Development of Mouthpiece Type Remote Controller for Disability Persons

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Disability persons like cervical cord injury have a lot of difficulties even in the activities of daily living, such as turn room light's switch ON/OFF and drive electric powered wheelchair. A variety of operation devices have been developed for such serious disability people; voice or breath control, head motion control and eye movement control system etc-. They have own merits and demerits respectively, but still now, there are need to develop another types of operation devices. The tongue movement is also available and one of solutions to apply to some operation devices for disability persons. In this study, we have tried to develop a mouthpiece type remote controller for those serious disability people. This remote controller has passive RFID (Radio Frequency IDentification) transponders but no battery.

The concepts and the mechanical design of the mouthpiece type remote controller were introduced in this paper. To investigate characteristics of the remote controller, MCR (Maximum Communication Ranges) was measured. The results indicated that this controller has enough performance to apply to operation device for disability persons.

To make sure that this remote controller was able to control electric powered wheelchair, we tried to operate an electric wheelchair on the market. With this system, we could get success in operating the powered wheelchair by pushing the switches on the mouthpiece remote controller by tongue.

Key Words: Cervical Cord Injury, Assistive Technology, Daily Living, Powered Wheelchair, RFID, Remote Controller

1. INTRODUCTION

Disability persons have a lot of difficulties even in the activities of daily living. It's well-known that those persons who have cervical cord injury or muscular dystrophy can't move nor walk to anywhere by themselves. In most cases, those

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difficulties are caused by mobility disturbance of not only lower extremity. The cervical cord injury or muscular dystrophy persons have mobility disturbance on both of lower and upper extremities. This leads that some tasks are also very hard for some of them, such as; "moving their hands and fingers when they try to drive electrical powered wheelchair" and/or "reaching their hand to switch when they need to turn room lights ON/OFF". Therefore, there are many requirements of development of new operation devices for cervical cord injury and muscular dystrophy persons.

As one of devices to control electrical powered wheelchairs for cervical cord injury people, chin control system is very popular. And also in these ten-twenty years, many authors have tried and studied to develop special tools and devices such as; voice control system[1-6], breath control, head motion control[7-11], and eye motion control system[12-15] for these serious disability people. They have own merits and demerits respectively.

For some of muscular dystrophy and cervical cord injury of C4~C6 level person, chin control system might be uncomfortable, since they are hardly to move their neck, head and chin. Since the same reason, head motion control system wouldn't be so easy to be used. Voice control system is one of solutions because even most of the people injured cervical cord can speak. In these years, the technique of voice recognition has been improved rapidly, but still now, there are many issues to overcome. One of well-known issue that making distinction between "voice command" and "noise of normal conversation" is hard task, and the confusing of these two leads user's un-safety. For the user's safety and accuracy of control, we might need to wait for improvement of the voice recognition technology.

These kinds of devices for disability people were controlled by one or some parts of the body that have no paralysis. Motion, movement, pressure, sound and/or force were generally useful. When we try to develop these devices, we need to know which part is paralyzed, and then which part can be moved as the voluntary movement. Basically, cervical cord injury person and muscular dystrophy person can move their eyes, mouth, teeth and tongue as they want, so many devices use eyes and mouth movement. The movement of tongue, on the other side, wouldn't be applied to these devices so much, even if disability people could move their tongue adequately. When using tongue's movement for the controller, it indicates that controller has to be inserted in the mouth with battery. But the batteries have strong toxicity, so it should not be put into the mouth. This would be the main reason that only a few researchers had tried to study and develop tongue control system[16-20].

In this study, we have focused on the tongue movement to apply a new remote controller for serious disability people. Tongue can move fast and accurately. It is connected to brain through cranial nerve and this nervous system avoids serious damage even in the case of cervical cord injury. These indicate that the tongue has enough requirements to operate some control devices for serious disability persons. To develop a new control device operating by user's tongue, we need to work out to the problem of the battery toxicity. To solve this issue, we applied RFID (Radio Frequency IDentification) techniques.

As a case of industrial application of RFID, "Suica" and "ICOCA" were well known system. They are rechargeable contactless smart card, used as a fare card on railroad in Japan. There are two types of RFID transponders; active and passive type transponders. Active type transponders need to have batteries to transmit their ID code, but passive types don't have to carry any batteries. Passive type transponders generate electricity by the electromagnetic induction. Therefore, if they can receive electromagnetic radiation that transmitted from RFID reader (main body of RFID recognition device), passive type transponders can generate electricity by themselves, and then they can transmit their own ID codes. In this study, passive type transponders were applied to the remote controller since it doesn't need to have any battery. The greatest merit of using passive RFID transponders is that it can work without battery and no toxicity of it. The mechanism of "without the battery" also contributes to the miniaturization and lightening of the remote controller.

The features of the mouthpiece type remote controller were these two points; it can drive without the battery, and it is operated by tongue. In this paper, we would explain the development concept and specification of the mouthpiece type remote controller with passive RFID transponders. Then we also estimate the characteristics of the remote controller we have developed.

2. Design Specification and Mechanism

2.1 The general design and its usage

To develop the trial remote controller of mouthpiece type with RFID transponders, general design and its usage were considered as follows. In this study, the operate target was fixed on an electric powered wheelchair. To operate an electric powered wheelchair, we thought that the mouthpiece type remote controller should have four channels of movements of "FORWARD", "BACKWARD", turn to "RIGHT" and "LEFT". Therefore, this mouthpiece type remote controller has four RFID IC chips and four switches. Every RFID has their own ID cords and they are corresponded to the commands of "FORWARD", "BACKWARD", "RIGHT" and "LEFT". When users want to drive wheelchair to forward, they will push the forward switch on the remote controller by their tongue. Only while they keep pushing the switch, the wheelchair can keep moving forward. At users release their tongue from the switch, wheelchair will stop. Also in the case of that users push any two or more switches, wheelchair will stop. This operation style would be natural and easy to drive for many users.

The mouthpiece type remote controller would be inserted into the user's mouth and fixed on the upper jaw using the artificial tooth stabilizer. The reader antenna of RFID transponders would be set beside user's cheek or under chin like "Hands free mike". Main body of RFID identifier system would be set on the back of the powered wheelchair.

System configuration was illustrated (Fig. 1). The remote controller was inserted into user's mouth and fixed their upper jaw, and the antenna was set beside their cheek. The operation commands for powered wheelchair were transmitted from the remote controller then they were received through the antenna. The condition of communication between the remote controller and the antenna is wireless, and this system can avoid of effusing of saliva. If users adopt any non-wireless device, saliva will effuse and this condition isn't sanitary.

The read antenna was connected to the main body of the RFID identifier system. The ID codes transmitted from the remote controller were identified through this identifier system. A special and small controller was connected to RFID identifier system. This special controller classify the each command of move "FORWARD", "BACKWARD", turn "RIGHT" and "LEFT", then it supply voltage signal to the electric powered wheelchair.

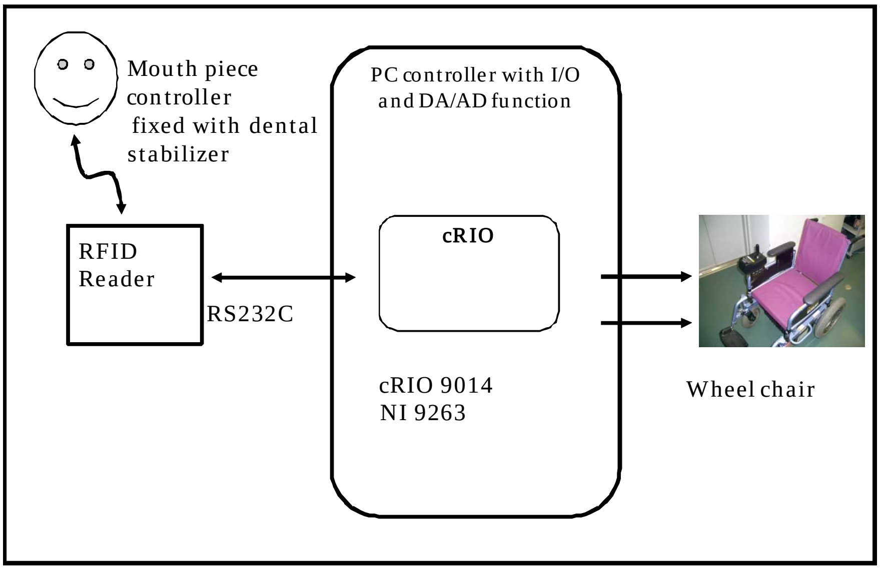


Fig. 1 Schematic diagram for an electric powered wheelchair control system using mouthpiece remote controller.

The RFID identifier and special controller were set back or under the seat of the powered wheelchair. The electric power of them was supplied through the battery of the powered wheelchair. These arrangements of the devices achieved that users can drive powered wheelchair anywhere without plugging them in.

2.2 The mechanism and the operation principle

1) Mechanism

Each RFID transponder on the market has only one IC chip and an antenna connected to the IC chip directly (Fig. 2-(A)). IC has its own ID code. RFID transponders can electro-magnetic induction through electric wave or electromagnetic wave. While it's in the communication area of reed antenna, it generates electricity and transmits its own ID code automatically. Therefore, to apply RFID transponders for this remote controller, every transponder has to have own switch to realize ON/OFF of transmitting ID code. For the miniaturization of the remote controller, only one antenna was set on the controller, and four IC chips shared the antenna (Fig. 2-(B)). This mechanism realized that mouthpiece type remote controller can transmit ID cords to operate the powered wheelchair without battery.

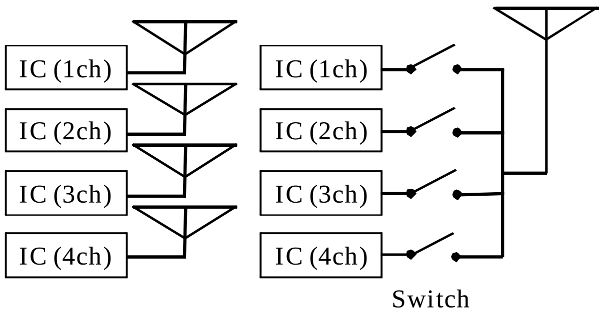


Fig. 2-(A) Fig. 2-(B)

Fig. 2 Schematic diagram of mouthpiece remote controller circuit.

2) Frequency band of RFID transponders

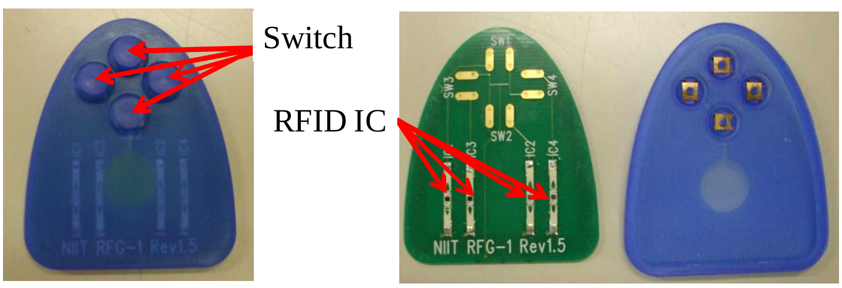
RFID transponders have several frequency classifications such as; from 134.2kHz of low frequency to 2.45 GHz of high frequency. In general, the maximum communication range (MCR) of low frequency type is not so long, but it doesn't have strong influence from moisture, water and other environmental equipments. On the other side, the MCR of the high frequency type is longer but it very susceptible to environment[21-26]. The reasons why is that, high frequency electromagnetic radiation was attenuated by water, skin, and/or fat, and then it lost its power. Therefore, in order to develop the mouthpiece remote controller, we need to know the basic communication characteristics of RFID and also what frequency type RFID should be applied to this mouthpiece remote controller.

As a preliminary experiment, several shapes and size of two frequency types of 134.2 kHz and 13.56 GHz RFID transponders on the market were estimated. The

MCR was measured in the conditions of atmosphere, water and meat. As the result, small differences of the MCR were confirmed by the conditions of atmosphere, water and meat, or the size and shape of transponders, but the both MCR of 134.2 kHz and 13.56 MHz type showed 130-240 mm. The MCR of 20-30 mm should be enough, because of that, as the usage of this remote controller, the antenna will be set beside cheek like “hands free mike”. The distance between the remote controller and the antenna should be less than 20-30 mm. On the other opinion, in these years, 13.56 MHz type has become more popular than 134.2 kHz, then 13.56 MHz type transponder is adopted for the remote controller. In addition, UHF frequency type was also one of candidates, but some researchers advocate that UHF electromagnetic radiation has adverse effect on the human body. For the users’ safety, it was thought that UHF type shouldn't be used for the mouthpiece type remote controller in this study.

3) Design and structure

Figure 3 shows the trial mouthpiece type remote controller of second version. The shape and its size were designed based on the odontology department specimen (45 mm depth * 40 mm width). Four switches were placed middle front of the controller, and four IC chips were set on the back part. The diameter of the every switch was 6mm.The height of the “FORWARD” button was 4 mm, “RIGHT” and ”LEFT” were 3mm, and ”BACKWARD” was 2 mm. This height arrangement was for easy to push. The loop antenna was printed on the rear face of the circuit board. The antenna was printed as about 7 rolls of 0.5 mm pitch along the outline of the circuit board. The antenna circuit was designed based on the principle of the loop antenna. For RFID transponders the principle of the loop antenna is generally used, especially for 134.2 kHz and 13.56 MHz. The length of the antenna was about 1m, it was almost of the maximum limitation of size of this controller. The direct current resistance of the antenna was calculated as about 3 Ω through the next equation (Equ. 1). For other specifications, inductance was $4.9*10^{-6}$ H (without IC chip).



Over View : with cover   Inside View : without cover

Fig. 3 Picture of the second version of trial remote controller.

$$R = r \times \frac{L}{S} = r \times \frac{L}{T \times W} \quad \text{(Equ. 1)}$$

where, R: direct current resistance [Ω]

r: electrical resistivity of copper ($1.68*10^{-8}$) [Ω·m])

S: Sectional area [mm^2]

T: thickness of the printed antenna ($30*10^{-6}$ [mm])

W: width of the printed antenna (0.2 [mm])

3. Investigation of the remote controller performance

To evaluate the performance and the operativeness of the mouthpiece type remote controller, three kinds of the following tests were examined.

3.1 The influence of the environment on the communication range (in vitro)

Generally, RFID transponders are very susceptible to environment. The characteristic of communication ranges of RFID was influenced by the environments of atmosphere, water, skin, and human's fat. Therefore, in order to develop this remote controller, we need to know the basic characteristics of RFID. To investigate the basic characteristics of the trial mouthpiece remote controller, MCR (Maximum Communication Range) was measured under three kinds of environmental condition of in the atmosphere, water and meat, as in vitro experiment. The MCR was measured as the distance of the remote controller and the RFID read antenna, while the communication is steady (Fig. 4-(A)). For the case of in the water, only the remote controller was soaked in a water tank, but the antenna was set beside the wall of the water tank (Fig. 4-(B)). For the case of in the meat, the remote controller was sandwiched between same thickness meat, and the antenna was placed on the bottom of this meat block (Fig. 4-(C)). The MCR was measured as the distance of the thickness of the meat between the remote controller and the antenna. Every channel of "FORWARD", "BACKWARD", "RIGHT" and "LEFT" were measured 20 times and the average and standard deviation was calculated.

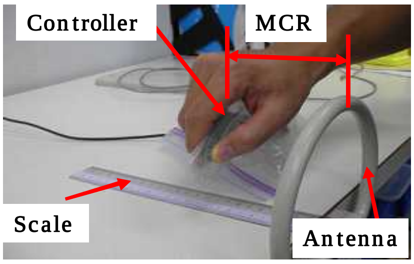


Fig. 4-(A)

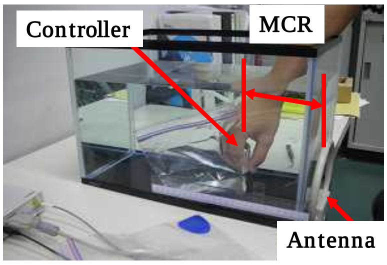


Fig. 4-(B)

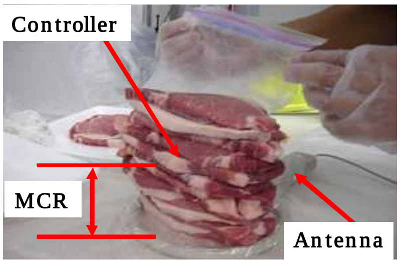


Fig. 4-(C)

Fig. 4 Experimental set up to measure the MCR in the atmosphere, water and meat (in vitro test).

3.2 Investigation of the suitable antenna position and the communication range (in vivo)

To achieve in vivo test, the remote controller was inserted into participants' mouth and fixed on the upper jaw by denture stabilizer. Three antenna positions of (1): front of mouth, (2): beside cheek and (3): under chin were considered, to examine where the best position to set the antenna is. In this case, the MCR was measured as the distance of between the skin of around participants' mouth and the antenna (Fig. 5). In these conditions of (1): front of mouth, (2): beside cheek antenna, the antenna was set 45 degrees against the horizontal plane. In the condition of (3): under chin antenna, it was held in the horizontal plane. The participants were 10 healthy male (aged 22-23). Every channel of "FORWARD", "BACKWARD", "RIGHT" and "LEFT" were measured 10 times and the average was calculated.

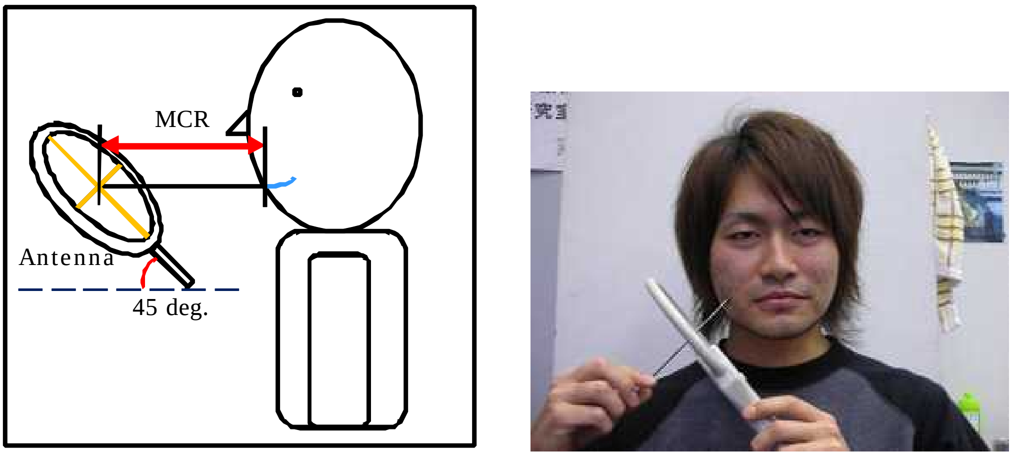


Fig. 5 Experimental set up to measure the MCR and check the best antenna position (in vivo test).

3.3 Evaluation of operativeness

To investigate the operativeness of the mouthpiece type remote controller we developed, following were examined. To simulate the same conditions of that user operate the remote controller by their tongue, the remote controller was inserted into participants' mouth and fixed on their upper jaw by denture stabilizer.

The operational commands of "FORWARD", "BACKWARD", "RIGHT" and "LEFT" were given randomly, and then participants tried to push the corresponding switch button. Only the tasks of that the participants could push the correct switch button in three seconds were "Success", but other tasks such as pushing incorrect button and/or taking three or more seconds to push were judged as "Failure". The success rates of each switch were calculated. The participants were 10 healthy male (aged 22-23). To consider the influence of tiredness, every participant examined 120 random operation tests. In addition, the mouthpiece type remote controller has two types of the hardness of the switch button. The both of "Soft switch" and "Hard switch" were tested.

As the RFID identifier system TR3-MD001E (Takaya Corporation, Japan) was used (Fig. 6). Hand held type antenna: TR3-HA101 (Takaya Corporation, Japan) was used. NI 9263 and cRIO 9014 (National Instruments, USA; in the following, it would be called as cRIO) were used to control an electric powered wheelchair (Suzuki, MC-16). But only for this operativeness test, for the participants' safety, the operational target was changed to a model car (Tamiya Corporation, Japan) instead of the powered wheelchair.

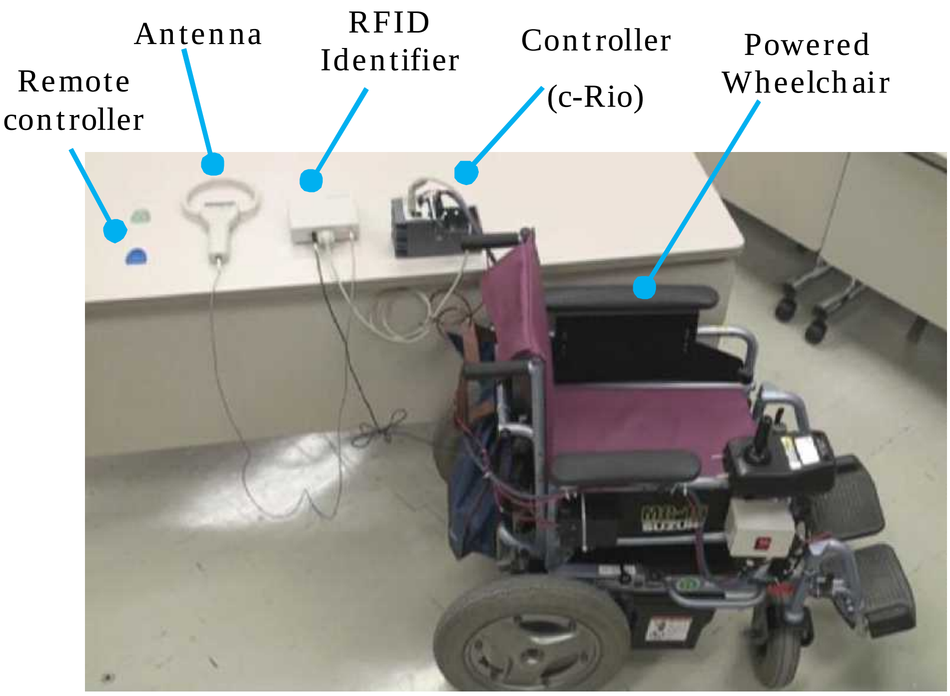


Fig. 6 Experimental set up to evaluate the operativeness.

4. Results and Discussions

4.1 The influence of the environment on the communication range (in vitro)

To investigate the basic characteristics of the trial mouthpiece type remote controller, the MCR was measured in the atmosphere, water and meat. The MCR of each four channel was calculated to the mean value with one standard deviation (mean±1 S.D.) (Table 1). Every mean value of MCR of each condition was over

110mm. The communication characteristic of each condition was clarified as good enough. This result leads that it would be able to work in the condition of humans' mouth.

4.2 Investigation of the suitable antenna position and the communication range (in vivo)

The mean MCR with one standard deviation (mean±1 S.D.) of each antennas setting position was shown in Table 2. Every mean value of MCR was 30 mm or more. As the usage and the concept of this system described in chapter 2.1, the distance between the remote controller and the antenna should be less than 20-30 mm. Therefore the performance of the trial remote controller was longer enough.

"Beside cheek antenna" shows the smallest SD, "Front antenna" also shows similar value. Suitable antenna position was thought as "Beside cheek" or "Front antenna". These results also indicated that if users set the antenna beside their cheek or around their mouth, the mouthpiece remote controller would work. It was suggested that this mouthpiece type remote controller system would be available to use as an assistive tools for serious disability people.

Condition	MCR (mean ± S.D. [mm])
Atmosphere	112.9 ±11.8
Water	129.7 ±18.9
Meat	119.4 ±14.5

Table 1: Result of MCR (Maximum Communication Ranges) of trial remote controller under the different conditions of the atmosphere, water and meat (in vitro test).

MCR	Front Antenna	Beside Cheek Antenna	Under Chin Antenna
Mean(mm)	31.1	31.5	31.7
S.D.(mm)	±9.53	±8.86	±15.1

Table 2 : The results of the MCR against the antenna position (in vitro test).

4.3 Evaluation of operativeness

Table 3 shows the result of the operativeness. The upper table shows the result of soft switch type remote controller, and the lower indicates the result of hard type. The success rates of each switch of both remote controllers were calculated. To estimate the relationship of the operativeness and users tiredness, the success rates were classified and listed up to "beginning", "middle" and "end" terms. The average of the total amount of the success rate of the soft switch type was 95.1%, and hard type was 88.2%. The success rate of hard type tended to decrease their value, but soft type didn't. These indicated that soft type switch is easier to operate and it might avoid getting tired. It was thought that for easy to push and operate, the hardness of the switch button should be around 0.5 N or less.

Comparing with the operativeness of each switches of soft type remote controller, the switch button of "BACKWARD" might be the easiest to operate, "RIGHT" and "LEFT" might be next. The success rate of operating "FORWARD" was lower than the others. But the success rate of "FORWARD" button of the soft type was over 91% and was thought still high enough. In addition, the switch is not pushed as so frequently as 120 times in such short period like these examinations. If we see the rates of initial and middle term, they were 93%, and these rates would be reasonable ratio in normal and usual situations.

Soft switch type controller

Success Rate (%)	Forward	Back -ward	Left Turn	Right Turn	Average
Initial term	93	98	93	87	92.8
Middle term	93	100	99	97	92.8
Latter term	88	100	98	95	95.3
Average	91.3	99.3	96.7	93	95.1

Hard switch type controller

Success Rate (%)	Forward	Back -ward	Left Turn	Right Turn	Average
Initial term	78	95	96	86	88.8
Middle term	77	99	98	92	91.5
Latter term	58	93	98	88	84.3
Average	71	95.7	97.3	88.7	88.2

Table 3 : The success rate for operativeness of the soft and hard switch remote controller.

On the other side, the position of the “Forward” button is set rather front part on the remote controller and a little bit far and small to push by tongue. The arrangement of the switches and/or redesign of the remote controller will lead more easy and suitable operativeness. The size and the stiffness of the switch buttons should be redesigned to push them easily. To suit the mouthpiece controller to users' mouth size, we need to provide a couple of sizes of the controller. Using a kind of flexible circuit board is also one of the solutions to suit the mouthpiece controller to users' upper jaw.

4.4 Trial operation of electric powered wheelchair

To make sure if this trial controller was able to control electric powered wheelchair, we tried to operate an electric powered wheelchair on the market (Suzuki, MC-16). For trial operation the electric powered wheelchair, the same control system was used. TR3-MD001E (Takaya Corporation, Japan) was used for the RFID identifier system. NI 9263 and cRIO 9014 (National Instruments, USA) were used to control the electric powered wheelchair (Fig. 6).

The trial mouthpiece remote controller was inserted in participant's mouth and was fixed on the upper jaw using denture stabilizer (basically using for artificial tooth). The RFID reader antenna was set beside cheek or under chin. The RFID identifier device was connected to the cRIO. The cRIO was also connected to the powered wheelchair.We have developed a program to control all of this system using Lab view (National Instruments, USA), which is one of graphical languages. This special program for this system was executed on the cRIO. The cRIO with this program identified the ID codes that have transmitted from mouthpiece remote controller, and then it output the voltage to powered wheelchair.

With this system, we could get success in operating the powered wheelchair by pushing the switches on the mouthpiece remote controller by tongue. This test also clarified that there were some problems and issues of the operativeness on the mouthpiece remote controller.

5. Conclusions

In order to develop the new type of remote controller for serious disability people, we have tried to develop a mouthpiece type remote controller. It has four switches and RFID IC chips, but doesn’t have battery nor any current supply. In this paper, the development concept and specification of the mouthpiece type remote controller were described. Then, the communication characteristic and performance of the mouthpiece type remote controller were investigated.

1) The mean MCR of each condition of the atmosphere, water and meat was over 110mm (in vitro test).
2) The mean MCR of each antennas setting position was over 30mm (in vivo test).
3) The operativeness of this remote controller was suitable.
4) With this system, an electric powered wheelchair was operated by movement of tongue.
5) It was suggested that this system can be applied to mouthpiece remote controller for serious disability people.

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