Springer

KSME

Journal of Mechanical Science and Technology 24 (2010) 257~262
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-009-1156-z

[Invited Paper]

Development of virtual reality-based universal design review system †

Keiichi Watanuki*

Department of Mechanical Engineering, Graduate School of Science and Engineering, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama-shi, Saitama 338-8570, Japan

(Manuscript Received July 5, 2009; Revised October 23, 2009; Accepted November 16, 2009)

Abstract

When designing universal design products or their interfaces, it is necessary to have knowledge about the environment in which the target product is going to be used. Product development should consider the interaction between the envisaged product or a demo product with the same functions on the one hand, and the users on the other, as well as observing the everyday activities of typical users, understanding the procedures and methods for using the product and subsequently pinpointing the areas which are problematic or in need of improvement. To evaluate whether the designed product is easy to use, and to improve its usability, it is also essential to record the perceptions of the people, the movement characteristics, the operability, any mental or physical stress, and so on. There is a need for products and environments which are easily applicable to various people and utilizational setups. In this paper, we present the development of a tangible design review system which makes use of virtual reality technology to display a close model of the actual product, making readily available not only visual information but also the perception of volume and weight through the fusion of kinesthetic information, enabling many people to communicate easily while experiencing this virtual reality. Furthermore, the design review of universal design products which makes use of this system will be discussed.

Keywords: Design review; Universal design; Virtual reality; Tangible interface

1. Introduction

In recent years, a design review method has been introduced for the stage of designing industrial products, whereby a digital mock-up created through 3D CAD is used for the inspection of the product without the need of preparing an actual model. This method entails cost reduction and shortening of the development time. By using digital mock-ups, since the product models are handled as digital data, it is possible for people who are located far from each other to look at the same models and communicate with each other over a network. Furthermore, this is a useful inter-department communication tool, since even people whose duties do not involve the design of the product can easily understand what stage the product is in by looking at the 3D model on their screens. The use of digital mock-ups will enable the development of products in the future to involve not the sequential advancement of each process but rather the participation of many departments in all developmental processes, as well as the parallel and simultaneous advancement of many processes.

However, in cases where design changes have occurred as a result of the inspection of the product by multiple departments or by many designers, the need arises for people who have been properly trained to perform complex operations in 3D CAD. It is not an easy task to convey the instructions of the people who propose the design changes to the CAD operator, and since the application of the changes on-site requires a long time, sometimes they are sent back to the design department, which causes delays in development time. Moreover, one disadvantage emerges from the fact that the feeling of volume and texture is lost when comparing the inspection of a real model with that of a 3D model displayed on a 2D computer or projector screen as shown in Fig. 1.

In this paper, we present the development of a tangible design review system which makes use of virtual reality (VR) technology to display a close model of the actual product, making readily available not only visual information but also the perception of volume and weight through the fusion of kinesthetic information, enabling many people to communicate easily while experiencing this virtual reality. The design review of universal design products which makes use of this system will also be discussed.

† This paper was presented at the ICMDT 2009, Jeju, Korea, June 2009. This paper was recommended for publication in revised form by Guest Editors Sung-Lim Ko, Keiichi Watanuki.
*Corresponding author. Tel.: +81 48 858 3433, Fax.: +81 48 858 3433
E-mail address: watanuki@mech.saitama-u.ac.jp

2. Universal design

Universal design is defined as the “design of products and environments usable by all people to the greatest extent possible, without the need for adaptation or specialized design” [1, 2]. Applicable to all ages, personal abilities and sizes, with an inclusive capability that transcends barrier-free and accessible design, the concept of universal design was coined in 1985 by Ronald Mace, an architect who had a disability himself. This concept has been accepted in a variety of design fields, such as architecture, engineering, product design, and landscape design. The principles of universal design are as follows. (1) Equitable use: The design is useful and marketable to people with diverse abilities. (2) Flexibility in use: The design accommodates a wide range of individual performances and abilities. (3) Simple and intuitive use: Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level. (4) Perceptible information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities. (5) Tolerance for error: The design minimizes hazards and the adverse consequences of accidental or unintended actions. (6) Low physical effort: The design can be used efficiently and comfortably, and with a minimum of fatigue. (7) Size and space for approach and use: Appropriate size and space is provided for approach, reach, manipulation, and use, regardless of the user’s body size, posture, or mobility.

3. Human-centered design and usability

When designing universal design products or their interfaces, it is necessary to have knowledge about the environment in which the target product is going to be used. Product development should involve considering the interaction between the envisaged product or a demo product with the same functions on the one hand, and the users on the other, as well as observing the everyday activities of typical users, understanding the procedures and methods for using the product and subsequently pinpointing the areas which are problematic or in need of improvement.

To evaluate whether the designed product is easy to use, and to improve its usability, it is also essential to record the perceptions of the people, the movement characteristics, the operability, any mental or physical stress, and so forth. As shown in Fig. 2, there is a need for products and environments which are easily applicable to various people and utilizational setups.

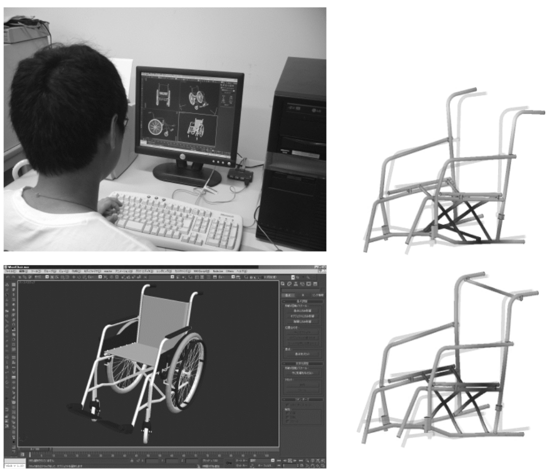


Fig. 1. Design review by using 3D viewer and FEM simulator.

4. Design review

A design review comprises an objective evaluation and deliberation of several aspects of the product quality (functions, cost, marketability, material quality, reliability, appearance, packaging, delivery time, etc.) during each phase of the design and the development. Generally, the further down the production line any defects are discovered, the more numerous the modifications which have to be applied, which raises the costs since more man-hours are required to apply the revisions. For that reason, it is important to discover any defects as early as possible and apply the corresponding fixes.

At present, the generally used design review uses two-dimensional graphics and text, and many people are involved in objective evaluation and deliberation. Depending on the industry, it is not uncommon for actual models and demo products to be produced and evaluated. There is an obvious

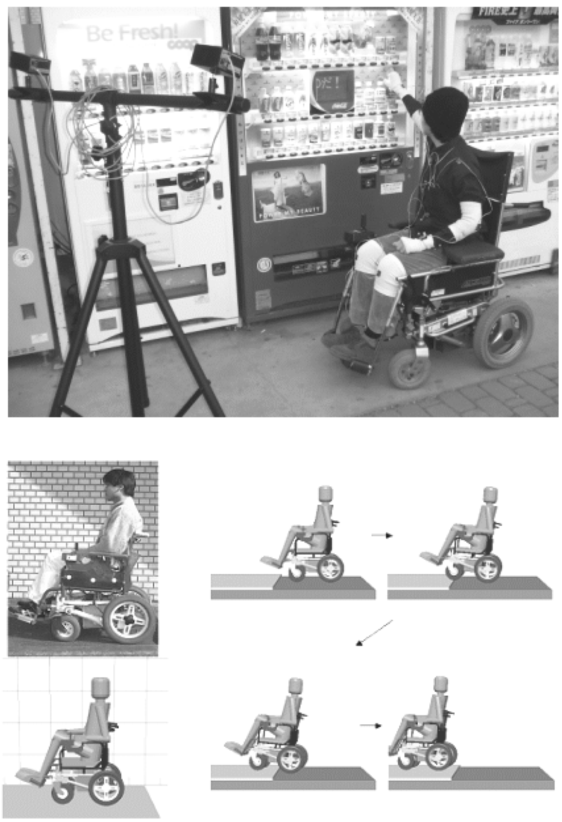


Fig. 2. Usability evaluation for wheelchair users.

disadvantage in using two-dimensional graphics and text since the people participating in the review must prepare a mental image of the configuration, which presents a difficulty when trying to grasp its overall size, weight and volume. Furthermore, misunderstanding often occurs between people participating in the review when a model with similar geometry is used in the factory. Preparing a demo product is a better method but is costly. To perform an efficient review, it is necessary to ensure the presence of sufficiently skillful and insightful reviewers, and a schedule needs to be prepared taking into account the man-hours needed for the review.

In design review, a different setup is needed corresponding to each stage of the development, since the purposes and the effects are different. Design review of design specification definitions and analysis procedures aims at removing defects stemming from ambiguities and contradictions in the design specifications themselves, thus clarifying the objectives. During this stage of the design review, the designers can confirm whether they understand correctly the design specifications. The people who usually participate in the review at this stage are the actual users of the product, as well as product planners, quality administrators and marketing experts. The aim of the design review of the designing stage is to remove defects, mistakes and contradictions in the design structure, and the designers are the ones who typically participate as reviewers. Finally, the design review of the manufacturing process aims at labor saving and improving the material quality, and local engineers and technicians represent the typical reviewers.

5. VR-based design review

When performing design review of universal design, it is extremely important to share the spatial and temporal "ba" of the specific improvements while looking at the full-size product, as shown in Fig. 3. Through sharing the "ba," the valuable information "obtainable only when one is present there and then" is made available besides the information obtained through the five senses. VR and similar technologies allow the combination and simultaneous perception of visual and kinesthetic information, which in turn allows the application of modifications based on the data collected through the parallel use of Therblig analyses, as in the problem points shown in Fig. 4. In real environmental conditions, it is necessary to consider various situations, and since there are cases in which it is difficult to alter the alignment or the location of the elements while performing the inspection, using a VR environment is beneficial.

Fig. 5 shows the outline of the immersive virtual environment system developed by the authors [3]. This VR system combines a three-dimensional stereoscopic device and a kinesthetic presentation device, which enable the users to visualize the configuration and feel the weight, etc., of three-dimensional objects. Fig. 6 shows examples of design reviews of products using this system. The present VR system comprises a three-dimensional stereoscopic device and a head-tracking device, as well as a kinesthetic presentation device. In the three-dimensional stereoscopic device, images which include the disparity between the left and the right eye are polarized and projected onto a large screen. The users of the VR system can visualize the three-dimensional image by using polarized glasses. Furthermore, the viewpoint of the user is sent as feedback by the head-tracking device to the computer, and a picture updated for the viewpoint of the user is projected back in real time. Also, kinesthetic information can be obtained from the image through the kinesthetic presentation device.

The displaying of the three-dimensional configuration in the three-dimensional stereoscopic device, as well as the controlled input towards the kinesthetic presentation device is cohesively performed in the PC; thus, the three-dimensional image and the kinesthetic perception are synchronized. The location of the viewpoint is fed back to the PC by the head-

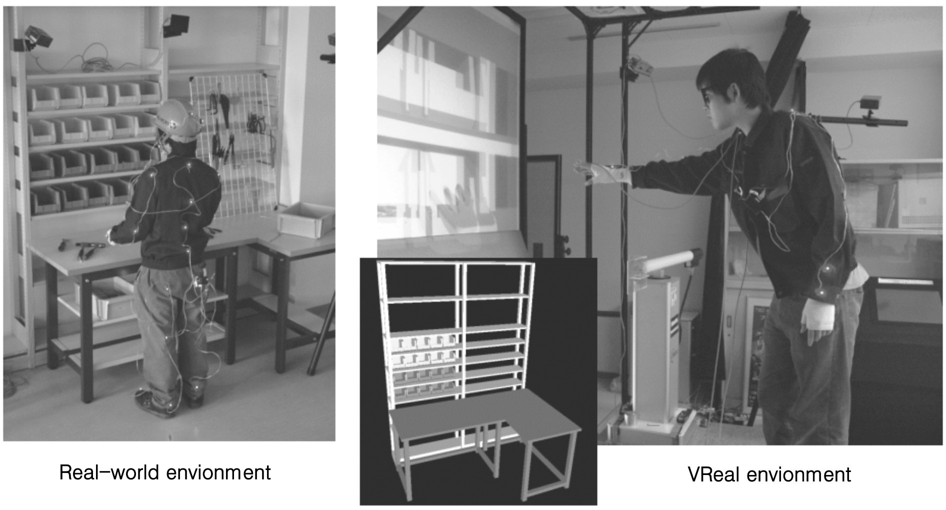


Fig. 3. Design review.

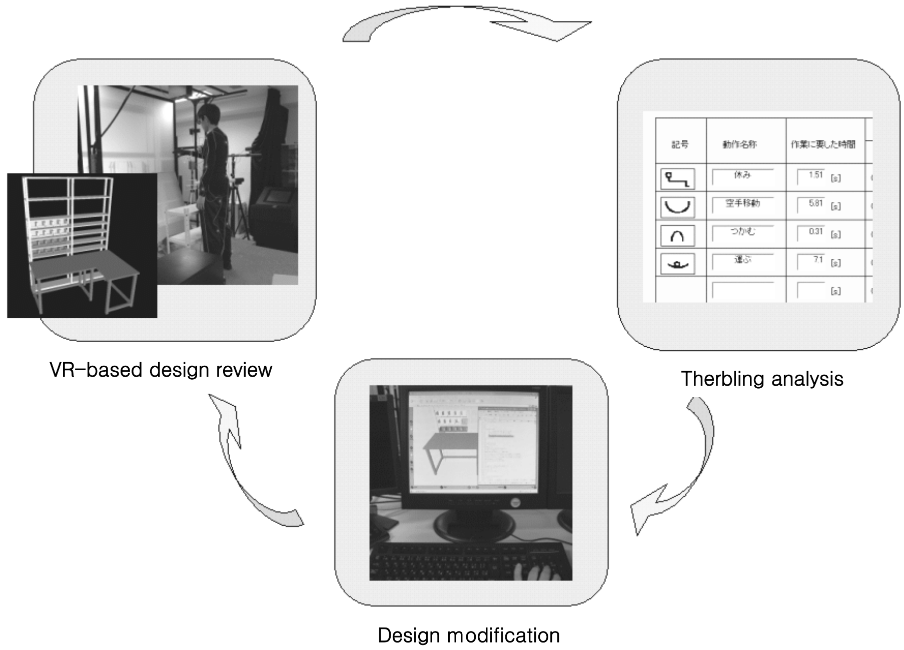


Fig. 4. Flowchart of VR-based design review.

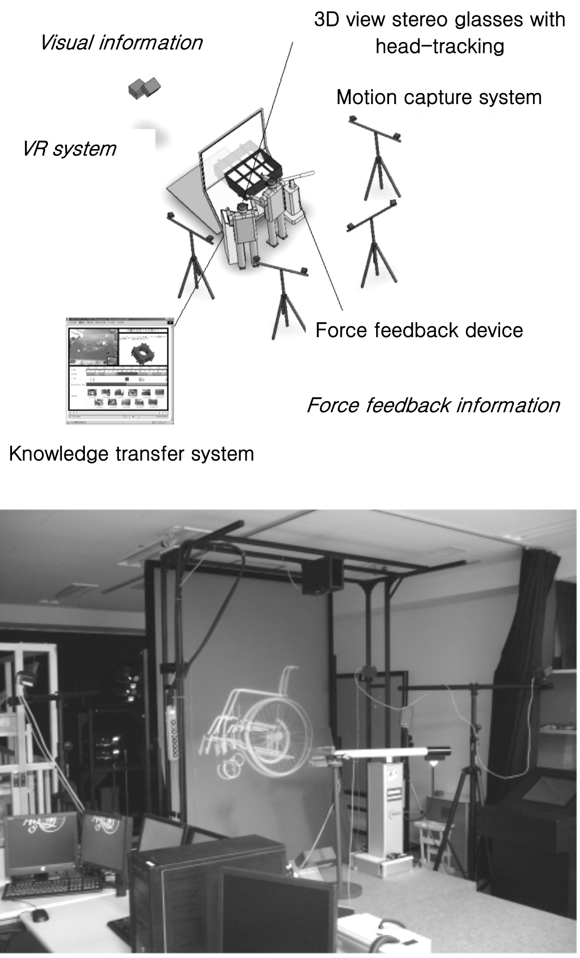


Fig. 5. Overview of immersive virtual environment system.

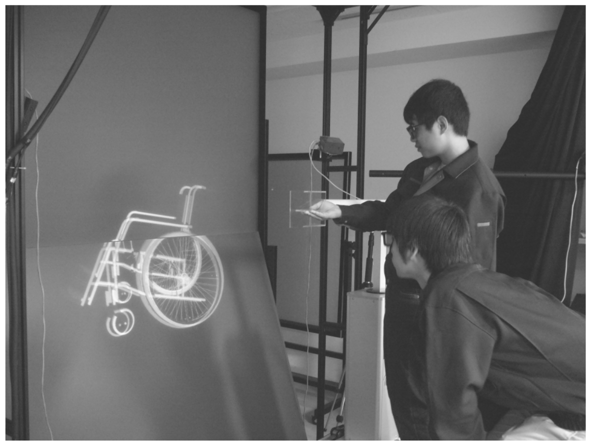
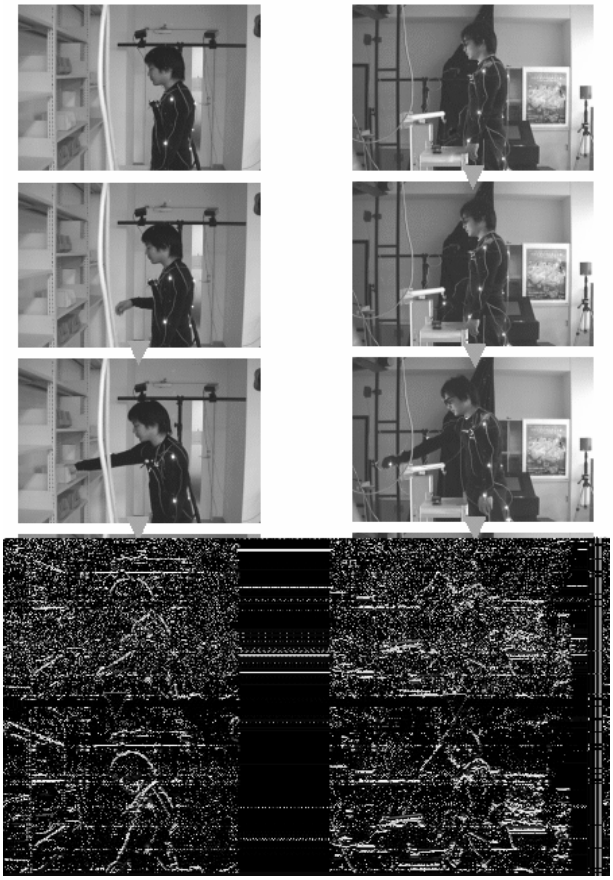


Fig. 6. VR-based design review.

tracking device situated in the three-dimensional vision glasses, and together with displaying a picture corresponding to the viewpoint in real time, the location of the tip of the manipulator and the load on the manipulator in the kinesthetic presentation device are fed back to the PC. The subsequently displayed three-dimensional image is considered, and the location and the torque of the manipulator are adjusted accordingly. Performing a design review in such a VR environment can be expected to have various advantages. Since the model of the product shown in VR space is represented as a three-dimensional image, it is easy to create a three-dimensional mental image. Moreover, since the image is full-sized, the configuration and the volume is easily comprehensible regardless of the level of proficiency of user. Also, apart from the configuration of the product, it is also possible to perform a



(a) Real-world environment (b) VR environment

Fig. 7. Operability evaluation.

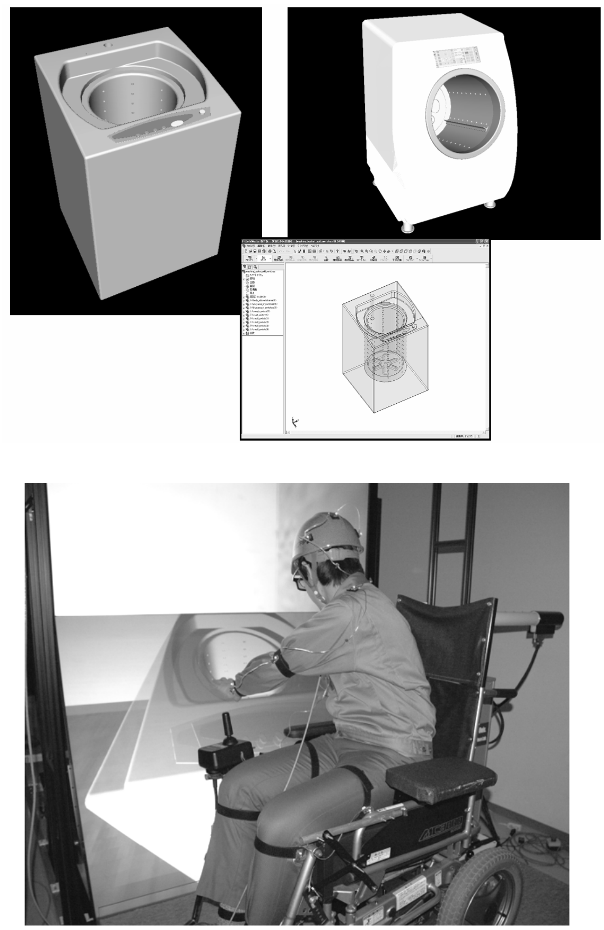


Fig. 8. Design review of universal design products.

design review of the functions and capabilities of the product, the operability, assembly, degradability and other kinesthetic properties. Since the necessity for repeatedly producing demo products disappears when both the design database and the shared immersive virtual environment are used simultaneously, the development time becomes shorter and the costs are reduced.

In the present research, we have used VR technology to construct a system capable of simulating a virtual part assembly working environment and the application of modifications. With regard to the operations performed in VR environment, the use of a motion capture system permits the movements of the operator to be recorded as numerical data, and we have constructed an automatic operability evaluation system. The trends in the operability evaluation using VR technology are shown in Fig. 4. Performing operations in VR environment is accompanied by the collection of data about the movements of the operator, which is the basis for performing the operability assessment. In case anything needs to be improved, the operating environment can be changed quickly by using VR technology, and the operations can be performed once again within a short period of time.

6. Design review of universal design products

To perform a universal design evaluation of a product at the designing stage, we have developed a system capable of simulating virtual experience of those operations.

First, we evaluated whether operations performed in the present VR environment behaved in the same way as operations performed in real-world conditions. Here, we compared the movements of five test subjects who performed operations in both real-world environment and VR environment, whereby the height of the access platform, the location of the elements and other parameters were identical for both environments. Fig. 7 presents one example of the operability evaluation experiment. The movement is taken as the distance which the body of the operator travels when fetching the elements from standing position. Each operator performed this operation seven times. Upon observing the test subjects, the operations performed in real-world environment and in VR environment were similar. In the cases when the operations were performed in VR environment where the test subjects could feel the three-dimensionality of the image, the behavior of the operations in the VR environment was similar to that in the real-world environment, and the results suggested that operation evaluation can be performed in VR environment.

Considering the low birthrate combined with the rapid aging of the population, a part of the Law Concerning the Stabilization of Employment of Elder Persons was adjusted in June 2004, and was designed to improve the employment and the working environment by making use of the knowledge and the experience of elderly people. Furthermore, female employees play a vital role in the development of the economic society, and it is necessary to further improve those environments where female employees are be able to realize their potential. By using this system, it is possible to construct working environments oriented towards elderly persons and females, as well as to modify the operations and conduct work training in this environment. Assuming various working environments and contents, inspections of the working environment applied to all employees including the elderly people and the women can be performed through virtual experience inside this system, and work training support can be provided. Moreover, as shown in Fig. 8, it is possible to create various working environments inside the VR environment and perform an evaluation of the properties of universal design by implementing various changes in the configuration of the product.

7. Conclusion

In this paper, we presented a tangible design review system which makes use of virtual reality techniques to display a close model of the actual product, making available not only visual information, but also the perception of volume and weight through the fusion of kinesthetic information, and enabling many people to communicate easily while experiencing this virtual reality. By making use of VR technology systems like the one presented here, it is possible to ensure a safer and less stressful working environment, as well as to alleviate the physical burden of performing design reviews of universal design products.

References

[1] Center for universal design, *The Principles of Universal Design Ver.2.0*, North Carolina State University, (1997).

[2] M. Helander, *A Guide to Human Factors and Ergonomics Second Edition,* Taylor & Francis, (2006).

[3] K. Watanuki and K. Kojima, Knowledge acquisition and job training for advanced technical skills using immersive virtual environment, *J. of Advanced Mechanical Design, Systems, and Manufacturing*, 1 (1) (2007) 48-57.

Keiichi Watanuki received his Ph.D. degree from Tokyo Institute of Technology, Japan, in 1991. He is currently a Professor in the Graduate School of Science and Engineering, Saitama University, and Saitama University Brain Science Institute. His research interests include human interface, brain-machine interface, robotics, knowledge management, virtual reality, and human-centered design.