Experimental Study on User Acceptance and Affordability of Intelligent Wheelchair

- Questionnaires on Human Machine Interface-

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Abstract—**We proposed the use of an intelligent wheelchair for new mobility for not only elderly people but also everyone. Our intelligent wheelchair has autonomous function and new gesture interface. For the introduction of the proposed intelligent wheelchair, there are several challenges associated with the use of the wheelchair. One of the most important points is the user acceptance, and it must be investigated with a plenty of subjects by experiments. In addition, the affordability is also important for the introduction. The two points were investigated by performing the several experiments with subjects. In the experiments, we did a questionnaire about the intelligent wheelchair. In this paper, we introduce experiments and the questionnaire results, and the results are compared and discussed in this paper. The questionnaire results proved that most subjects had the favorable opinions about autonomous function and new gesture interfaces. On the other hand, the challenging issues for improving the user acceptance of intelligent wheelchair were also found especially for the gesture interface. These results must be valuable for developers and researchers of new wheelchairs.**

Keywords- Intelligent Wheelchair; Elderly People; User Acceptance; Human Machine Interface; Pilito Study.

I. INTRODUCTION

The rapid increase in the proportion of elderly people in the population has caused several issues in Japan [1]. Thanks to the advancing science and inherent adaptability of humankind to though life conditions, there has been an increase not only in the average life expectancy, but also the population of aged and disabled people that in the need of mobility aid. The current figures report that nearly 15% of the population, corresponding to one billion in the world, are with some form of disability or impairment [2]. Besides that, according to the studies [3][4] the household rate of the people using wheelchair only in the USA, doubled from 1.5% to 3% from 1990 to 2010 and the majority of the wheelchair users are elderly. Useful, affordable and safe wheelchair is expected for elderly and disabled people [5-7].

We proposed an intelligent wheelchair to solve mobility issues [8-12]. The proposed wheelchair has two new features. One is an autonomous function, and the other is a new interface. With the autonomous function the rider in the wheelchair is not required to control the chair by a joystick, which is a conventional controller for a wheelchair. However, there are several challenges associated with the use of an autonomous system, the most difficult being cost. Several expensive sensors are necessary for a wheelchair to achieve complete autonomous functionality. These sensors increase the cost of an intelligent wheelchair, making it difficult for elderly people to purchase an intelligent wheelchair. With respect to new interface, as wheelchairs are smarter and more intelligent, a conventional joystick controller cannot be suitable. Also, people usually would like to use a new interface, and elderly people would like to use cool interface, because they want to look younger than they are. Seeing that the gestures as a one-way process from mind to body; how can gestures be used in creating user interfaces remains an open research question. A few numbers of studies discuss the usability and acceptance of gestural interfaces by the different age groups while touching the fact that design of intuitive gestures must be separately handled.

Preliminary experiments were performed with the proposed wheelchair, and we proved that there was a possibility to use the proposed wheelchair by performing experiments. It is important to evaluate user acceptance, and affordability with real subjects, and to get feedback from the real users

In this paper, the performed experiments with the proposed intelligent wheelchair and questionnaire results will be introduced, and user acceptance will be evaluated with questionnaire result.

Herein, in Section 2, the Tsukuba Designated Zone, where the real-world experiment was conducted, is described. In Section 3, we explain the proposed intelligent wheelchair. In Section 4, the experiments and the questionnaire result of real-world experiments with the proposed intelligent wheelchair used by several subjects are explained.

II. TSUKUBA DESIGNATED ZONE FOR EXPERIMENTS

This section describes the Tsukuba Designated Zone, where the experiment was performed. This institution was formed to improve robotics technology. It was officially approved as the Tsukuba Designated Zone by the Cabinet Office in Japan on January 29th, 2010 [13].

The Designated Zone has two areas for conducting experiments. One is the Tsukuba Center Station area, and the other is the Kenkyugakuen Station area, shown in Fig.1. The Tsukuba Center Station area consists mainly of a pedestrian road from the University of Tsukuba to Akatsuka Park, with a major focus on Tsukuba Central Station. The width of this road is greater than three meter and is sufficient to allow use by bicycles. For these reasons, this public area is appropriate for experimental research. Even within the Tsukuba Designated Zone, there are some regulations that apply to conducting experiments. The committee of Tsukuba Designated Zone is applying relaxations of regulations for the experiments. We performed experiments on automated function in Tsukuba Center Area and Kenkyugakuen Area, and experiments on gesture interface.

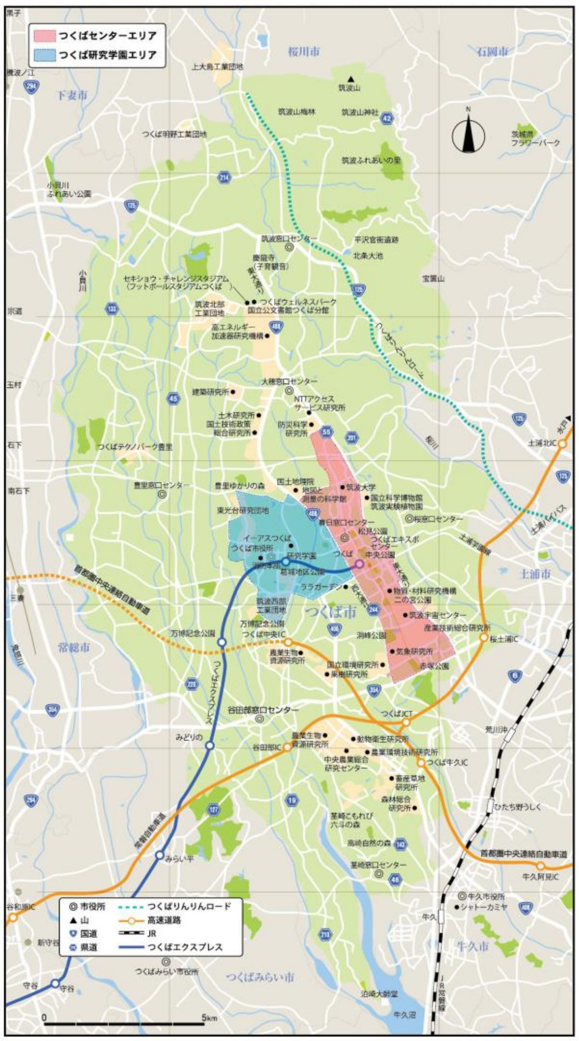

Figure 1. Tsukuba Designated Zone (Red: Tsukuba center area, Blue: Kenkyugakuen area) [13]

III. DEVELOPPED INTELLIGENT WHEELCHAIR

The intelligent wheelchair used in the experiment have been developed at the National Institute of Advanced Industrial Science and Technology (AIST). This wheelchair was modified from the wheelchair produced by AISIN SEIKI Corporation, shown in Fig.2. Figure 3 shows the system configuration of this wheelchair. It can be controlled by an on-board PC through an electrical signal. This wheelchair can move at 6 [km/h]; hence, the maximum velocity was set to 4 [km/h] during the experiments. This wheelchair can be used for traveling for about 2 hours without charging. The wheelchair has one Real Time Kinematic (RTK)-GPS sensor, one laser scanner sensor (LSS), one gyro sensor, two encoder sensors for counting left and right wheel speeds, a laptop PC, and an onboard PC. This wheelchair has two modes, one is autonomous mode and the other is a gesture interface mode.

In the autonomous mode, the system enables the intelligent wheelchair to travel autonomously with accurate positions estimated by the Kalman Filter and desired path[8][11][14]. In this mode, the rider doesn't need to do anything on controlling. This autonomous function was already developed and has enough level to do experiments outside and indoor environments.

Figure 2 Intelligent wheelchair

In the gesture interface mode, functions of obstacle avoidance and autonomous navigation were not used during the experiments. A gesture based interface is implemented by adding a Leap Motion camera to the wheelchair under the arm support, shown in Fig.4. Gesture interface needs the gesture recognition algorithm, which can estimate which rider's gesture is. This algorithm was already proposed [9][10] by referring to the presented theory[16-20]. There are four patterns of gestures, which were defined for the wheel chair control. These gestures are "Go Straight", "Turn Left", "Turn Right" and "Stop" hand gestures, shown in Fig.5. The gesture recognition algorithm recognizes both the hand gestures and postures with an overwhelming accuracy. Along with the gesture recognition system, a function of the Leap Motion development kit is used to recognize fingers touching and hand fist actions to add extra caution to the stop gesture. The system halts using three stop conditions as the experiments were conducted in a public area in Tsukuba. The wheelchair comes to stop in three conditions for either of finger touches, hand fist or hand is not seen in the sight volume of the camera. It was confirmed that the algorithm can correspond to everyone including elderly people [12]. Thus, it has enough robust and high accuracy to perform experiments in indoor and outdoor environments.

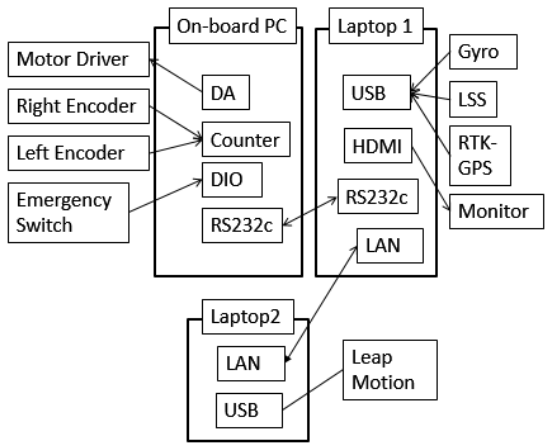

Figure 3 System Configuration

Figure 4 Gesture Sensor

Figure 5 Gesture Pattern

IV. EXPERIMENTS WITH INTELLIGENT WHEELCHAIR

We conducted an operational evaluation through real-world experiments and introduced some of the experimental results the previous papers [10][11][14]. In this section, two conducted scenarios are described with the proposed intelligent wheelchair. The experimental conditions, the questionnaires provided, and the experimental results, as well as an overall discussion are explained. In addition to previous results, discussion based on experimental and questionnaire results, which were not presented in the previous papers, will be done in the next section. Experimental places used in this study were located in the Tsukuba Designated Zone in Japan, which is described in Section 2. Before conducting the experiments, we applied a risk assessment of riding the intelligent wheelchair for every route. Each of the two scenarios is described in the following sub-sections.

A. *Experiments for autonomous wheelchair*

59 subjects who are not disable people were employed for these experiments. We asked the subjects to ride the intelligent wheelchair with automated function. The experimental duration was set to 20 minutes for each subject. After the experiments, several questionnaires about the intelligent wheelchair were done.

1) *Provided Questionnaire*

Before participating in the experiment, the subjects answered same questionnaire about gender and age.

After experiments, the questionnaires, which all subjects answered are as follows:

- Q1. Did you feel any near miss events during the riding? (If yes, please explain in detail. If no, please imagine near miss event with the intelligent wheelchair)
- Q2. What distance do you think is appropriate between the wheelchair and surroundings?
- Q3. How much do you want to pay for this autonomous function?
- Q4. How do you feel about the stability on a scale of one to ten? (10 is best)
- Q5. How do you feel about the fun on a scale of one to ten? (10 is best)
- Q6. How do you feel about the comfortability on a scale of one to ten? (10 is best)
- Q7. When these intelligent wheelchairs are available in a supermarket or shopping center, do you think do they encourage you to go there?
- Q8. If you have any comments regarding these experiments, please let us know.

2) *Questionnaire Result*

In question1 (Q1), about 20 % subjects answered “yes”, and comments about the event are as follows:

- The wheelchair traveled very close to pedestrian
- The wheelchair suddenly stopped for the obstacle
- He unintentionally touched joystick controller

- The route, which the wheelchair chose, was different from the route he expected
- Suddenly, a pedestrian crossed in front of the wheelchair

Those who answered “no”, and comments they imagined are as follows:

- The wheelchair travels at high speed
- The rider forgets to turn off the switch
- The wheelchair travels in rainy, crowded, non-flat or slope conditions
- Software bugs exist
- High speed obstacles including bicycle cross in front of the wheelchair

With respect to Q2, average distance is about 1.29[m] and standard deviation is about 0.64[m]. This distance is about double person’s width, and the personal differences are large by considering the standard deviation. Thus, it is supposed that autonomous wheelchair needs to keep enough distance (more than 1.2[m]) between obstacles and the wheelchair, and the distance should be able to be changed by users.

With respect to Q3, average cost is about 137000 Japanese yen (1370 US dollar) and standard deviation is about 209000 Japanese yen (2090 US dollar). In Japan, an electric wheelchair costs from 200000 to 500000 Japanese Yen [21]. This autonomous function must be under this wheelchair costs, and the number of this standard deviation means that the value of autonomous function depends on users, thus, some users strongly want to use this function, and there is a strong possibility that they will pay for this function.

With respect to Q4, Q5 and Q6, Table 1 shows the questionnaire results. This result shows that comfortability and fun are enough high, but stability needs to be improved. This means that subjects didn’t trust the autonomous function yet, despite no accident in the experiments.

In Q7, the result shows that about 90 % subjects answered “yes”. This means that the intelligent wheelchair is very attractive for a supermarket or a shopping center.

Their comments in Q8 are given below.

- The design of the wheelchair should be changed
- Interface for a rider is important even when the wheelchair travels autonomously
- The wheelchair should move more smoothly
- A rider wants to confirm surroundings, as the wheelchair recognizes

We found that the subjects expressed favorable opinions regarding the intelligent wheelchairs, and many expressed a desire to use it again in the future.

TABLE. 1 QUESTIONNAIRE RESULT OF Q4, Q5 AND Q6 (Average and Standard Deviation of each score. 10 is best and 1 is worst.)

	Q4	Q5	Q6
Average	6.99	8.20	8.95
Standard Deviation	2.03	1.96	1.80

B. Experiments for new interface

The experiments for evaluating the intelligent wheelchair with the new gesture interface were performed. The subjects who are not disable people were instructed how to use these gestures to command the wheelchair before using the intelligent wheelchair. The experimental place was Tsukuba designated zone, which was explained in Section 2. The duration of the experiment for each subject was about 20 minutes. Figure 6 shows the experimental scene.

Figure 6 Experimental Scene

1) Provided Questionnaire

Before participating in the experiment, the subjects answered their gender, age. We wanted to know the impressions of two kinds of controlling wheelchair (one is new gesture method, the other is conventional joystick method), thus we asked the following questions after we showed the movie about joystick and gesture interfaces.

Q1. How do you feel about the gesture interface on a scale of one to five? (5 is best)

Q2. How do you feel about the conventional joystick interface on a scale of one to five? (5 is best)

After the experiment, each subject filled out a questionnaire providing answers to the following questions.

Q3. How did you feel about the gesture interface on a scale of one to five after you used it? (5 is best)

Q4. How did you feel about the conventional joystick interface on a scale of one to five after you used it? (5 is best)

Q5. Can you tell me pros and cons of using the joystick for controlling the intelligent wheelchair?

Q6. Could you control the intelligent wheelchair by the gesture interface? If not, please let know about when and what condition you thought that you couldn’t control it.

Q7. Do you have any comments about the gesture for “go straight”?

Q8. Do you have any comments about the gesture for “turn right”?

Q9. Do you have any comments about the gesture for “turn left”?

Q10. Do you have any comments about the gesture for “stop”?

Q11. Where or which condition would you like to use the gesture interface?

Q12. If you have any comments regarding these experiments, please let us know.

2) Questionnaire Result and Discussion

Table 2 shows the results for Question 1, 2, 3 and 4 (Q1, Q2, Q3 and Q4). From this results, before using gesture, subjects thought the gesture interface was very interesting and useful more conventional joystick. On the other hand, after the experiments, unfortunately, the subjects thought the gesture interface wasn't satisfied yet. Thus, there are several challenging issue remaining in the gesture interface, and comments, which will be introduced in the result of Q6-Q12, are important.

Their comments in Q5 are as follows:

- Good reaction of turning and forward
- Easy to operate than gestures
- To get accustomed to the joystick interface more easily than the gesture interface
- Easy to use, without learning

With respect to Q6, 14.2% subjects answered "no". Those who answered "no" regarding Q6, their reasons are as follows:

- It was difficult to understand proper spacing of the hands and the sensor
- It was possible to smoothly steer in the beginning of the experiment. But, after practicing the gesture interface, it became easy.
- I wasn't able to successfully steer because the sensitivity of the sensor wasn't enough.
- Operation of the left hand, which was not dominant hand, was difficult
- I was able to operate "go straight" and "turn left", but to operate "turn right" was difficult.
- It was possible to operate "turn left", but to operate "turn right" was difficult.

From this result, it is confirmed that we need to improve the gesture interface, but this comments are valuable for improving the gesture interface. For example, the specification of the sensor should be improved, and explanation and trial are important to get accustomed to this new interface. The operation of "turn right" seems to be difficult for several users, and this problem can be fixed if this gesture pattern of "turn right" is changed.

With respect to Q7, Q8, Q9 and Q10, Table 3 shows the questionnaire results. As shown in the result of Q6, the operation of "turn right" should be changed and appropriate places of the arm and the hand must be easily fixed.

With respect to Q11, several interesting comments about condition are given and they are as follows:

- Operations using the center of gravity of the body
- Operation by using the leg or the neck.
- I want to operate in my dominant hand for the gesture interface.
- Not for me, but I think some people are interested in this gesture interface by considering the level of disability

In these experiments, we chose hand gesture but it will be interesting that other body gestures are employed for the new interface.

Their comments about the gesture interface in Q12 are as follows:

- The hand and arm should be fixed for keeping the appropriate place of the hand.
- We expect that the system should be more reliable and accurate
- It takes some time for this operation to get accustomed to.
- Gesture interface was funny
- I was impressed that the wheelchair moves with the gesture interface, and I want to use this sometime.
- It was fun to use, but it may be difficult for elderly to understand the operation for proper use

We found that the subjects expressed favorable opinions regarding the gesture interface, and many expressed a desire to use it again in the future. These comments indicate that we need to strongly improve the intelligent wheelchair.

TABLE.2 QUESTIONNAIRE RESULT OF Q1, Q2, Q3 AND Q4
(Average and Standard Deviation of each score. 10 is best and 1 is worst.)

	Q1	Q2	Q3	Q4
Average	4.14	3.71	2.71	4.00
Standard Deviation	0.35	0.88	1.16	0.76

TABLE.3 QUESTIONNAIRE RESULT OF Q7, Q8, Q9 AND Q10

Go Straight	Turn Right	Turn Left	Stop
Good	To keep appropriate distance between the hand and the sensor was difficult	Good	Good
Very easy	Difficult to operate	It was easier than "turn right"	Reaction of the wheelchair was good
It was easy to operate straight comparing to left and right	"Turn right" is more difficult than "turn left"	Turn left was simpler than "turn right"	Easy
It was difficult to fix the place of the hand	At first, it was not able to turn right. It was possible to operate after changing position of the arm	It was easy to operate. Distance between the sensor and the hand was important	It was easy because the system recognizes "stop" when the hand was released from the sensor
Hard to operate	On operationg "turn right", the left hand was too close to the sensor, and sensor couldn't recognize the hand	It was able to operate as intended	I didn't feel the anxiety because the wheelchair stopped in safety
I could not proceed straight without shifting a little to the left		Very easy	Very easy

V. Conclusion

We proposed the use of an intelligent wheelchair for new mobility not only for elderly people but also for everyone. Our intelligent wheelchair has autonomous function and new gesture interface. For the introduction of the proposed intelligent wheelchair, there are several challenges associated with the use of the wheelchair. One of the most important points is the user acceptance, and it must be investigated with a plenty of subjects by experiments. In addition, the affordability is also important for the introduction. The two points were investigated by performing the several experiments with subjects. In the experiments, we did a questionnaire about the intelligent wheelchair. In this paper, we introduce experiments and the questionnaire results, and the results are compared and discussed in this paper. The questionnaire results proved that most subjects had the favorable opinions about autonomous function and new gesture interfaces. On the other hand, the challenging issues for improving the user acceptance of intelligent wheelchair were also found especially for the gesture interface. One of the most important points is to choose easy operation especially for elderly people. These results must be valuable for developers and researchers of new wheelchairs.

For future work, we will perform the experiments under more situations and with more subjects including disable subjects. In addition, we will develop new intelligent wheelchairs by using feedback from this research.

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