in the hands or arms

On the other hand, the RAPUDA is not capable of performing following tasks:

- a4454: throwing
- a4455: catching

This kind of information is still not sufficient, and additional information on B) what objects can be handled, and C) in what environmental condition the robot can work, should be indicated as the extension of the ICF.

The representation of D) indication and contraindication of the assistive robot is also quite important from a medical treatment point of view. This indicates who can/should/may utilize and who can't/shouldn't/mayn't utilize a certain robot. This viewpoint is one of the most important common sense in the medical and welfare field, however there has not been research publications taking this point of view or exploring this idea in the robotics field. Usually the user is implicitly required to have specific abilities to make use of a robot, such as the eyesight, the ability to press a button or an appropriate mental state. However, such information should be clarified in order to commercialize assistive robot. It should also be noted that excess functions of robots and inappropriate use of them may result in disuse syndrome, which is a large of risk for a user.

D.Evaluation of Assistive Robots

In the robotics community, the developed assistive robots tend to be evaluated in the tentative experiments such as performing a simple task in a short time. However, it is obvious that the final evaluation of robots should be conducted in the actual life of the user. This can be done by observing the life before and after introducing a robot, and finding out the difference qualitatively and quantitatively between them. ICF can be utilized for observing and describing the functions in daily living.

IV. Conclusion

In this paper, we described our ideas on the development of assistive robots which fit the real needs of users based on ICF (International Classification of Functioning, Disability and Health). By utilizing ICF, the development process of assistive robots - analyzing and discovering needs in daily lives, designing robots and evaluating the products - will be achieved in more objective manner than before, and we believe that this will lead to the realization of assistive robots which can be utilized by many users who needs assistance in daily living.

References

[1] Bornman, J.: The World Health Organization's terminology and classification: application to severe disability, Disability and Rehabiliation, 26, 182-188, 2004.

[2] Kato, T. Ukai, K. Kodama, Y. Tsukumori, Y. Ando, Y. Mizukawa, M.,: Investigation of service management system design of RT-service, Proc. of IEEE Int. Conf. on Fuzzy Systems, pp.1496-1500, 2009.

[3] M. Narita and M. Shimamura: A Repart on RSi's activities (Robot Services Initiative), IEEE Workshop on Advanced Robotics and its Social Impacts, p.17, 2005.

[4] Makoto Mizukawa, Hideo Matsuka, Toshihiko Koyama, Akihiro Matsumoto: ORiN: Open Robot Interface for the Network, a proposed standard, Industrial Robot: An International Journal, Vol. 27 Iss: 5, pp.344-350.

[5] Ainsworth BE et al.: Compendium of physical activities: an update of activity codes and MET intensities, Med Sci Sports Exerc, Vol.32, No.9, pp.498-504, 2000.

[6] Romer, G.R.B.E, Stuyt, H.J.A., and Peters, A.: Cost-Savings and Economic Benefits due to the Assistive Robotic Manipulator (ARM), Proc. of the 9th Int. Conf. on Rehabilitation Robotics, pp. 201-204, 2005.

[7] Young Sang Choi, Travis Deyle, Tiffany Chen, Jonathan D. Glass, and Charles C. Kemp, "Benchmarking Assistive Mobile Manipulation: A List of Household Objects for Robotic Retrieval Prioritized by People with ALS," IEEE 11th International Conference on Rehabilitation Robotics (ICORR), pp.510-517, 2009.

[8] Bio-inspired Assistive Robotics: Service Dogs as a Model for Human-Robot Interaction and Mobile Manipulation, H.Nguyen and C.C. Kemp, IEEE RAS/EMBS Int. Conf. on Biomedical Robotics and Biomechatronics, pp.542-549, 2008.

[9] Walter M. Bortz II," The Disuse Syndrome", West J Med. 1984 November; 141(5): 691–694.