Usability Test of KNRC Self-Feeding Robot

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***Abstract*—Various assistive robots for supporting the activities of daily living have been developed. However, not many of these have been introduced into the market because they were found to be impractical in actual scenarios. In this paper, we report on the usability test results of an assistive robot designed for self-feeding for people having disabilities, which includes those having spinal cord injury, cerebral palsy, and traumatic brain injury. First, we present three versions of a novel self-feeding robot (KNRC self-feeding robot), which is suitable for use with Korean food, including sticky rice. These robots have been improved based on participatory action design over a period of three years. Next, we discuss the usability tests of the KNRC self-feeding robots. People with disabilities participated in comparative tests between the KNRC self-feeding robot and the commercialized product named My Spoon. The KNRC self-feeding robot showed positive results in relation to satisfaction and performance compared to the commercialized robot when users ate Korean food, including sticky rice.**

Keywords—assistive robot; self-feeding; usability test

I. INTRODUCTION

Caregivers need to physically interact with disabled and elderly persons in order to provide efficient caregiving. For example, caregivers have to assist people in performing the routine activities of daily living such as eating, changing clothes, changing their posture, moving from one location to another, and bathing. Eating meals is one of the most crucial of these daily activities. In this regard, caregivers must interact with people frequently to assist with food selection and feeding intervals. Existing robotic technologies can be utilized to perform certain functions of caregivers. Thus, assistive robots represent one of the solutions by which disabled or elderly people can receive support in performing the activities of daily life.

A self-feeding robotic system allows people with disabilities of the upper limbs to eat what and when they desire. Most feeding systems such as Handy1, the Winsford Feeder, Neater Eater, Meal Buddy, and the Mealtime Partner Dining System scoop the food with a spoon [1]. These systems are not suitable for use with boiled rice, which is a staple food in Korea. In addition, some systems have a single dish, and thus, different types of food might be mixed during scooping. Other self-feeding robotic systems also have difficulty scooping this staple Korean food. Therefore, over a period of three years, we built and revised a novel self-feeding robot that would be suitable for use with Korean food, including sticky rice.

Feeding robots enable users to enjoy food independently during mealtimes. After the food is prepared, users can choose when they want to eat the desired food. We developed an assistive robot for self-feeding by taking into consideration the feedback of candidate users and clinical experts. We then evaluated the self-feeding robot by performing a series of user tests. The overall process, that is, concept formulation, design, building, and evaluation, involved feedback from users and clinical experts. The development process was performed on the basis of the philosophy of participatory action design [2]. We also evaluated the self-feeding robot by performing a series of usability tests.

The primary users of self-feeding robots are people with physical disabilities, who have difficulty moving their upper limbs. Such people include those suffering from high-level spinal cord injuries, cerebral palsy, and muscular diseases. The user group could also include senior citizens, who have difficulties with the motor functions of their upper limbs, such as the fragile elderly. It is certain from exponential increase of the elderly due to demographic shift that the number of overall target users of self-feeding robots will grow in the near future.

The usability of the developed self-feeding robots was evaluated through the participation of people with disabilities. The usability of assistive robots for people with disabilities should be evaluated by their potential users because different users have different characteristics. Usability is defined in ISO 9241 as *the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in a particular environment* [3]. Usability can be defined as *the degree to which a product fits the characteristics of a person or a group of people* [4]. For instance, several usability studies were performed for a wheelchair-mounted robotic arm [5], meal-assistance robot [6], in-home telerehabilitation robot [3], and other assistive robots. As an outcome measure in this study, the concept of the Canadian Occupational Performance Measure (COPM) [7] was followed. We collected feedback from users on the robot performance and the degree of satisfaction. Additionally, we gathered evaluation results for the appearance of the systems.

In this paper, we briefly introduce the overall configurations of the novel self-feeding robots. We then report the results of usability tests that were performed with several people having disabilities. In Section 2, we present three versions of the KNRC (Korea National Rehabilitation Center)

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self-feeding robot. The results and discussion of the comparative usability tests is presented in Section 3. Section 4 contains the results of a five-day usability test. Finally, we present the conclusion in Section 5.

II. KNRC SELF-FEEDING ROBOT

The main findings of the survey are as follows [8, 9]. First, we found that a user should be able to control the feeding interval for the desired food. One of the common problems in caregiving is the difficulty in controlling the feeding interval. People with cerebral palsy have difficulty indicating their intentions quickly when the feeding interval is too short. Second, the specialists and candidate users felt that the existing feeding systems were designed more for western-style food. These systems were not suitable for Korean food, which includes boiled rice, soup, and side dishes. Third, a feeding robot should be suitable for use in private homes and facilities. Further, the location of bowls or a tray is also an important factor.

We developed a simple robotic system with a dual-arm manipulator capable of handling Korean food such as boiled rice, placed in an ordinary food container, as shown in Fig. 1. We divided a self-feeding task into two subtasks: picking up/releasing food and transferring food to a user's mouth. The first robotic arm (a spoon-arm, Arm #1) uses a spoon to transfer the food from a container on a table to a user's mouth. The second robotic arm (a grab-arm, Arm #2) picks food up from a container and places it on the spoon of the spoon-arm. The two proposed arms with their different end-effectors mimic Korean eating behavior. Specifically, Koreans use a spoon and steel chopsticks during mealtime. The spoon-arm has two degrees of freedom (DOF). The grab-arm includes a three-DOF SCARA joint for the planar motion, a one-DOF prismatic joint for the up and down motion, and a gripper. The overall number of DOFs of the dual-arm system without a gripper is six.

We observed that releasing rice is as important as picking up the rice. The stickiness of boiled rice can change, depending on its temperature. Slightly cool rice is difficult to release from the gripper. In order to solve this problem, the feeding robot automatically places the gripper of the grab-arm in water before grasping the food. The water is located in a bowl next to the rice. Once this is done, the gripper can release the rice on the spoon because the stickiness of the rice has thus been reduced.

The amount of rice picked up is adjusted based on actual experiments on rice grasping. The gripper's mechanism involves the simple opening/closing of gripper fingers via a linear actuator. The weight of the rice corresponding to one grasping motion increases depending on the width of the extension of the fingers of the gripper when grasping begins. The width of the gripper when its fingers are closed generates the grasping force required to hold food. Thus, the gripper can be made to grasp various foods through the adjustment of its open/close width.

We developed three types of self-feeding robots, as shown in Figs. 1, 2, and 3: (1) the KNRC self-feeding robot, version 1 (V1); (2) the KNRC self-feeding robot, version 2 (V2); and (3) the KNRC self-feeding robot, version 3 (V3). The third version of the KNRC self-feeding robot adopts relatively low cost actuators and stable mechanical parts. The spoon-arm of version 3 utilizes a spoon, which is attached to the arm via a mechanical spring. The lateral angle of the spoon is also adjustable. The data in Table 1 describe the three versions of the self-feeding robot.

We built two types of arm configurations for the developed self-feeding robot: a dual-arm configuration and a single-arm configuration. The dual-arm configuration follows the original design concept of using both a spoon-arm and grab-arm. The single-arm configuration uses only the spoon-arm, while a caregiver takes the role of the grab-arm. The spoon-arm could be used independently without a grab-arm. The single-arm configuration has a lower cost in comparison with the dual-arm configuration. The single-arm configuration is also suitable for an outdoor environment because of the simplified construction of the self-feeder.

Fig. 1. KNRC self-feeding robot, version 1.

Fig. 2. KNRC self-feeding robot, version 2.

Fig. 3. KNRC self-feeding robot, version 3.

Two joysticks are employed as input devices. Originally, it was determined that users prefer to use two joysticks rather than one joystick and buttons. Because of the gap between the two joysticks, a user can easily manipulate one of the joysticks without any resulting malfunction of the other joystick. Users have expressed satisfaction with the flexibility of the joystick and its silicon cover, which can be connected to the user's skin [1].

TABLE I. DEVELOPED KNRC FEEDING ROBOTS

Item	KNRC Self-Feeding Robots		
	Version 1	***Version 2***	***Version 3***
Development Period	Nov 2009~ April 2010	July 2010~ Mar 2011	April 2011~ Nov 2011
Size (mm)	509 × 608 × 377	329 × 501 × 333	347 × 508 × 305
Weight (g)	8353	3726	4659
# of motor	7	6	7
Max height of gripper (mm)	76.2	87.9	76.3
Characteris-tics	· Large size · Heavy weight · Stable operation · High material cost	· No case · Reduced size · Reduced weight · Low cost motor · Structural problem (bending) · Many parts	· Low cost and stable parts · Reduced number of parts · Improved degree of completion · Adjustable angle for spoon

III. COMPARATIVE USABILITY TESTS AND DISCUSSION

We carried out usability tests with the help of 14 participants who had disabilities: seven persons had spinal cord injuries, five persons had cerebral palsy, one person had traumatic brain injuries, and one person had muscular dystrophy. After they ate food fed to them by three robots, namely, the first version of the KNRC self-feeding robot (V1), the third version of the KNRC self-feeding robot (V3), and My Spoon, we collected their feedback to determine the appearance scores, performance scores, and satisfaction scores for the systems, as shown in Fig. 4. My Spoon is a commercialized robot designed for self-feeding.

The average appearance scores of V1, V3, and My Spoon were 5.14, 6.71, and 6.79, respectively (on a scale of 1 to 10, where 10 was the highest appearance level). V1 was generally described as large and complex, having a dark tone and strong appearance. V3 was described to resemble V1, but was found to appear lightweight owing to its smaller size. My Spoon was perceived as simple and refined. The operation of My Spoon was also found to be simple.

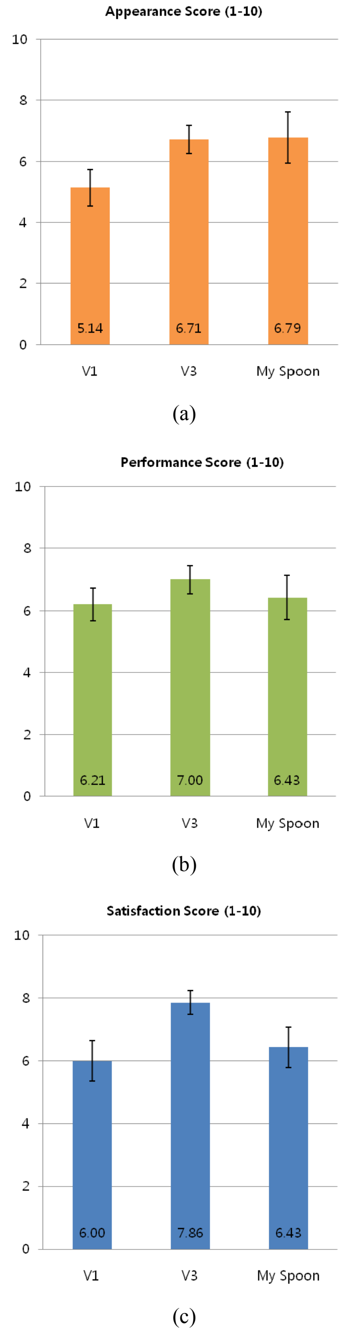


Fig. 4. (a) Appearance scores, (b) performance scores, and (c) satisfaction scores for the first version (V1) and third version (V3) of the self-feeding robot and for My Spoon. Error bars represent standard error.

The average performance scores for V1, V3, and My Spoon were 6.21, 7.00, and 6.43, respectively (on a scale of 1 to 10, with 10 denoting the highest performance level). In the case of V1, users felt that the input device was slightly sensitive. The initial setting was not comfortable because the computer was required to set the initial values of the system. Some subjects felt that the system placed the food on the spoon in a very natural manner. In the case of V3, the system was similar to V1, but the subjects found it easier to use. The size of the system was smaller than the previous version;

however, the motion was not affected by the size. In the case of My Spoon, some users said that the amount of rice was very small. Further, some users felts that the manipulation of the input device was considerably stiff. The motion of the robot was stable because it was a commercialized product. The sensor in the spoon created discomfort at some instances. When a subject touched the spoon by mistake, the robot immediately stopped the spoon from serving the food, and then returned it to the home position. A comparison of the results showed that the developed system was effective for handling Korean food.

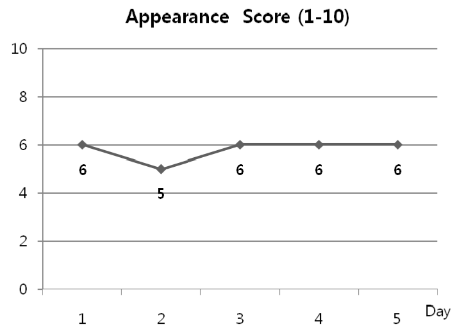
The average satisfaction scores for V1, V3, and My Spoon were 6.00, 7.86, and 6.43, respectively (on a scale of 1 to 10, with 10 denoting the highest satisfaction level). In the case of V1, users expressed a preference to eat the meal by themselves to some degree. However, these users were not accustomed to the system and thus found it uncomfortable to use. A caregiver was better than V1 from the viewpoint of satisfaction. V3 was found easier to use than V1. The overall structure of V3 was found to be similar to V1, but it was preferred by users owing to its smaller size. Further, its motion was found to be satisfactory. In the case of My Spoon, the food picking operation was found to be dissatisfactory. For instance, My Spoon uses a grasping function to pick up food, but this system has difficulty serving Korean rice because of its fixed grasping strength and maximum grasping width of the gripper. As a result, My Spoon's gripper was sometimes covered by a large quantity of rice that attached to its surface.

Most of the users who participated in the experiments provided positive feedback for the KNRC self-feeding robot. Some users were impressed that they were able to eat what and when they desired. User feedback was obtained with regard to the self-feeding robot as well as the input devices.

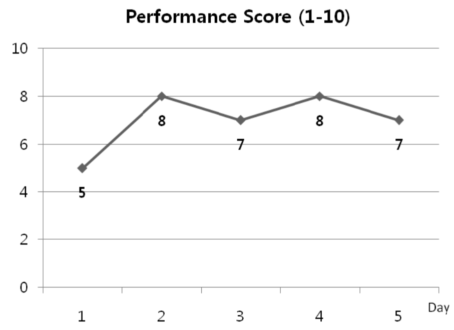
The presently developed robot has three distinguishing characteristics: the ability to handle sticky rice, compatibility for use with an ordinary meal tray, and incorporation of a modular design in which functions could be divided into two arms. Specifically, the spoon-arm could be used by itself when a caregiver lifted food onto the spoon of the spoon-arm. We have developed a novel assistive robot for self-feeding, which strongly depends on the culture of a user. This robot could be an exemplary assistive robot for a specific culture.

IV. USABILITY TEST PERFORMED FOR A FIVE DAY PERIOD

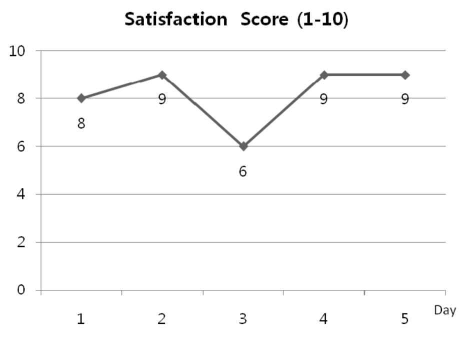
One subject used the third version of the KRNC self-feeding robot for five days. The subject was a 30-year-old female who had cerebral palsy and used a power-wheelchair. She used the KRNC self-feeding robot once a day. Fig. 5 presents the appearance scores, performance scores, and satisfaction scores for the self-feeding usability. On first day, the performance was not good because this was the first-time use by that subject. However, the subject gave higher scores from the second day onward. The degree of satisfaction was somewhat dependent on her health condition. On the first day, she was not accustomed to using the system. That day she required 40 min to complete a meal. Further, it was not easy for the system to pick up small pieces in the side dishes. On the second day, the subject was interested in the functions of the system and its method of use. The subject found the input device to be somewhat sensitive. On the third day, the subject's health condition was not good. Thus, her degree of satisfaction was relatively lower. The subject preferred not to operate the system at high speed. On the fourth day, she changed from using a hand to using her chin to control the input device. She found that pushing the button was slightly difficult. On the fifth day, the time she required to complete a meal was reduced to 20 min, which was half the amount of time required on the first day. The subject preferred to manipulate only the joysticks rather than using push buttons and the joystick. Additional preferences expressed by her were that she would like to use the Arm #1 mode with a caregiver, and that she would like to simultaneously eat rice and a side dish using a single spoon.



(a)



(b)



(c)

Fig. 5. Scores for appearance, performance, and satisfaction over five days of use for third version of self-feeding robot. The scores are obtained via one user.

V. New Version Prototype of Self-Feeding Robot for Commercialization

Most of the robotic parts were improved for the commercialization of the self-feeding robot in 2012. In essence, the mechanical joints were enhanced to make them more solid and reduce vibrations while serving. The electrical circuits and mechanical parts were improved for the entire system. RS-485 was used for the conveying the communication signal between the controller and all the actuators. Arm #1 and Arm #2 were made easily separable, without the need to remove bolts. Hence, Arm #1 easily latched and separated from Arm #2 through the implementation of a snap-in mechanism using a spring. Fig. 6 shows the new prototype of the KNRC self-feeding robot designed for commercial applications.

Fig. 6. New prototype of KNRC self-feeding robot intended for commercialization.

VI. Concluding Remarks

This paper presented user evaluations of newly developed assistive robots in comparison to a commercialized self-feeding robot. We first presented three versions of the assistive robot for self-feeding. We developed a novel concept for an assistive robot for self-feeding that is capable of handling Korean food, including sticky rice. The developed robot has three distinguishing characteristics: the ability to handle sticky rice, compatibility for use with an ordinary meal tray, and incorporation of a modular design in which functions can be divided into two arms.

The user group includes people with physical disabilities who have limited arm function as a result of spinal cord injuries or cerebral palsy. During the complete development process for the robot, we considered the feedback provided by several users and experts. In addition, candidate users comparatively evaluated the considered self-feeding robots. Most of the users who participated in the experiments provided positive feedback with respect to both the performance and degree of satisfaction for self-feeding using the developed robot. However, the commercialized robot, My Spoon, had a relatively high score in terms of appearance. We also discussed the five-day evaluation results for a specific user. This user needed one day to become accustomed to using the new robot for self-feeding. Finally, we briefly introduced the prototype designed for the commercialization of our robot. In future work, we will further improve the reliability of the basic operations of our robot such as its food grasping and releasing functions.

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