Study on Environmental Control System for People with Serious Disabilities

February　2016

Department of Advanced Technology and Science for Sustainable Development, Nagasaki University

Chao　Zhang

Contents

Chapter 1 Introduction

1.1 Background

Recently a declining birthrate and a growing proportion of elderly people is one of the notable social issues in Japan, China and Korea. In addition to these population changes, the number of disabled peoples are increasing every year. The newest report shows that, *there are one billion disabled people on the earth, which is the 15% of the whole people*[1]. In Japan, *there were 3.93 million disabled people* from the Ministry of Health, Labour and Welfare's report in 2015[2]. The data is shown in **Fig. 1.1.**

In 2006 it was reported that the number of limbs disabilities was almost 1,780 thousands, which correspond to 50% of disability people and also corresponds to 1 % of the total population.

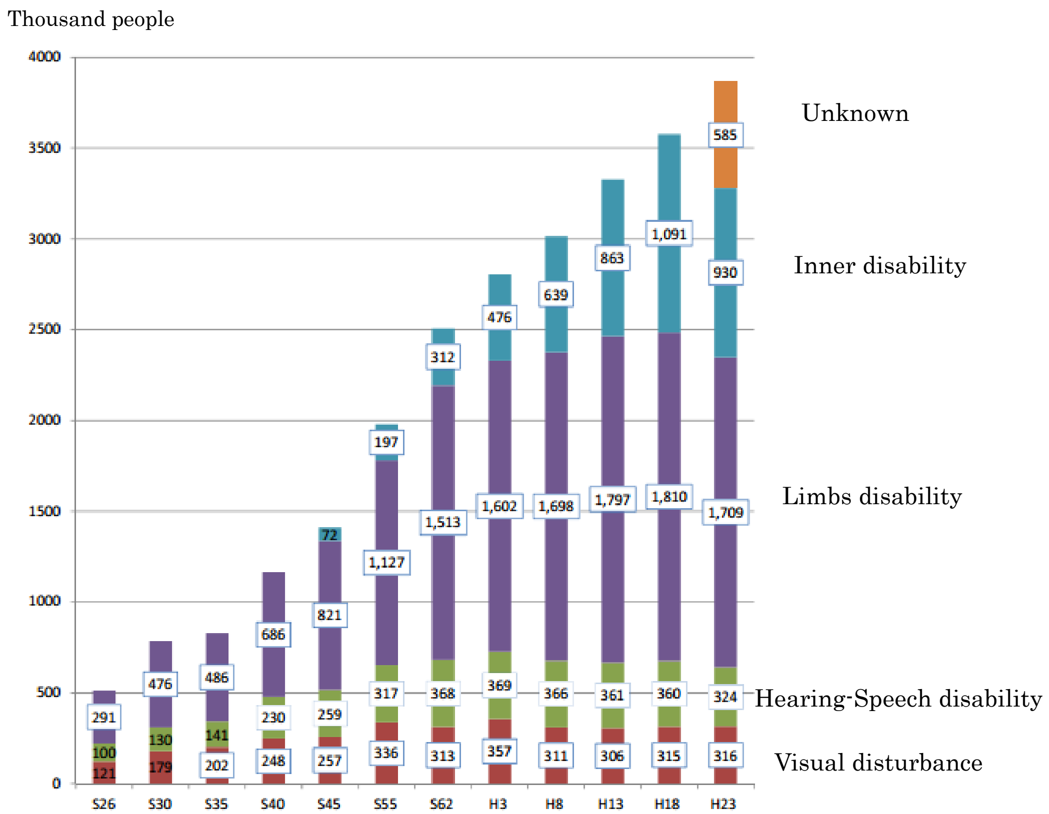


Fig. 1.1 Number of different type disabled people[3]

The aging of the population has become an increasingly striking social problem in Japan. Also the aging of disabled population has become a social problem as well. In **Fig. 1.2**, an age proportion of disabled people data is shown. From this figure, people with disabilities who are over 60 year's old have become a great parts of the whole population with disability. Therefore, the burden of disabled people and caregivers are increasing.

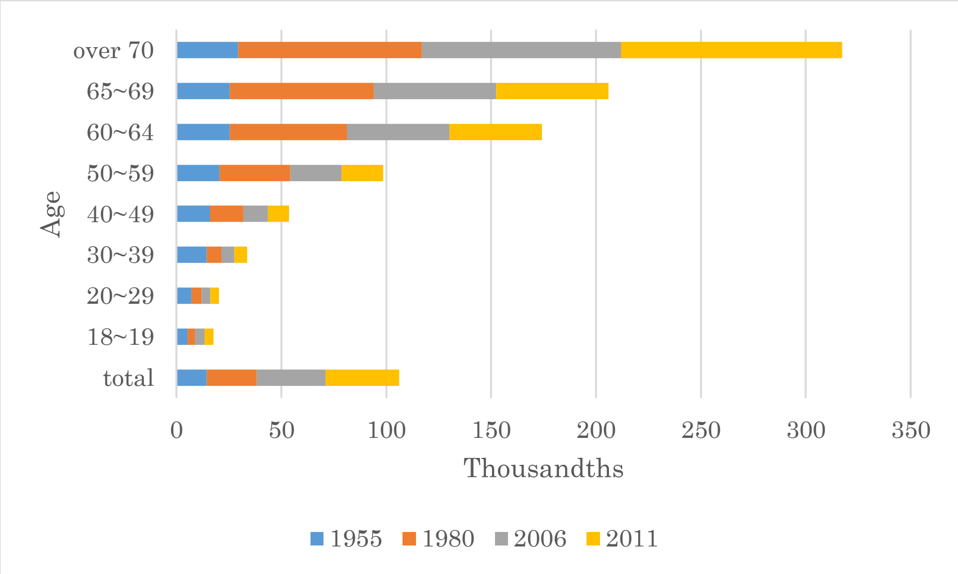


Fig. 1.2 Age proportion of disabled people[2]

With the increase of people with disability, the number of people with serious disability is also increasing. From Ministry of Health, Labour and Welfare's report in 2013, *serious disabled people increased to 42% of all disabled people*[3]. Many of them are under the bed-ridden status, and require physical support of care-givers. Shortage of care-givers and increase of budget for medical and care treatment are serious social problems. It should be noticed that every people should live sound and safe life even under the difficult conditions from the stand point of human right. In the followings, a patient suffered by incurable disease ALS (Amyotrophic Lateral Sclerosis) and also a patient injured by an accident are introduced.

ALS is *a progressive and devastating neurodegenerative disease, which affects motoneurons in the cerebral cortex, brainstem and spinal cord leading to paralysis and death*[4]. The patient with ALS disease could only be found one or two person in one hundred thousand. And they are difficult to be cured. These diseases cause muscle weakness and atrophy throughout the body caused by the degeneration of the upper and lower motor neurons. Individuals affected by the disorder may ultimately lose the ability to initiate and control all voluntary movement. In fact, not only ALS, but also the other neurological incurable diseases like cerebral gore sequel patients could just move there eyeball only in their later diseases period.

Fig. 1.3 ALS patient

An ALS patient is shown in **Fig. 1.3**. This patient suffered ALS for two years. Patient had muscle weakness and muscle atrophy at the early period, which was the initial symptom of ALS disease. And his muscle around his leg, hand and also lungs became so weaker that he was not able to walk, use his hands and breathe. Therefore, he will need an artificial respirator. As you can imagine, the patient to use artificial respirator is often obliged bed-ridden status and activity out of the bed and his caring-room is limited remarkably.

At present, this patient can move his fingers a slightly and he cannot utter voices clearly so that he had difficulty to communicate with his family and care-givers. His finger movement is not enough to push the button for the emergency case and also to operate the remote controller for the electric appliances. There his daily life depends on care-givers and family members. If he wants to watch TV, he will call his wife and ask her to switch on the specified channel. Communication is achieved by using the unclear voice and also a character table. Of course, care-givers work in his house is a great help for him. But it is not enough. His wife had to care his husband under the stressful conditions spending most of her time.

Fig. 1.4 Serious spinal cord injury patient

In the following, a patient (**Fig. 1.4**) suffered by a spinal cord injury is explained. Spinal cord injury refers to any injury on the spinal cord that is caused by trauma instead of disease. Spinal cord injuries have many causes, but are typically associated with major trauma from motor vehicle accidents, falls, sports injuries, and violence.

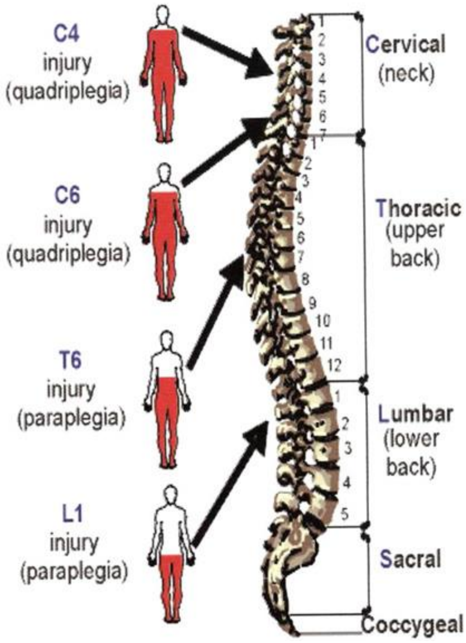


Fig. 1.5 ***Levels of Injury and extent of paralysis*****[5]**

Depending on which part of the spinal cord and nerve roots are damaged, the symptoms can vary widely, from pain to paralysis to incontinence, from lower to upper bodies. In **Fig. 1.5**, the white parts of the human models show where the physical ability of voluntary movement remains. And the red parts show where he loses the ability of voluntary movement. C4 means the 4^{th} spine of cervical is hurt. People who hurt as C4 level is often called serious spinal cord injury patient.

In order to cope with this situation, introduction of technology into the welfare and medical field are expected. The recent development in computer and networking technologies has promised great benefits to those, who suffer such extreme disabilities. Using the computer and network system, they can communicate and talk with others over greater distances even if they are confined to bed. Furthermore, the computer enables the people with disabilities to control the home electric appliances. Various computer systems to support their motor functionality are already commercialized.

But difficulties remain at welfare devices for serious disabled patients. In this paper people with serious disabilities suffered by intractable diseases like ALS and SCI will be our focus.

1.2 Situation of daily caring for serious disabled

The patients in serious cases lose the ability of voluntary movement: all their intentional muscular abilities are limited only to slight head movements, fingers movements and eye movements. Therefore, the patient daily lives are dependent on family and care-givers. The relationships of these patients with society are extremely limited and the patients could not achieve individual needs with others.

In addition, for the ALS patients who are in the final phase or cervical 4-level spinal cord injury, their breathing ability will deteriorate and will require an artificial respirator. The patients have to be restricted to living in a bed-ridden condition. The biggest problem between patients and care-givers is communication, as it is difficult for the patients to articulate any message through mouth. Development of a communication device for such patients is essential.

Here are two examples to introduce the details of the people with the serious disabilities. The first example is an ALS patient as shown in **Fig. 1.3**. This patient suffered ALS for several years. The patient felt muscle weakness and muscle atrophy at the early period, which is the initial symptom of ALS disease. And his leg or hand muscle became so weaker that he was not able to walk or use his hands and arms.

At present, this patient just maintains some slight finger movement. However, he lost the ability to speak clearly so that he was not able to communicate with his family and care-givers smoothly. This patient could not make an emergency call himself nor control the electrical appliances when he is alone. It is difficult for him to live without any caregivers. Furthermore, this patient will eventually lose the ability of breathing and have to use an artificial respirator. In that phase, he will lose all of sound communication abilities.

The second example is an SCI patient as shown in **Fig. 1.4**. This patient have a cervical (neck) injuries caused by a falling accident in January 2010 and is in full tetraplegia (Quadriplegia). His physical abilities are limited only to his neck and above. And he lost the ability of breathing so that he needs an artificial respirator. It means that he could not phonate by himself and could not move his arm and legs. It is impossible for him to live independently and others have to take care of his daily essentials.

In April 2010, he was moved to hospital in Nagasaki and had the rehabilitation. His mother requested the mechanical control laboratory in Nagasaki University in 2011. The laboratory offered him a communication device and emergency call device, which are controllable by his head movement. And in May 2011, the mechanical control lab offered a new version of the communication device which is developed for him. The function of the device is achieved to use computer as follow.

Communication function using nodding and shaking head movements.

Control of electric appliance such as TV, air-conditioner, etc.

In December 2011, he moved to his family house in Nagasaki. His nursing room is constructed under the environment computer control system, which is shown in **Fig. 1.6**. The system will be introduced in next chapter. And in April 2011, he moved to a nursing facility in Fukuoka. The maintenance of his environmental control system has been conducted by the mechanical control laboratory in Nagasaki University.

Fig. 1.6 Environment computer control system

1.3 Current environmental control system and input devices

Even though the people with serious disabilities may have lost their independence and communication skills, it can never be denied that they are living as an individual human beings. Also, from the viewpoint of care work, communication with the disabled patients is an important element of implementing the nursing work. Therefore, helping them to recover the independence and communication abilities are the top priority. In this regard, there are many mature technologies to help communication between the patients and the caregivers smoothly, and to improve patients' quality of life.

Environmental control system is a development which could solve the disabled people's problem of communication and independence. It was developed to control appliances, such as TV, air-conditioner, etc.

In the initial period a typical environment control system was developed as shown in **Fig. 1.7**. The environment control system consists of an LED display monitor like **Fig. 1.7(a)** and an input device which is available for the user. One typical input device is a breathing switch as shown in **Fig. 1.7(b).**

(a) LED monitor[6]

(b) Breathing switch[7]

Fig. 1.7 LED monitor types environmental control system

The LED monitor consists of 16 LEDs in the outer circle, 16 LEDs in the inner circle and a number indicator in the center of this LED monitor. Another part of this environmental control system is a breathing switch, which could detect a slow and slight breathing action (blow and sniff) by people. A patient was able to use breathing action as a nursing call or turn on/off room lights in other environmental control system.

Fig. 1.8 Breathing action to control[7]

This environmental control system can control 16 electrical appliances at most. When patient blow air to the breathing switch as shown in **Fig. 1.8** the LED light will shifted one by one. Different LED light indicates different electrical appliances. The patient could sniff air to the breathing switch when he wants to control an appliance what he has selected. After appliance selection, the patient was able to blow air to choose different operation mode which is shown as a charging number in the center of the LED monitor. And then the selected operation mode could be activated by a sniff action from the patient. The environmental control system was able to control radio, air-conditioner, room-light and other electrical appliances through LED monitor by breathing switch as shown in **Fig. 1.9**

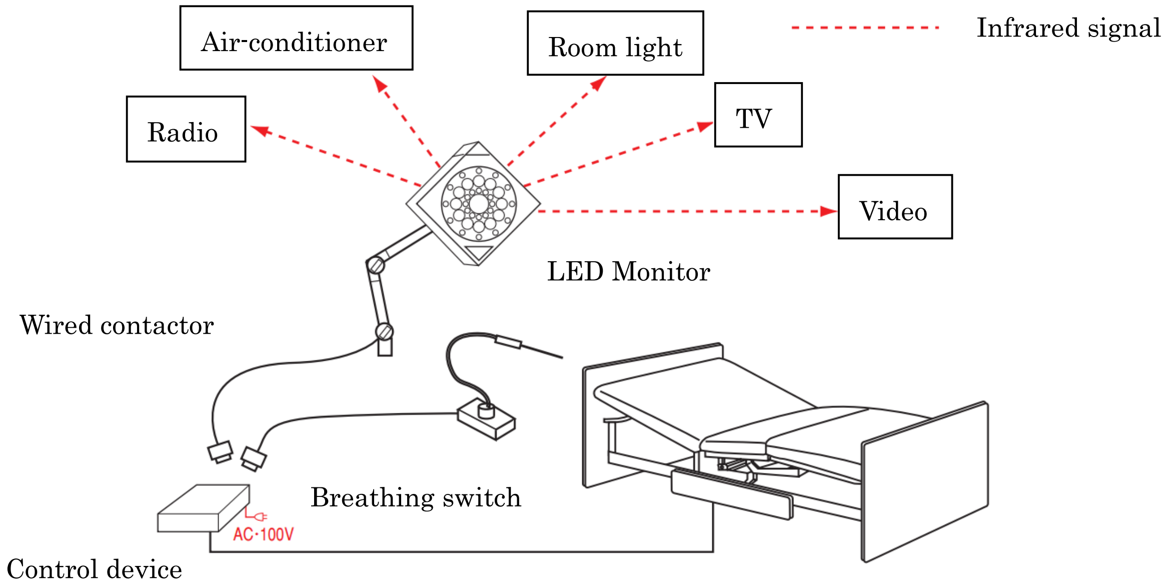


Fig. 1.9 Environmental control system[8]

Fig. 1.10 shows another environmental control system named E-612S. This system has 60 channels for different function controlling such as phone call, TV control, room lighting and etc. The patient could use breathing switch, touch switch, push bottom switch and other switches to change the vertical and horizontal LED, to choose the function which he want to use.

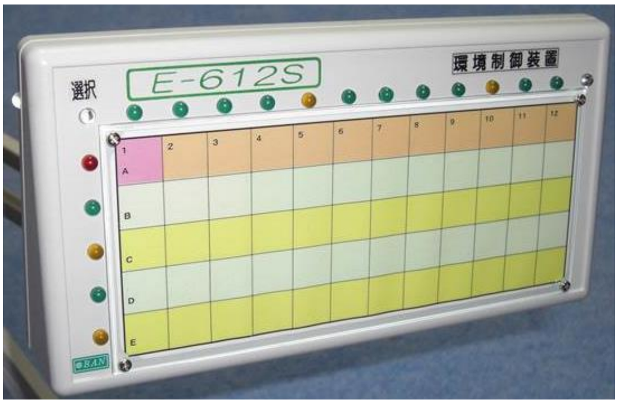


Fig. 1.10 Environmental control system (E-612S)[9]

In the second period, the environment control system was achieved by using computer. And the communication function of environment control system in this period was almost employed "Dennosinn" or "hearty ladder", which are shown in **Fig. 1.11** and **Fig. 1.12**

Fig. 1.11 Dennosinn[10]

The most popular environment control system in this period called "Dennosinn", was made by Hitachi KE Systems, Ltd. The patients with serious disabilities are able to use their slight body/head movement to operate sensors and switches. And then they could input words or sentences through a pre-installed screen keyboard software. The cursor moves sequentially on the screen keyboard. The patient with serious disabilities could do a slight movement of one body part when the cursor arrives at the purpose icon or character, then that character will be selected. This screen keyboard software achieve voice synthesis. Therefore, the user can recognize the input data by the voice signals as a support for communication. With an infrared signal remote controller, electrical appliances could also be controlled by the patient's slight movement.

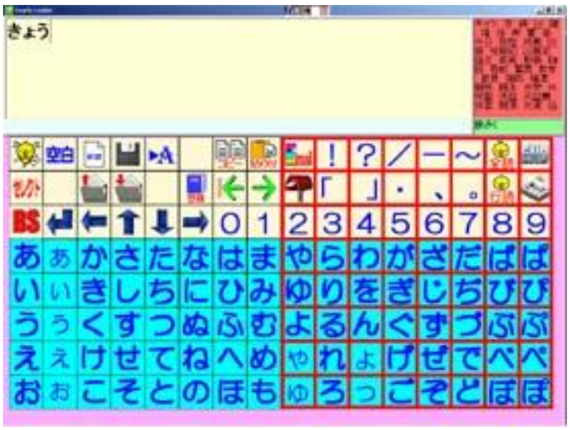


Fig. 1.12 Hearty ladder[11]

Fig. 1.12 shows hearty ladder. This is a free software which has the same functions as “Dennosinn”. There are various cursor selection modes for patients with different disabilities. It supports multiple computer interfaces like touch sensor, mouse, joystick, etc. The word input method is various, select as normal mouse movement, just click the left button of mouse, combination click between left button and right button of mouse, etc. Patients could also use an infrared signal remote controller like “Nanndemo IR(**Fig. 1.13**)” to operate the electrical appliances.

Fig. 1.13 Nanndemo IR[12]

It is necessary to develop an appropriate input device for people with disabilities base on their remaining physical ability: finger movement, mouth/lips movement, head movement, eye movement and breathing ability. Below, the input devices based on the different physical ability will be introduce as introduced.

Fig. 1.14 Push button switch[13, 14]

Push switch is a common switch which has different button size as shown in **Fig. 1.14**. Disabled people who have the finger movement ability could use this switch as an input device. But the patient should have enough power of finger otherwise the push switch could not give the input signal to the environmental control system.

Fig. 1.15 Touch switch[15]

Touch switch (**Fig. 1.15**) is another type of switch as an input device. This switch is often fixed on the table or bed that is nearby the patient with serious disability. The patient could use a slight movement to touch the top of the touch switch, and then the on/off signal could be sent. This switch does not need strong power from the patient. It is suitable for disabled people who didn’t have strong physical abilities.

Fig. 1.16 Breathing switch[16]

Breathing switch, which is shown in **Fig. 1.16,** could detect the a slow and slight breathing action by people. It is also suitable for the disabled people who has low physical abilities. The patient could use blow action or sniff action as two different input signals, in order to control electrical appliance with environmental control system.

Fig. 1.17 Pressure sensor[17]

The **Fig. 1.17** is a pressure sensor. Pressure sensor will detect slight movement of the skin surface because of capacitance changing. The sensor could be set on the skin surface or object surface easily.

The sensors which are introduced above are based on the electrical and mechanical technology. Actually image processing technology could also support the daily life as a parts of environmental control system. It uses a camera to detect and track the position of a target, which is like patient's mouth, eye balls or the whole head. With the target's movement, users will control the mouse cursor to do what they like.

Fig. 1.18 Image processing technology support ECS

Of course, here are lots of method to achieve that. For example, a traditional image processing method, template matching method is often used for environmental control system. This method uses a particular image data named template image, to detect and track the most similar area in the real-time image data. A conventional algorithm named Normalized Correlation Coefficient (NCC) is usually used for the template matching. The Equation is shown as following.

$$R(x,y)=\frac{\sum_{x',y'}\left(T'(x',y')\cdot I'(x+x',y+y')\right)}{\sqrt{\sum_{x',y'}\left(T'(x',y')^2\cdot\sum_{x',y'}I'(x+x',y+y')^2\right)}} \quad (i)$$

where two images are correlated. $R(x,y)$ is the Normalized Cross-Correlation value between the template image $T(x',y')$ and the sub image $I(x',y')$. The more the value is close to 1, the better matched point between these two images should be found. By processing this algorithm, the displacement of the user's face could be obtained in real-time video image.

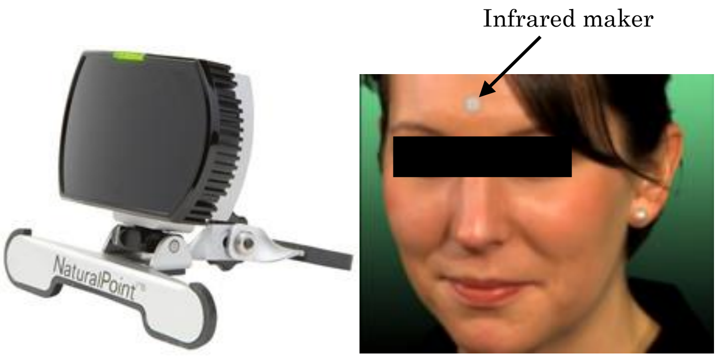


Fig. 1.19 SmartNav4[18]

SmartNav4 is a total hands-free mouse solution which is shown in **Fig. 1.19**. SmartNav uses an infrared camera to track patient's head movements. First, a patient could paste an infrared maker on the face or glasses. Then SmartNav4's LEDs will emit infrared light, and the infrared light is reflected back to the imager by a corner cube reflector. This reflected light is imaged by a CMOS sensor and the video signal is passed to the preprocessing electronics[19]. Finally, the video signal is thresholded against a reference level and all passing data is sent to the USB microcontroller to send to the PC for object tracking. By using a software, the patient could move the mouse cursor position by head movement, or achieve a clicking action when the patient holds his head movement. Therefore, SmartNav4 is easy to use for a seriously disabled patient who retains head movement only.

Fig. 1.20 Tobii EyeX[20]

Tobii EyeX is an image processing input device as shown in **Fig. 1.20**, which is made by Tobii Technology, Ltd. Tobii EyeX uses three cameras which have infrared lighting and infrared sensitivity to detect the position of the eyeballs by corneal reflection method. Pupil could change position along with gaze direction, but corneal reflection of infrared lighting could not change with gaze direction. Therefore, with the position relationship of pupillary and corneal, the gaze direction of patient should be obtained by calculation. And then the mouse cursor position should be synchronous with calculated gaze direction. The seriously disabled patient could use their slight head movement to change the gaze direction themselves, then control the mouse position by Tobii EyeX.

1.4 Problems of environmental control system

Patient with serious disability has the problem in operation of environment control system. Skill and practice for system operation is necessary to patient and care-givers. It will spend lots of time on a new system so that patient and care-givers are bored to do that. They need a system which is easy to operate. And then, the system and device must have enough humanity reliability and durable structure. Because patient and care-givers don't to want to spend extra energy on the system stability and maintenance. Furthermore, patients and care-givers desire a clearly simple structure environmental control system. Because it is possible that patient and care-givers don't have the sufficient knowledge of machinery and electrical equipment. They are not accustomed to do mounting or adjustment for themselves/the patients. There are a mount of people who are anxious about that.

Serious disabled patient such as ALS patient has another problem. This muscle disease is a progressive disease. ALS patient loses muscle ability step by step. And they would not be able to operate the old version device when the symptoms progress. An adaptation functions environmental control system is expected by Patient and care-givers. The system could fit the symptoms progress clearly and simply.

Caring environment problem is also an issue of environmental control system in this current period. Normally, a serious patient has to use a lot of medical equipment such as artificial respirator, aspirator, disinfection equipment, etc. Large size medical equipment and amount of wired cables will be a nuisance to serious disabled patient and care-givers. A small and convenient device system with the wireless surrounding for caring is expected. It will be easy to operate by a small size device and reduce the stumbling accident when caring.

High cost of purchase is a significant problem about input device. Serious disabled patient and their care-givers don't know which the best choice is for themselves. They must do a high price payment for lots of input device to try which is the best choice for the patient in this current. It spend not only money but also time to evaluate which is the most suitable one.

Most of electrical appliances have infrared remote control system, however, some of them do not have that function. Patients supposed to control them by environmental control system, which is a new problem.

In the area of image processing input device, the traditional algorithm Normalized Correlation Coefficient (NCC) has low robustness against brightness changing and noise object in the detection area. As an untouchable input device, robustness for long time using is a significant evaluation criteria. To develop and applicate a more stable algorithm is necessary.

The electric wheelchair is an effective machine for people with lower limb disability. Normally, the user controls the wheelchair by a joystick that helps the user to navigate the wheelchair along the desired path. However, only wheelchair controlling is not enough for patient with serious disabilities to improve quality of their life. They require to operate electrical appliances and computer also by the joystick, for the independent life.

1.5 Research purpose

Considering the problems related to the current environmental systems, the purposes of this research are as following.

1) One research purpose is to develop an environmental control system to employ a tablet computer using wireless signal transmission network. A feature to the employment of tablet environmental control system is a flexible and smart system for serious disabled patient. The tablet based environmental control system is easy to move monitor location with different postures of patient, for his/her various daily requirement. Another feature of wireless signal transmission, position of patients and devices are able to be moved freely. And another advantage is that the system price is lower than desktop computer device.

2) The second purpose of this research is to propose an effective and user friendly input device for ALS patient with remaining physical ability on her/his fingers. Already many kinds of input devices are commercially available. However, patients require friendly input devices. In some cases the patient couldn't use the commercial input devices. The input devices often requires singular design considering her/his remaining physical ability of the patient. In this research several input devices are prototyped and evaluated through the experiments by different serious ALS patients under bed-ridden status.

3) The third purpose of this research is to propose a high robustness image processing algorithm which is used for environmental control system. The image processing technique are admitted powerful tool by using the computer. However, the cost and compactness of the computer system have been not acceptable for the environmental control system. But, recent advancement of the computer technologies enable to build the environmental control system with satisfying performances. The employed algorithm in this research is an image processing method named orientation code matching (OCM). The technique is also employed a multiple pattern image technique. Using these two techniques, it has high robustness than the conventional algorithm when detecting a declining object or operating a distortion image data.

4) The fourth purpose of this research is to propose a joystick controller

which is used for environmental control system by lower limb disability on the wheelchairs. The joystick could be used as an input device in an environmental control system. By modifying the joystick controller on the wheelchair, patient could operate computer and electrical appliances with just one joystick.

1.6 Structure of this paper

This thesis consists of five chapters. And the summary of each chapter will be introduced as following:

In chapter 1, the situation of the disabled people is introduced. Because the number of people with serious disabilities grows up, the nursing for disabled people will be more important. Looking after a disabled people with less involvement of the care-givers becomes a problem which should be solved immediately.

Two famous diseases which have been the causes of physical disabilities are introduced. In order to improve the daily lives of these patients, environmental control system is purposed and developed. This thesis shows some examples of environmental control system and input devices for people with disabilities that are used until now. This thesis then discusses the nursing drawbacks of environmental control system. To solve these drawbacks, the purpose of this thesis is expressed.

In chapter 2, an environmental control system with tablet and blue tooth is developed. Firstly, the configuration of this environmental control system is designed. The details of the environmental control system consists of four parts, the tablet, input devices, infrared controller and bed controller. Secondly, in order to evaluate different input devices for this environmental control system, some evaluation tests about different input devices are achieved by ALS patient. At last, disabled patient comment the different types input devices based on the evaluation results.

In chapter 3, a vision-based interface for spinal cord injury patient is introduced. The thesis discusses the reason why the spinal cord injury need this image processing interface. And the configuration of the vision-based interface is described. For high robustness, an algorithm of image processing is proposed. A comparative experiments for comparing new algorithm with conventional algorithm are implemented. The results are evaluated and discussed.

In Chapter 4, a joystick controller is introduced, which enables the user on the wheelchair to operate the computer settled on a nearby table. The joystick controller could be achieved by mounting the sensor unit on the joystick without any modification of the conventional wheelchair controller. The principle of the sensing unit is to measure the inclination angle and the direction of the joystick with an acceleration and gyro sensor. Then the sensing unit sends the control data to the computer via an infrared or wireless signal. This proposal is based on a requests done by the wheelchair users.

In chapter 5, a sEMG-driven Musculoskeletal Model to Control Exoskeleton Robot which is used in Lower ExtremityRehabilitation is studied. This control framework could make exoskeleton offer assistance to patients during rehabilitation by guiding motions on correct training, rehabilitation trajectories, or give force support to be able to perform certain motions.

In chapter 6, the conclusions and future of this thesis are described. This concluding section consists of four parts.

In the first part of the conclusion, input device component of environmental control system is evaluated from the standpoint of feasibility, sensibility and reliability. It is proved that a sheet type input device with pressure was highly preferred by the ALS patients and care-givers. Due to the original shape of the proposed device, care-givers praised its usability since it was easy to mount them.

In the second part of the conclusion, a vision-based interface for seriously disabled patient is summarized. A comparison test between two algorithms for this vision-based interface is achieved. The OCM algorithm has high robustness feature which is proved. This OCM algorithm had an outstanding performance on the tilt imaging processing and covered object detecting.

In the third part of the conclusion, a joystick controller system to operate the computer is summarized. One distinguishable feature of the system is that the system is mounted on the wheelchair joystick not requiring additional equipment. It is important to note, since the joystick of the wheelchair is familiar to the user, the joystick of the wheelchair can be a friendly and a proper computer interface for the user with physical disability.

In the last part of the conclusion, a control system framework based on Neuro-Musculo-Skeletal model is summarized. A sEMG is adopted as an indicator of subject’s voluntary intention in the system. Therefore, it is an intuitive interactive interface between the exoskeleton and operator.

Compared to the traditional control by way of an external device, intuitive interface can reduce operator's mental load.

Chapter 2 Environmental Control System for ALS Patient Using Finger Movement

2.1 Introduction

Amyotrophic lateral sclerosis (ALS) is a well-known disease because of the worldwide ice bucket challenge. The challenge highlighted the needs to continue the research and social supports for ALS patient. In japan around 8,000 people have this disease and 30,000 in the USA. The ALS is a progressive and devastating neurodegenerative disease, which affects motoneurons in the cerebral cortex, brainstem and spinal cord leading to paralysis and death.

Patients who suffer from ALS require constant attention from a nurse. A typical ALS patient can be observed in **Fig. 2.1**, where all his intentional muscular abilities are limited only to slight head movements, fingers movements and eye movements. It may happen that in less than a year his breathing ability will deteriorate and will need an artificial respirator. Until now patient daily lives are dependent on family and care-givers. Therefore, relationships of the ALS patients with society are extremely limited.

Fig. 2.1 ALS patient

In order to assist their daily lives and give them more independency, scientific technologies were introduced. *Communication devices were developed to substitute patient's vocal communication by using sensors and computers* [21]. For example, *communication devices that use acceleration* *sensors and also image processing were developed for ALS patient* [22]. Also *environmental control systems to enable the patient to control electric appliances were developed* [23]. Due to these developments, *every ALS patient with serious physical disabilities could enjoy the TV and internet using his remaining physical abilities by himself* [24]. *As everyone notices the scientific technologies are developing, therefore devices to assist ALS patients should be developed* [25]. One remarkable development in our lives is the mobile devices which are widely used in various fields. Communication using compact touchpads and mobile phones is available in every place and anytime. *These mobile devices have various potential abilities in the field of assisting devices for patient with serious disabilities like ALS patient* [26].

In this chapter an environmental control system using an android tablet is proposed. A distinguished feature of the system is that the tablet and controlled devices are connected wirelessly. Therefore, the system could be compact and available under various nursing environment. Also various input devices operated by slight finger movement are focused in this paper. Already various input devices were proposed based on image sensor, acceleration sensor, touch sensor, etc. An important aspect of the input device is that it should be introduced based on the patient physical condition. The devices proposed in this paper are designed to be comfortable, stable and wearable. Applicability of the tablet system and the input devices were evaluated by ALS patients.

2.2 Configuration of environmental control system

The proposed control system that employs the tablet as a main controller is shown in **Fig. 2.2**. The tablet is connected to two controllers via Bluetooth. The first one is an input controller, which receives the signal from the input device. The second one is an infrared controller for the home appliances such as Room-light, TV, Air-conditioner and so on. It should be noticed that the infrared controller includes an original bed remote controller. Additionally the tablet is connected to the telephone network, so the patient can make phone calls to his relatives or the hospital. The user is supposed to operate the tablet by using his slight finger movements.

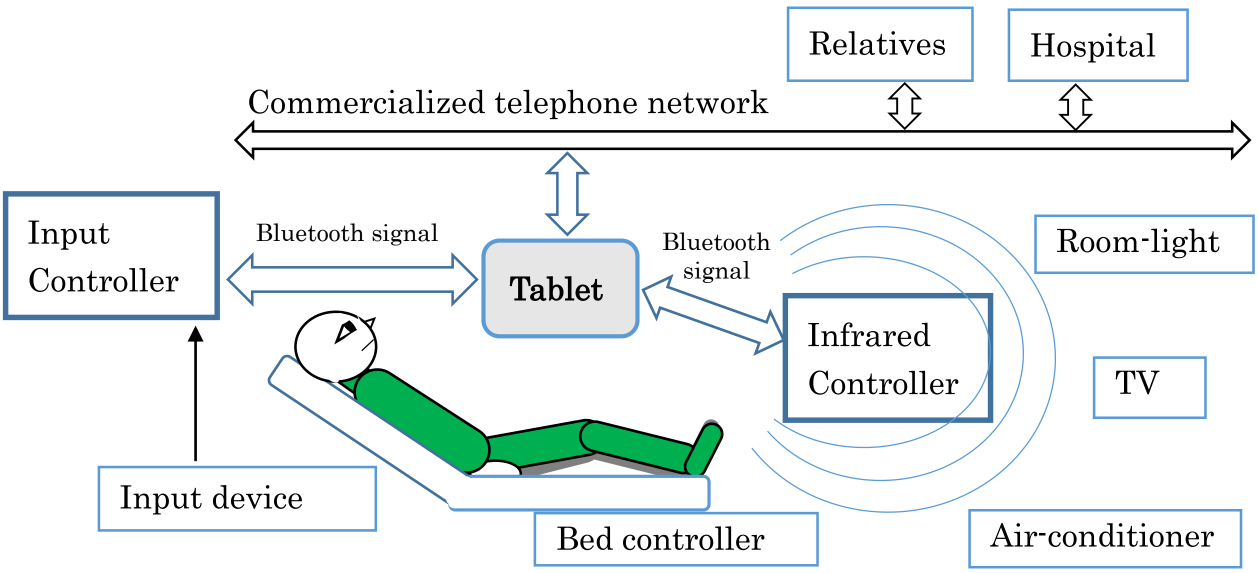


Fig. 2.2 System configuration with wireless network

In the following sections each of these are explained in detail.

2.2.1 Tablet computer

Fig. 2.3 Application screen for supporting ALS patient

The tablet main function is to serve as a visual interface for the ALS patient. In this tablet the developed android application program is executed, the application screen is shown in **Fig. 2.3**. On the left side of the screen the main menu is listed, and on the right side, the sub-menu items are listed. The patient selects the desired menu or sub menu through an input device. Depending on the selected menu or sub menu the patient can make phone calls through the Wi-fi internet to relatives or hospital; or control the home appliances that have functions controlled by infrared signal. In addition to the home appliances, the tilt angle and height of the bed can be changed by the infrared controller.

The selection method is as follows:

On the tablet screen, menu item or sub-menu item is highlighted sequentially one by one.

In case, the desired menu item or sub-menu item is highlighted the user activates the input device.

The desired menu item is selected and corresponding application program starts.

Relation between main menu and sub menu is explained in **Fig. 2.4**.

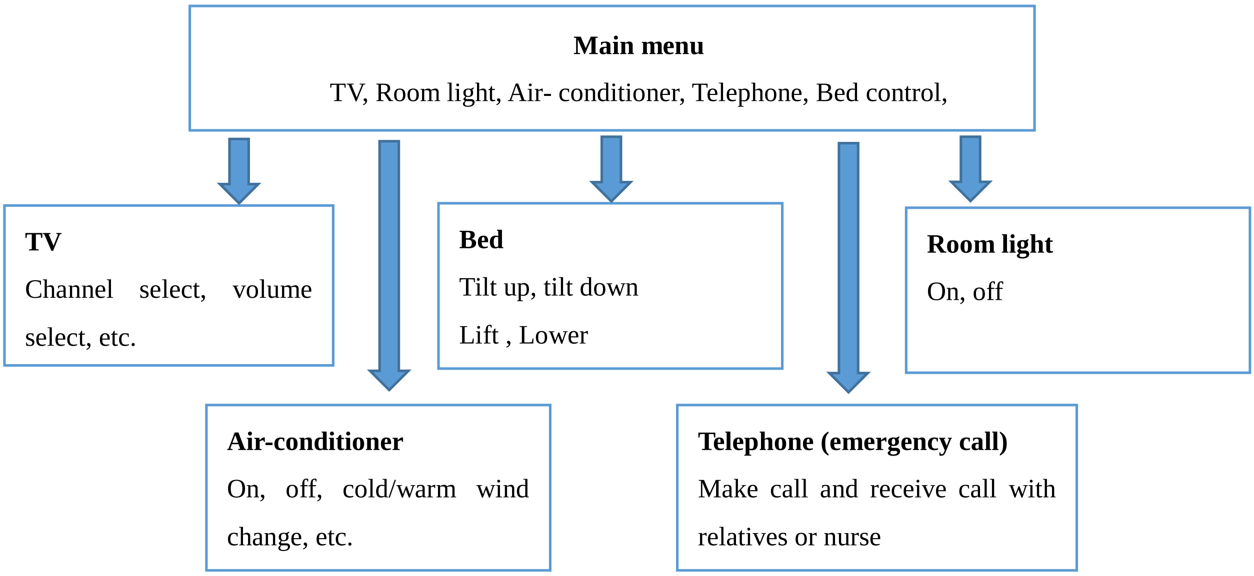


Fig. 2.4 Relation between main menu and sub menu

2.2.2 Input device based on pressure and touch sensor

As a human interface for ALS patient input devices are essential to live independent and well life. In this paper, a slight finger movement is focused as effective input signals. The controller obtain the signal from input device and send the data to tablet through Bluetooth. **Fig. 2.5** shows the input device controller.

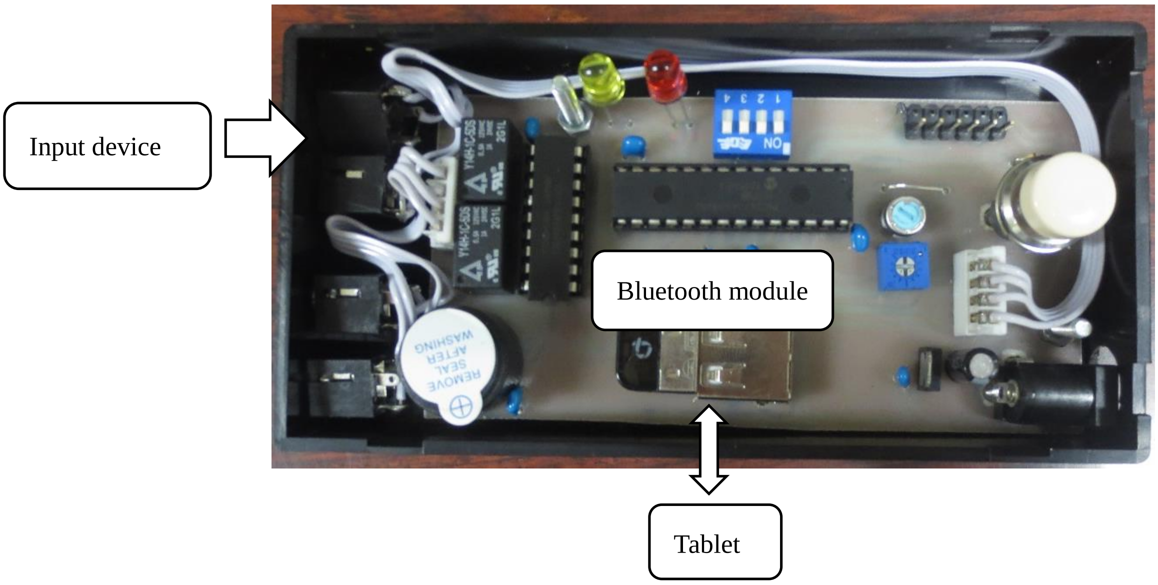


Fig. 2.5 Developed input controller

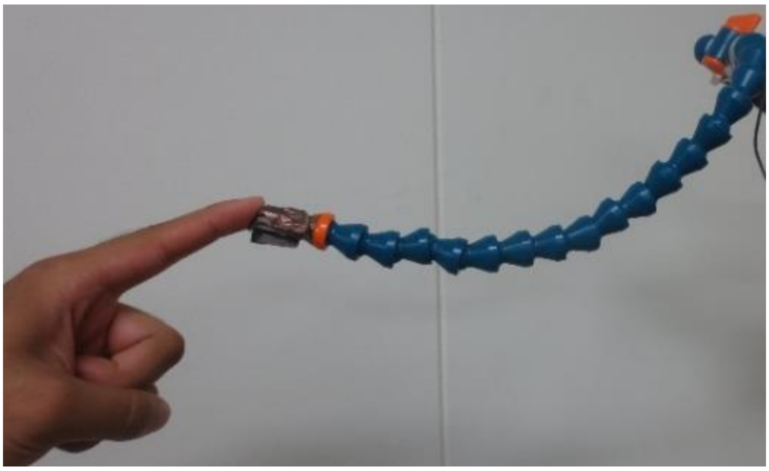
In this paper input devices to detect slight finger movements of ALS patients are considered. In **Fig. 2.6** three type of input devices (touch switch, mouse switch and push button) are shown. This touch switch is activated by a slight touch of the human body using static electricity. Currently many of the ALS patient use these techniques.

In **Fig. 2.6** (a) an ALS touches the tip of the sensor. Then, the output signal of the touch sensor is activated

In **Fig. 2.6** (b) an ALS patient clicks the mouse button with his index finger. A problem for him and the care-giver is that his fingers and the mouse needs to be properly arranged with accuracy. This arrangement task is annoying for the care-giver.

In **Fig. 2.6** (c), an ALS patient is pushing the button. Also the arrangement is an annoying task.

In addition, both ALS patients feel that pushing the click button is becoming hard. Therefore, care-givers are seeking for alternative methods.



(a) Switch to use touch sensor

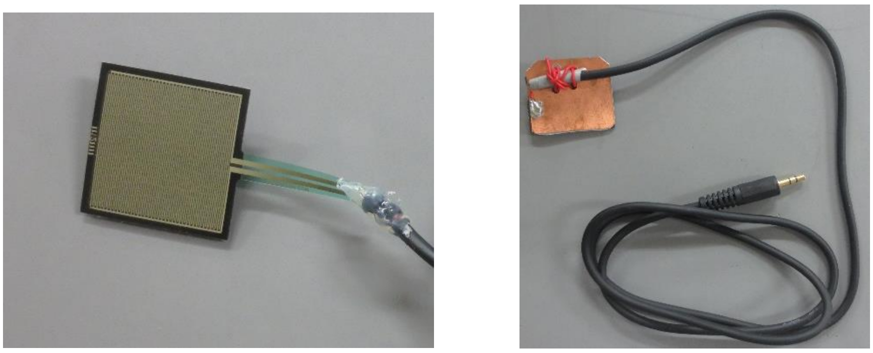
(b) Switch to use computer mouse

(c) Switch to use push button

Fig. 2.6 Current input methods for ALS patient

Alternative devices to detect slight finger movement are considered and various types of input devices are designed considering the stable and reliable switching by the user and easy setup for the care-givers as shown in **Fig. 2.8-Fig. 2.10**

In these devices, pressure sensor (Interlink Electronics model FSR 406) and touch sensor are used. In **Fig. 2.7**, the pressure sensor and electrode of touch sensor which are used in our devices are shown.



(a) Pressure sensor (b) Electrode of touch sensor

Fig. 2.7 Two type sensors

A feature of the grip type input devices is its easiness to wear on the hand. The input devices (a), (b) uses pressure sensors. The input device (a) has a simple bar-type. And the input device (b) is hand shaped so that this device can fit in the palm of the hand. The input device(c) uses touch sensor is activated by a slight touch of the fingers.

(a)Grip type device1 (b) Grip type device 2 (c) Grip type device 3

Fig. 2.8 Grip type input device

Fig. 2.9 shows box type input device. The user locates his hand on the box type input device so the user can push or touch the sensor by his slight finger movement. The front side of the box pressure sensor or touch sensor should be settled based on the physical ability of the ALS patient. By shaping the box, the locating task can be easier for the care-givers.

Fig. 2.9 Box type input device

Fig. 2.10 shows the sheet type input device. The pressure sensor is placed on the square board over a wide board. By introducing this convex shape, the user can feel the position of the sensor by his hand. A feature of this device is that the user doesn't need to wear it. The care-giver can move the sensor conveniently according to the user's hand position.

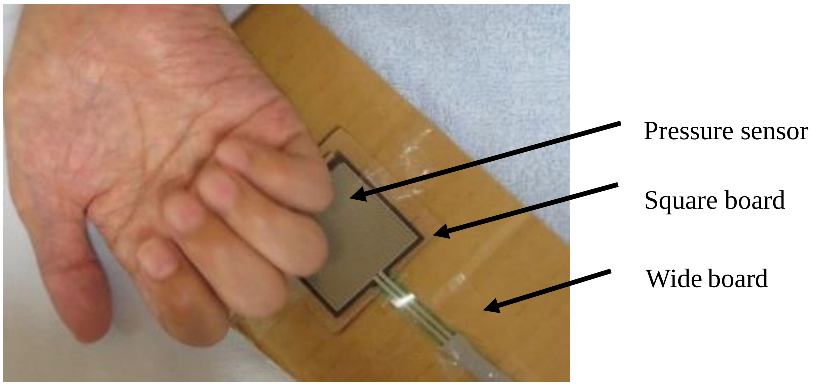


Fig. 2.10 Sheet type input device

2.2.3 Infrared controller

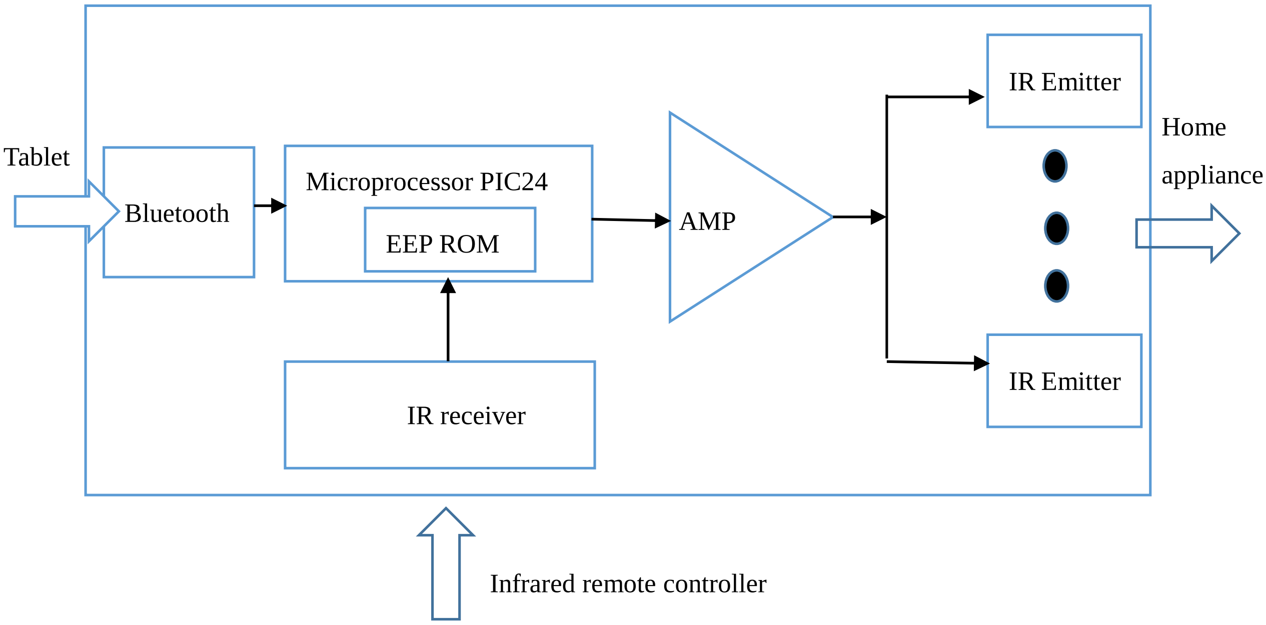


Fig. 2.11 Developed infrared controller

In order to control the home appliances, an Infrared controller is developed. This controller receives commands from the tablet through the Bluetooth and emits the corresponding infrared signal to the home appliance. The infrared controller is composed as shown in **Fig. 2.11**. The infrared controller is available for various types of home appliances since the controller has the function to learn the signal from the remote controller. The acquired data are stored in EEP ROM on the microprocessor (PIC24).

In **Fig. 2.12**, the photo of the infrared controller is shown. This controller employs ten infrared emitters.

Fig. 2.12 Developed infrared controller in a bear shape bottle

2.2.4 Bed controller

ALS patients often spend most of their time on the bed. They want change their body position and posture by themselves. The bed remote controller which is already prepared is difficult to operate by slight finger movement of ALS patients. Therefore a mechanical switching device is proposed as shown in **Fig. 2.13** and **Fig. 2.14**.

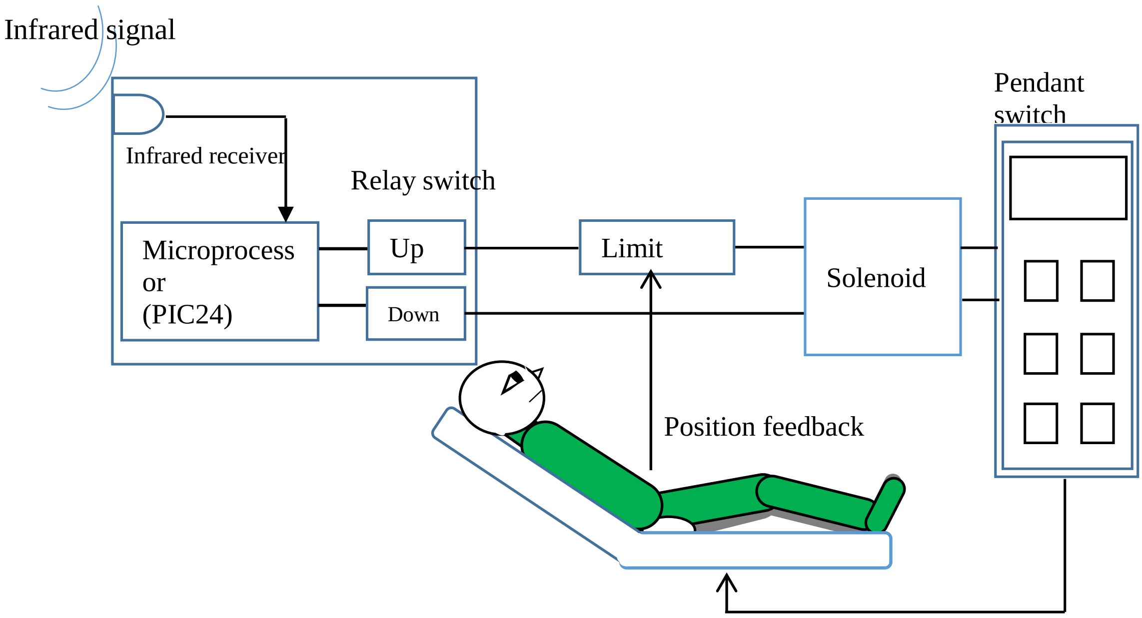


Fig. 2.13 Bed controller

Fig. 2.13 shows the structure of the bed remote contro ller. The microprocessor (PIC24) receives the commands from the infrared controller and activates the corresponding relay switch. The relay switches physically push the corresponding lever on the remote controller through the solenoid as shown in **Fig. 2.14**. In this figure, four solenoids are mounted. Two solenoids control the tilt angle of the bed. And the other two solenoids change the height of the bed. For safety reasons, a limit switch is employed to limit the tilt angle of the bed up to 45 degree.

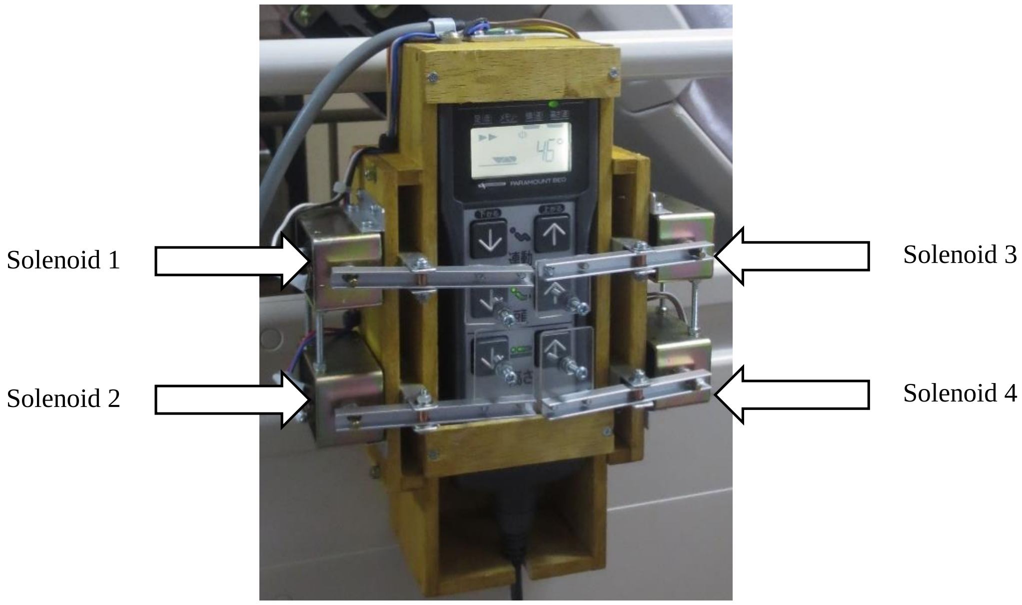


Fig. 2.14 Pendant switch with solenoids

2.3 Evaluation by ALS patient

Four ALS patients evaluated the proposed input devices. All of them have difficulty for computer input task. Also adjustment of input device position is a problem for care-givers. In Table 2.1, patients' background, medical history and problems in their daily life are explained.

Table 2.1 Features about ALS patients

Patient(age)	Medical history	Symptom	Conventional control methods and problem
A(45 age)	Diagnosed in 2010	His physical abilities are slight movements of the index finger. The patient could not pronounce a word. The patient is under bed-ridden status.	Patient uses the index finger to push the mouse button for clicking (**Fig. 2.6**b). Care givers have difficulties to adjust the fingers and mouse position adequately.
B(64 age)	Diagnosed in 2013	His physical abilities are right hand finger and wrist movement. The patient could pronounce words with some difficulty.	Patient can use the mouse with some difficulty. The patient symptom is becoming serious and requires environmental control system and input devices.
C(48 age)	Diagnosed in 2012	He can stand and walk with some difficulty. He can moves his hands slightly. The patient could not pronounce a word.	He operates a smart phone to communicate with others using slight finger movements. But the symptom is becoming serious. He requires an input device for computer.
D(72 age)	Diagnosed in 2009	The patient can move her finger slightly. The patient could not pronounce a word. The patient is under bed-ridden status.	She uses the index and middle fingers to push the button (**Fig. 2.6**c). But the task requires lot of concentration and physical strength.

All of them were requested to evaluate the effectiveness of the proposed input devices. And the following comments were obtained.

- Comment about grip type input device:

Patients C could operate this input device without difficulty. Other patients could not operate this input device with stability.

But care giver said the setting task on the hand is easy. This input device is effective for certain kind of ALS patients.

- Comment about Sheet type input device

Patient A, B, C were satisfied with the usability of this input device. Comparing the two versions of this device one with the pressure sensor and the other with the touch sensor, the pressure sensor was friendlier since the touch sensor was too sensitive. Patient B was satisfied because wearing the sensor on the hand was annoying for him.

- Comment about box type input device

Patient A, C and D were satisfied with the functionality of this input device. Patient B could move his hand position on the bed but he could not lift his hand to an adequate position on the box. Therefore, he preferred the sheet type input device.

- Comment about input device with touch sensor

Input device with touch sensor had high sensitivity. Therefore, users don't require strength on the finger and hand. This feature was important for the patient with serious physical disabilities. Patient A and C in the near future will have difficulties to move the fingers. In that situation the touch will become handily for them.

- Comment about input device with pressure sensor

It is important to note that sensing abilities on the body and fingers remains in ALS patient. When people operated the switch, they wanted to feel the switch action. The input device with pressure sensor is less sensitive to the finger movement. This feature is preferable to the user since he can feel the position of the switch before activation. All patients were satisfied with this feature and especially patient B.

The proposed environmental control system to use tablet was tested by the ALS patient B for three weeks as shown in **Fig. 2.15**. The patient uses the grip type input device to communicate with his family through a laptop which is connected to the tablet. He and his family were satisfied with its functionality. Especially they were impressed with the telephone function to call the nurse and also with the TV control functions. Due to these functions his wife was grateful with the system, and she could sleep soundly in the night.

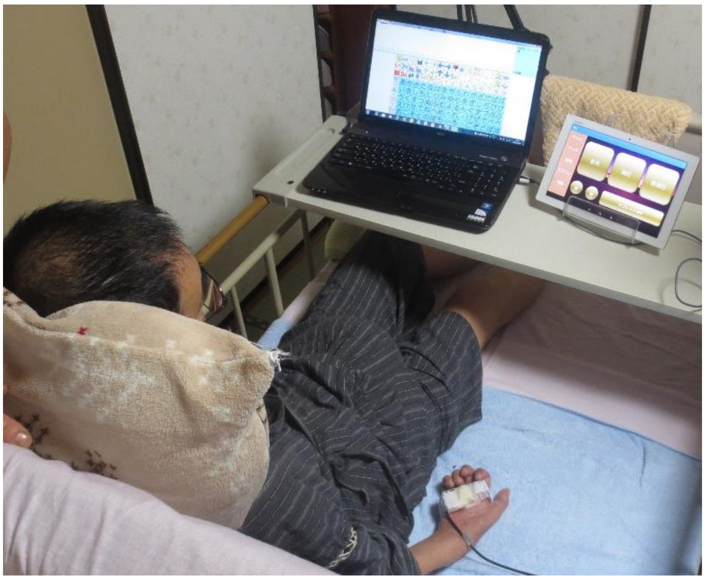


Fig. 2.15 Implemented environmental control system for an ALS patient

Chapter 3 Vision-Based Displacement Sensor for People with Serious Spinal Cord Injury

3.1 Introduction

Spinal injuries occur due to accidents, such as traffic accidents, accidental falls both on the job, at home and during sports activities. The resulting level of disability varies with the location and severity of the injury. The resulting injuries may be broadly categorized into losing functionality of the legs, requiring use of a wheelchair to loss of all limbs limiting the patent to being confined to a bed. The loss of functionality of limbs often includes loss of sensation in the limbs. Finally, in the extreme situation a person's ability to breath may fail requiring an artificial respirator, in this situation the person's ability to speak becomes very difficult.

Features of symptoms caused by spinal cord injury are listed as follows:

- Intellectual ability is typically not affected.
- If proper physical therapy is carried out the patient's condition may remain stable that is not deteriorate.
- As many such patients are young they will most likely live for a long time with the disability.
- In case of serious spinal cord injury on the neck ,remaining abilities are mostly limited to upper part from the neck.

Many kinds of supporting devices are commercially available. Using such devices some spinal cord injury patients can continue to enjoy sports, travelling and work. One such example was seen at the London marathon in 2012. Wearing an advanced exoskeleton suit a paraplegic woman succeeded to run the London marathon. Development of supporting devices is improving the quality of the lives of such patients.

However, the situation is more serious in the case of serious spinal cord injury patients. Their communication ability is very limited and they are restricted to living in a bed-ridden condition. Development of a communication device for such patients is essential.

Many supporting devices and communication devices are commercially available; some of these advanced devices use sensors, such as the device shown in **Fig. 3.1**.

Fig. 3.1 Input device using multiple sensors

The device is attached on the user's forehead. Head movements are detected using an acceleration sensor located in the device. Data detected by the sensor is used to position the cursor on a computer display. In addition, the input device has a function to detect the user's chewing action. The chewing action signals detected are used to click the computer mouse. The principle of operation to detect chewing actions is based on the technique developed for the chewing counter[25].

However, *optimizing and/ or customizing devices to match the remaining limited abilities of such patients is often difficult*[27].

To overcome this problem, displacement sensors based on video image processing, referred to as "vision-based displacement sensors" have recently been developed for patients with limited abilities such as spinal injuries.

For these serious disabilities, a convenient tracking of head or face movement by video camera provides an accurate measurement of changing facial features. However, robustness should be considered for input devices used by serious disabled. A conventional technique, multiple image tracking algorithm is applicable to the vision-based displacement system. In order to increase the robustness of the system we introduce orientation code matching (OCM) algorithm. A feature of the algorithm is that accuracy of the template matching can be increased even under the hazardous conditions.

The objective of this study is to improve the quality of the patient's life by using vision-based sensors. It is expected that these sensors could be effectively used to assist seriously disabled patients such as spinal injury patients in their daily lives. The structure of system is explained in the following section.

3.2 Configuration of the vision-based input device

The vision-based sensor system configuration considered in this study, as shown in **Fig. 3.2**, consists of a desktop computer connected to one web video camera with a telephoto lens, which can measure target's displacements correctly.

This sensor system is used as computer input device for the serious disabled patient where the cursor is positioned according to the lip position in the image. And opening action of the mouth is used to click the computer mouse.

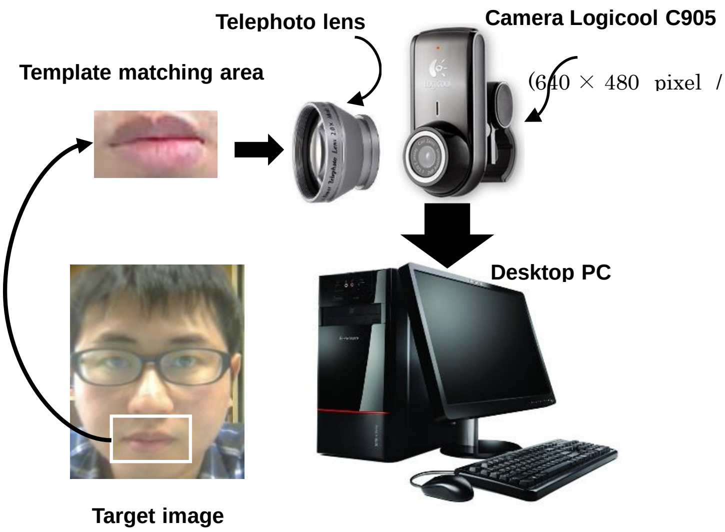


Fig. 3.2 Vision-based displacement sensor

The video images of a target on a face, such lips and eyeballs, captured by the camera are digitized into 640 × 480 pixel images in 8 bit scales and streamed into the computer with a maximum sampling rate of 60 frames per second. The primary advantage of this device is, it can be fixed in a location apart from the patient. As mentioned above this aspect of not-requiring external device to connect the device to the patient body as well as not-requiring wiring around the patient with spinal cord injury is significant.

3.3 Matching technique in vision-based interface

In the case of using image processing there are a number of essential aspects[28]. *For one thing it must be possible to detect head movement quickly and accurately even under poor lighting conditions or in the presence of extraneous light sources*[29]. For another it must be possible to detect the physical action of the mouth or eyes without any prior system training.

In order to achieve this function, the Normalized Correlation Coefficient (NCC) algorithm which talked in chapter 1 is used.

However, the features of images of the user's head vary with head movement and also angular variation. This fact reduces the accuracy of conventional pattern matching techniques.

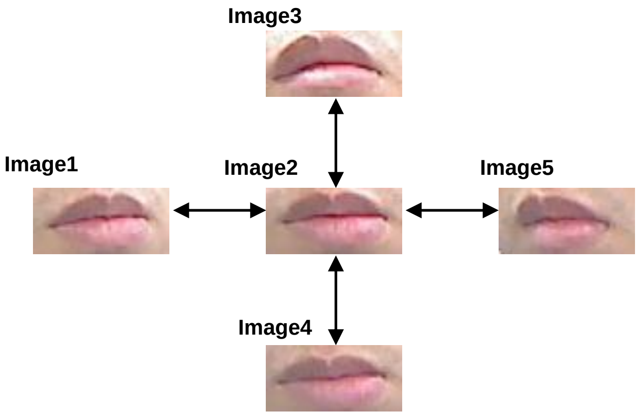


Fig. 3.3 Multiple pattern image processing

In order to achieve accurate tracking of the image using template matching, the captured image and the multiple template images which are prepared in advance must be similar. Suppose image 1 in **Fig. 3.3** is captured by the vision sensor and image 5 in **Fig. 3.3** is an image pattern prepared in advance. Since the similarity between these two images is insufficient, tracking accuracy of the mouth position may become unreliable and/ or fail[30]. This problem can be overcome by employing multiple pattern images captured under various head movement conditions. The captured image and the pre-prepared multiple pattern images are compared sequentially and the best matching image is selected. In this template matching technique the number of potential matching images must be kept to a minimum in order to increase the system speed as well as accuracy. This can be achieved by considering the continuity of the images during head movement. Suppose the captured image is well matched with image 5 in **Fig. 3.3** , the next captured image needs only to be compared with the neighboring pattern images 2, 3 and 4.

Furthermore this pattern matching technique can be applied to detect the mouth's opening and closing actions as well as eye opening and closing actions. By adding opening mouth images to the pattern images the neighboring relationships between the pattern images become as shown in **Fig. 3.4.** Based on the multiple template matching the current position of the mouth and the mouth status can be obtained. The transition from the image 6 to image in **Fig. 3.4** means the mouth is closed. This transition is designed to activate the switching of the mouse click button.

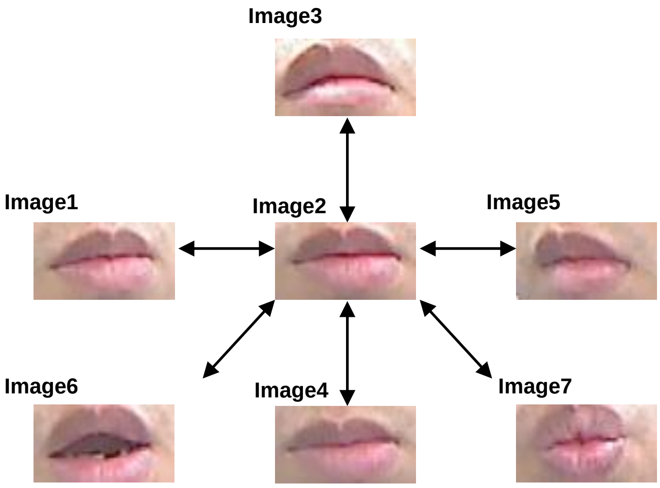


Fig. 3.4 Multiple pattern image processing with more patterns

3.4 Improvement for robustness: orientation code matching

The orientation code matching algorithm is based on the matching of the gradient information. It has the advantage of being robust to abnormal brightness variations such as highlighting or shadowing background. Around each pixel it computes using orientation codes, rather than gray levels directly. *Application of gradient information has been previously studied for finding texture orientation* [31] and *recognizing gestures* [32]. *Moreover a recent study by the project team has shown that the matching can be made robust by using only differences or tendencies of adjacent pixel brightness values rather than their actual values* [33], based on this, *the OCM algorithm was proposed and formulated* [34-36]. These merits are suitable for this vision-based sensor system for spinal injuries patients.

In the OCM scheme, orientation code representations for an object image from the captured images and the template are constructed from the corresponding gray images such that each pixel represents an orientation code that is obtained by quantizing the orientation angle at the corresponding pixel position in the gray image. The orientation angle refers to the steepest ascent orientation evaluated from the neighboring pixels, and measured with respect to the horizontal axis. The orientation codes thus obtained are a function of the texture and shape of the object and hence pivotally invariant to object translation and the effects of shading, background and illumination variations. The detail of the OCM technique is represented below.

Suppose an analog image is expressed by $I(x, y)$, the horizontal derivative is $\nabla I_x = \frac{\partial I}{\partial x}$ and vertical derivative is $\nabla I_y = \frac{\partial I}{\partial y}$. For the discrete version of the image, it is evaluated around a pixel position (i, j), then orientation angle $\theta_{i,j}$ is computed by using the tan^{-1} function as $\theta_{i,j} = tan^{-1}(\nabla I_y / \nabla I_x)$. Since the numerical value of tan^{-1} function is confined to $\left[\frac{-\pi}{2}, \frac{\pi}{2}\right]$, the practical orientation is determined after checking signs of the derivatives, thus making the range of θ to be $[0, 2\pi]$.

The orientation code is obtained by quantizing $\theta_{i,j}$ into N levels with a constant width Δ_θ. For precise detection of template instances, this width Δ_θ should be fixed upon as an adequate value. This should be considered in relation to the inherent amount of information and possible spatial resolution.

The orientation code of each pixel is defined by the following equations:

$$c_{i,j} = \begin{cases} \left[\dfrac{\theta_{i,j}}{\Delta_\theta}\right] & : \quad |\nabla I_x| + |\nabla I_y| > \Gamma \\ N = \dfrac{2\pi}{\Delta_\theta} & : \quad |\nabla I_x| + |\nabla I_y| \le \Gamma \end{cases} \qquad \text{(ii)}$$

If there are $N(=2\pi / \Delta_\theta)$ orientation codes then $C_{i,j}$ ranges in value from 0 to N. N is the quantization level of direction. In this paper, N is set to 16 typically as shown in **Fig. 3.5**, and in this case $\Delta_\theta = \frac{\pi}{8}$ where Γ is the threshold level for the suppressing of small gradient pixel. The purpose of using Γ is to prevent uniform or semi-uniform regions from influencing the error evaluation as the pixels in low contrast areas are more sensitive to noise.

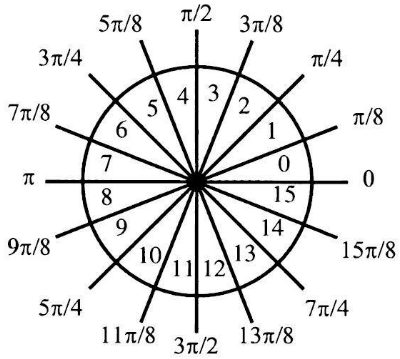


Fig. 3.5 Orientation codes (N = 16)

A dissimilarity measured based on the definition of orientation codes is designed to evaluate the difference between any two images of the same size. The best match is determined between orientation code images of the template T and any object image I from the same scene. This is defined by the following equation:

$$D = \frac{1}{M} \sum_{I_{m,n}} d\left(O_{I_{m,n}}(i, j), O_T(i, j)\right) \qquad \text{(iii)}$$

where $O_{I_{m,n}}$ and O_T are the orientation code images of the sub image and the template respectively, M is the size of the template, (m, n) shows the position of the sub image in the scene, and $d\left(O_{I_{m,n}}(i, j), O_T(i, j)\right)$ is the error function based on an absolute difference criterion.

$$d(a,b) = \begin{cases} \min\{|a-b|, N-|a-b|\} & if \quad a \neq N \cap b \neq N \\ \dfrac{N}{4} & if \quad a \neq N \cap b = N \\ 0 & otherwise \end{cases} \qquad \text{(iv)}$$

When a comparison is performed between a pixel having an orientation code evaluation given by the $\tan^{-1}$ function and the one whose code was set to N due to low contrast, the error cannot be computed by finding the difference. In order to avoid such an inconsistent comparison, we need to assign a reasonable value to the error function corresponding to such pixels. The assigned value should be such that it does not bias the dissimilarity evaluation for the sub image. For such cases, we assigned the value of $\frac{N}{4}$ as an error function. This is the error value which is expected when these two pixels have no relation between each other. A large value of N is helpful for discriminating such incompatible comparisons.

Since the orientation codes are cyclic in nature, the absolute difference is not used directly for computing the error function, rather the minimum distance between the two codes is determined. For example, in Figure 4, the code 0 is only one unit difference away from the code 15, whereas their simple difference yields 15. Such evaluation makes the matching stable against minor position variations of the object, regardless of the direction of the movement. As a consequence of this cyclic property of orientation codes, the maximum distance between any two codes is never more than $\frac{N}{2}$.

Finally, the similarity ratio s is derived as follows:

$$h = \frac{2}{NM} \sum_{I_{m,n}} d\left(O_{I_{m,n}}(i,j), O_T(i,j)\right) \qquad (0 \le h \le 1) \quad \text{(v)}$$

$$s = 1 - h \qquad (0 \le s \le 1) \quad \text{(vi)}$$

where h is the discrimination ratio obtained by dividing the average absolute difference D by the maximum of absolute difference $\frac{N}{2}$. s is the similarity ratio. To find the best matched point, at which the similarity reaches the maximum value, the template image must be compared with the entire target frame pixel by pixel. This is obviously time consuming. In order to significantly reduce the computational time, a ROI window is defined based on the currently best-matched point, and the OCM processing is carried out only within this limited window.

3.5 Evaluation

The image sensor of camera is usually divided to two parts. One is CMOS (Complementary Metal Oxide Semiconductor Image Sensor), the other is CCD (Charge Coupled Device Image Sensor). CMOS is cheap and low power consumption, but weak at noise disturbance especially brightness changing. CCD is more expensive and complex than CMOS but low noise disturbance.

For these reason, this study uses CCD image sensor from Logicool in **Fig. 3.6.** Data sheet is shown in **Table 3.1**.

Fig. 3.6 BWC-30L01/SV

Table 3.1 Specific of BWC-30L01/SV

Interface	USB2.0
Picture element	1/4 inch CMOS
Resolution	Min 2 million pixels （1600×1200）
	Max 8 million pixels（3264×2448）
frame rate	Max 30 frame/s
Focal length	4.9mm
Focal range	50mm～infinity
PC Camera code length	1.5m
Size	W47×H90×D60mm
Weight	54g
Operating environment 20%～80%	Temperature 5℃～40℃、Humidity

In order to evaluate the effectiveness and stability of the proposed algorithm (OCM), a vision input device was tested employing current algorithm NCC and proposed algorithm OCM. In the experiment seven pattern images of the mouth were used as shown in **Fig. 3.4**. Image 6 in **Fig. 3.4** was captured at the instant of opening the mouth. Image 7 in **Fig. 3.4** was captured when the mouth was puckered. The neighboring relationship is shown by the arrows in **Fig. 3.4**. By using this template matching technique, two kinds of switching actions could be achieved as well as positioning of the computer cursor on the computer display. Image 6 was correlated to the left button on the computer mouse and image 7 was correlated to the right button. Using these functions, the user could operate the computer by head movement and mouth opening actions.

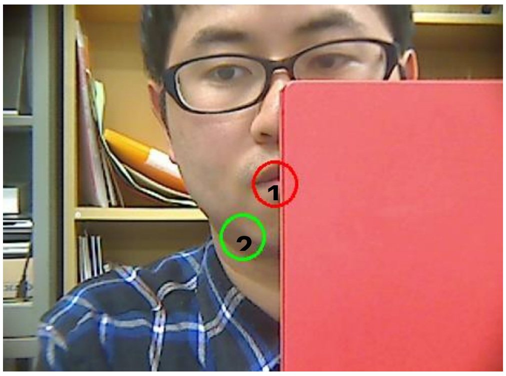


Fig. 3.7 Comparison of OCM, NCC feature matching algorithms

3.6 Robustness to the partially obscured image

At the first experiment the effectiveness of the OCM technique in dealing with the image which is partially obscured with some obstacles. **Fig. 3.7** shows that the OCM technique (circle 1) successfully detected the mouth, which is partially occluded by a board without any pattern on it. Conventional template matching techniques (normalized correlation coefficient algorithm) gives wrong position data of the mouth. The circle 2 in **Fig. 3.7** is the estimated position of the mouth obtained by NCC technique. These results are obtained by the features of the OCM algorithm. OCM algorithm compares captured image and template image focusing on the trend of orientation extracted at every pixel. Therefore, if the obscuring objects have some pattern with some strength, the OCM data will be affected. In this experiment since the obscuring object is simply gray colored, the OCM data are not affected.

3.7 Typing test

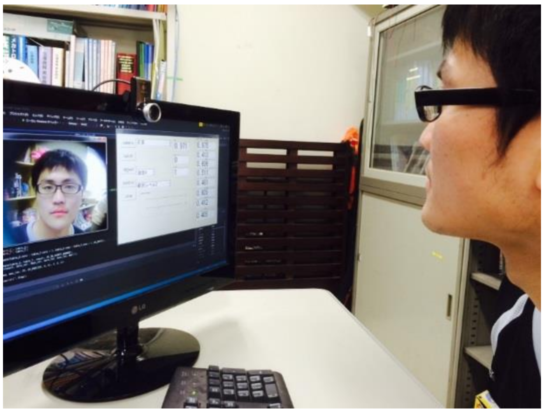


Fig. 3.8 Experiment environment

Using the proposed vision input device, experiments were conducted to write the text "good morning my friends" on the soft keyboard. The time required to complete this task by five users is shown in **Table 3.2**. This task requires 24 positioning actions and also 24 switching actions.

Table 3.2 Typing test data

Methods / Users	Conventional NCC algorithm (sec)				OCM algorithm (sec)			
	1st	2nd	3rd	Ave	1st	2nd	3rd	Ave
A	117	103	102	107.3	87	107	92	95.3
B	94	97	89	93.3	88	108	78	91.3
C	100	95	88	94.3	85	88	84	85.7
D	119	101	99	106.3	85	81	89	85
E	99	96	92	95.7	87	101	82	90
Average	105.8	98.4	94	99.4	86.4	97	85	89.5

From this test data, it is clear that the OCM algorithm users could write the text a little faster than the NCC algorithm users. While OCM algorithm requires longer processing time compared to the NCC algorithm, due to the robust feature of the OCM algorithm, the template matching test allowed users to control the cursor with better positioning accuracy with less mistakes.

3.8 Robustness comparison

In order to convince the robust feature of OCM algorithm, the trajectory tracking test of the mouse along the pre-specified rectangle by using NCC and

OCM algorithm was conducted. The mouse cursor was moved to follow a rectangle (512*384 pixels) starting at the left-lower corner and rotating counter clockwise. **Fig. 3.9** and **Fig. 3.10** show the result with these two different algorithms. Both results were satisfactory. **Fig. 3.11** and **Fig. 3.12** show other experiments where the user tilted his neck rightward with thirty degrees at the right-lower corner of the rectangle. The NCC algorithm could not track the rectangle as shown in **Fig. 3.11**. The NCC algorithm could not detect the position of the mouse correctly. And around the right upper corner of the rectangle the tracking task was aborted. Although, the OCM algorithm succeeded to trace the rectangle even under the condition that the user tilted his head thirty degrees during the tracking task.

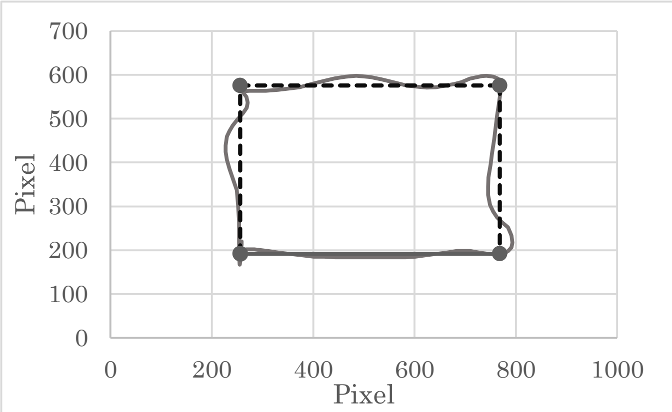


Fig. 3.9 Trajectory of mouse cursor by NCC algorithm

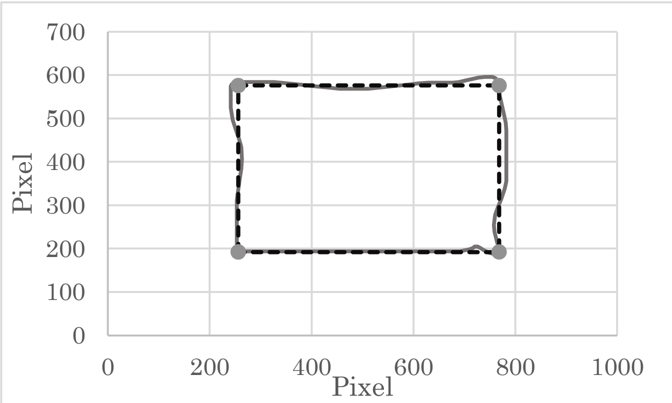


Fig. 3.10 Trajectory of mouse cursor by OCM algorithm

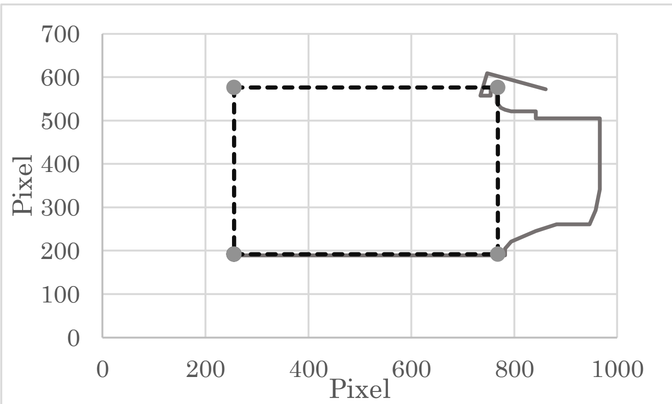


Fig. 3.11 Trajectory of mouse cursor by NCC algorithm with 30 degree misplacement

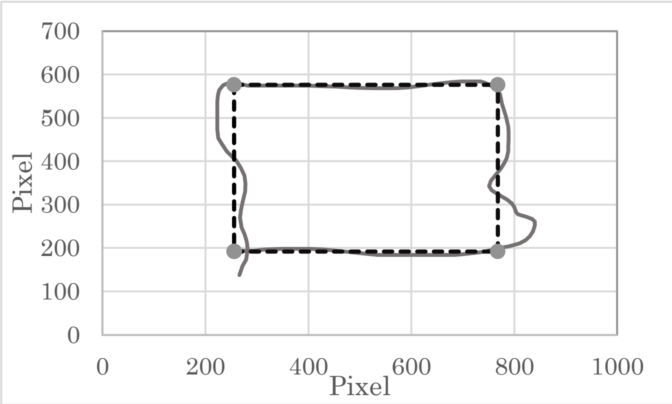


Fig. 3.12 Trajectory of mouse cursor by OCM algorithm with 30 degree misplacement

Chapter 4　Improvement of a Joystick Controller for Electric Wheelchair User

4.1 Introduction

For the people with lower limb disability many electric wheelchairs are commercialized and some of them use a joystick controller. The wheelchairs made their daily live independent and active. Users with upper limb disability often manipulate the joystick with their chin. *Some advanced wheelchairs can be operated without the use of joystick lever; instead, vital signals or brain signals enabled to control the electric wheelchair*[22],[27]. However, the joystick control is still admitted as practical and user friendly. It is important to notice that manipulation of the joystick can be recognized as a good physical training and also a mean to live an independent life. In **Fig. 4.1** an electric wheelchair user who suffered cerebral palsy is shown. While his four limbs are paralyzed, he operates the joystick with his chin and enjoys an active life with the wheelchair. In order to improve their quality of lives, assistive devices need to be developed. Such development is becoming easier and cost effective since the surrounding technologies are developing.

In this chapter a joystick controller for the wheelchair is proposed that enables the wheelchair user to operate the computer on the computer desk nearby. A distinguished feature is that the operation of the computer on the desk can be achieved by using the familiar joystick mounted on the wheelchair without any modification of the conventional electric wheelchair. Only mounting the sensing unit on the joystick is enough for the user to operate the computer.

As everyone knows, the computer is a convenient and useful device for people with physical disabilities. They often use computers as a communication device and also an environmental control device to control home appliances like the TV, air conditioner and so on.

People with physical disabilities often desire to use the computer under various conditions. The wheelchair user in **Fig. 4.1** who suffered cerebral palsy expected to operate the computer on the wheelchair without transferring to a computer desk. Every time he wants to operate the computer, he has to ask the care-giver to mount another joystick on the wheelchair. His desire was to be independent from care-givers.

Another wheelchair user with slight upper limb disability engaged in computer design wants to use a joystick to operate the computer. He tried to design graphics with various joystick without satisfactory results. Proper settlement of the joystick and also training with the new joystick are important. After several trials it became clear that the joystick on his wheelchair was an appropriate computer interface for his designing task, since he is already accustomed with this joystick in his daily life on the wheelchair.

For the wheelchair users that employ a joystick; the joystick is expected to be use as an interface with the computer. By modifying the joystick controller on the wheelchair, the computer operation with the same joystick can be achieved. However, modification of the joystick controller is not preferable from the standpoint of safety. Therefore, a unit which can be settled on the joystick to enable computer operation is proposed in this paper.

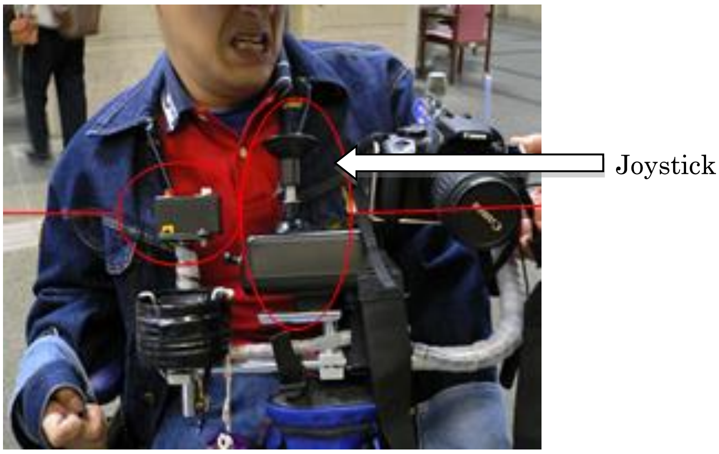


Fig. 4.1 Wheelchair user using a chin control device

4.2 Computer interface to use joystick on the wheelchair

4.2.1 System configuration of joystick controller

In order to enable the joystick controller on the wheelchair to work as a computer interface, a new joystick controller is proposed as shown in **Fig. 4.2**. The joystick sensing unit obtains the data related to the joystick like inclination angle and orientation.

The sensing unit is composed of an acceleration sensor, gyro sensor and microprocessor (PIC16F88). The data is converted to infrared signals and emitted from the wheelchair to an infrared signal receiver on the computer desk. The mouse controller moves the computer mouse on the monitor. Of course, the three buttons near the joystick are used to activate the click actions of the computer mouse.

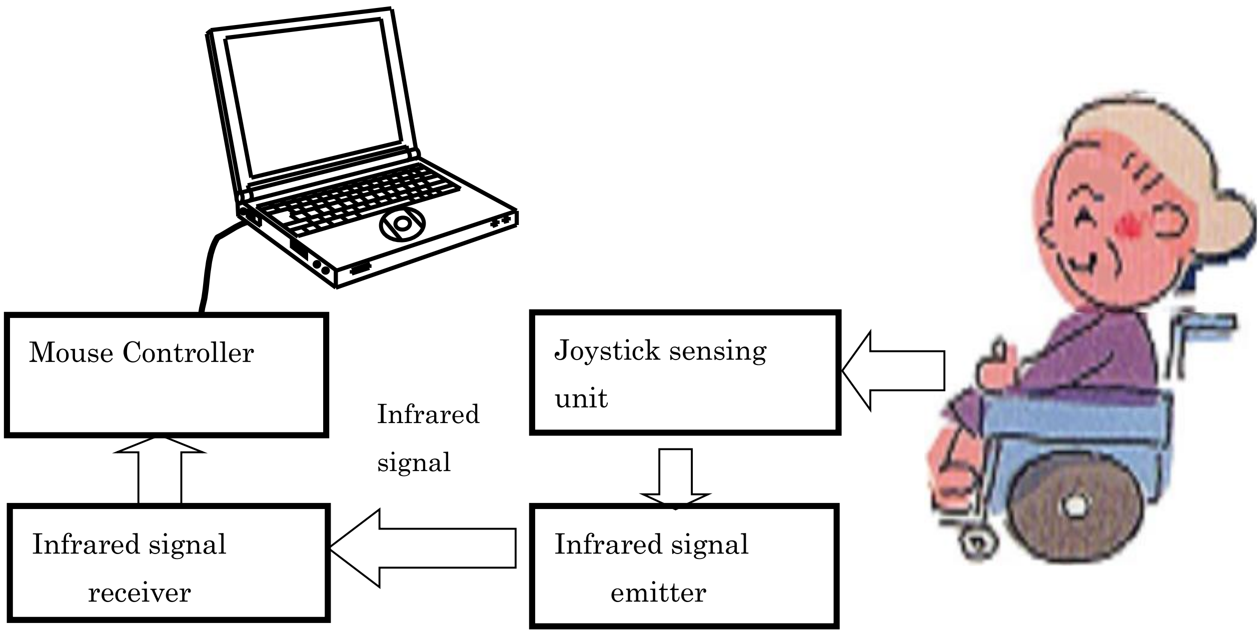


Fig. 4.2 System configuration

The joystick sensing unit is shown in **Fig. 4.3**. The inclination angle of the joystick can be obtained based on the principle of the detected data by the acceleration sensor. By introducing three-dimensional acceleration sensor, inclination angle and direction of the gravity can be obtained. It is important to note that the inclination angle and direction obtained are effected by the acceleration of the sensor. By incorporating the gyro-sensor, the inclination angle and direction of the joystick can be estimated by suppressing the effect of the acceleration.

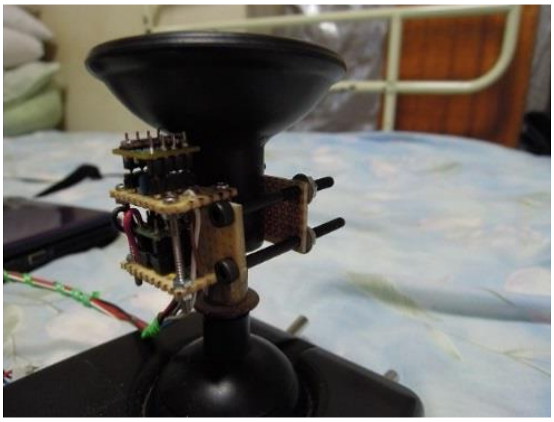


Fig. 4.3 Joystick with acceleration and gyro-sensor

The equation to estimate inclination angle θ k+1 at k sampling time is as follows [37]:

$$\theta_{k+1} = \theta_k - \omega\theta_k \triangle t + \omega\theta_{acc} \triangle t + \theta_{gyro} \triangle t \qquad \text{(vii)}$$

where ω is cutoff frequency, $\triangle t$ is sampling interval, θ_{acc} is data obtained by acceleration sensor, θ_{gyro} is data obtained by gyro sensor.

4.2.2 Experiments of the sensing unit

Experiments to evaluate the applicability of sensing unit were conducted as shown in **Fig. 4.4** .

Fig. 4.4 Experiment using proposed joystick controller

In the first experiment the effect of introducing the gyro-sensor is discussed. The acceleration data gather during the joystick operation by the user shown in **Fig. 4.1** was obtained as shown in **Fig. 4.5**. The dotted line shows the data obtained only by the acceleration sensor. The solid line shows estimated inclination angle compensated by equation (vii). The acceleration data reveal sudden standing up and falling down phenomena of the joystick. By incorporating the gyro-sensor data, the inclination curve was modified to a smooth curve.

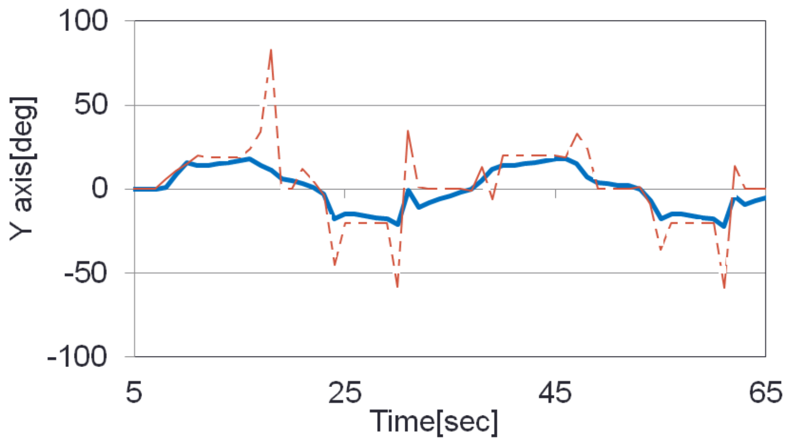


Fig. 4.5 Estimated inclination angle and acceleration data

In the second experiment the joystick was inclined to the maximum angle (18 degree) toward the right and rotated to make one circle. The data estimated is shown in **Fig. 4.6**. In this figure the inclination angle could be estimated with accuracy. Considering that some conventional wheelchairs can be operated with the on/off signal of the joystick, accuracy of this sensing unit is enough to navigate the wheelchair with the inclination angle and orientation data from the joystick.

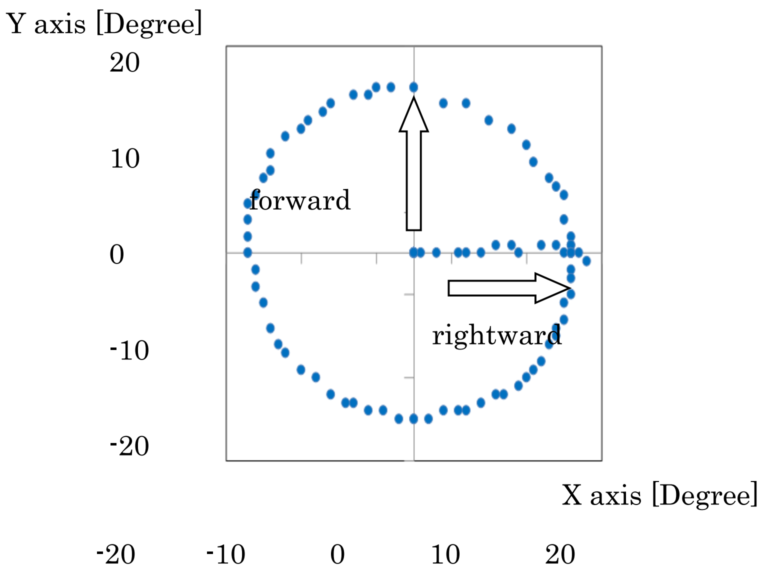


Fig. 4.6 Inclination data of joystick

In the third experiment the user was requested to move the computer cursor along the square trajectory (600×512 pixels) on the computer monitor. The results of this experiment is shown in **Fig. 4.7**, where the trajectory of the cursor is shown as a solid line. And the dotted line shows the target square trajectory.

The trajectory of the cursor shows some deviation from the target path in the right down part, but with a proper joystick operation by the user the trajectory returned to the target square trajectory.

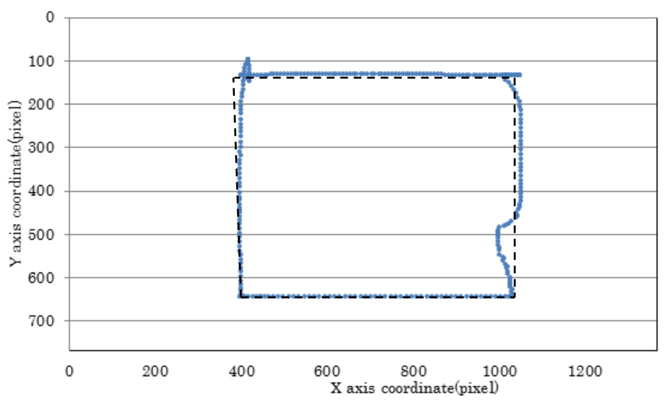


Fig. 4.7 Tracing test using the proposed joystick controller

Considering these experimental data, the mouse control speed and the direction are settled in proportion to the joystick movement. It should be noticed that the joystick is used as a computer interface while the wheelchair is not running.

The fourth experiment consisted of typing task to write a message by selecting alphabets letters on a screen keyboard three students without any physical disability and the user introduced in **Fig. 4.1** performed this experiment using their chin movement.

The message in Japanese was “konnnichiwa kyoumo genkidesu” meaning “Good morning. I am fine today”. All the examinees succeeded in this task in less than forty seconds as shown in **Table 4.1**. It is interesting to note that the wheelchair user who suffers cerebral palsy could finish this task with a short delay time respect to the others.

The performance of proposed joystick controller was compared with other computer input devices[21, 23, 38]. All these input devices controlled the computer cursor with the user’s head movement. Average time to select one alphabet letter were obtained from the same experiment, the results are shown in **Table 4.2**. The experimental conditions were controlled to be same. Average time to select one alphabet were obtained between 3.4 second and 5.4 second. The comparison means that these devices have not remarkable differences and that the proposed joystick controller is applicable as a computer input device.

Table 4.1 Required time for typing message

Examinee	A	B	C	D
Required time	38.8sec	34.8 sec	30.2sec	40.2 sec

Table 4.2 Average Time to select one Alpabet

Input Device	Proposed Joystick	Image processing Ref.[21]	Pillow type Ref.[23]	Face Mount Type Ref.[38]
Average time	4.5sec	3.9sec	5.4sec	3.4sec

4.2.3 Mechanical sensing unit of joystick

Sensing unit can is achieved by using mechanical switches. In **Fig. 4.8** a mechanical sensing unit of the joystick is shown. Eight limit-switches are arranged around the joystick. Based on the on/off signals of the eight limit switches the inclination and the orientation of the joystick can be detected.

As everyone notices, the resolution of this sensing unit is limited. But from feedbacks of the wheelchair user, he could use this device to operate the computer and also navigate the wheelchair.

Fig. 4.8 Joystick with eight limit-switches

Chapter 5 Application of Muscle Activity Signal

5.1 Introduction

With the rapid arrival of the aging society and the increase of physical movement disorder patients caused by various disease, the demand for occupational therapists has increased drastically. The traditional rehabilitation mainly relies on therapist's one-by-one rehabilitation therapy, obviously which is gradually not in conformity with the needs. In parallel to this situation, researchers have been using robotic technologies to develop many kinds of assistive and rehabilitative devices for people with disabilities or to develop medical devices used by caregivers. Our research team's core work is just to use robot technology to develop a intelligent rehabilitative training system that can be used to do lower limb gait rehabilitation for patients following a disease or a neurological condition. For this purpose, we develop an exoskeleton device that can be worn around human lower limb to offer assistance to patients during rehabilitation of the locomotor system .Its recovery principle is that robot drives patients to simulate normal subjects walking to complete the rehabilitation training mission under the control of control system

To date, this kind of rehabilitation has been developed for many rehabilitation purposes by other researchers and many of the clinical trials also verify they are valid. Among them, the lokomat exoskeleton is *an example of the early gait*[39, 40] trainer. Evidence based data shows that lokomat therapy can improve gait symmetry, walking ability, increases muscle strength and so on compared to conventional physical therapy in *stroke patients*[41, 42]. Moreover, there are many other exoskeletons besides LOKOMAT. They were generally divided into two categories: treadmill gait trainer and over-ground gait trainer. Other treadmill exoskeletons besides LOKOMAT have *LOPES*[43, 44], *ALEX*[45] , *ANDROS*[46] and so on .The developed over-ground gait trainers have *Hybrid Assistive Limb(HAL)*[47] from University of Tsukuba, *EXPOS from Sogang University*[48] and *Vanderbilt exoskeleton*[49].For these exoskeleton devices ,regardless of their different mechanical types, some common considerations must be paid on the design of their control system.

As a kind of *wearable robot*[50], the distinctive, specific and singular aspect of exoskeleton is its kinematic chain maps on to the human limb anatomy. Thus its controller design must be imposed strict requirements as regards safety, effectiveness and dependability. It must be designed as person-oriented device and is under the control of operators at all times. For control of the exoskeleton rehabilitation robot, Of course, a large number of control system have been proposed in earlier studies using various approaches, such as *machine learning, decoders, pattern recognition, and proportional control*[51, 52]. Except for proportional control, these control methods have two inherent drawbacks: (1) they only allow the subject to perform predetermined movements and (2) they limit the user's ability to control the magnitude of torque production. Alternatively, proportional myoelectric controllers use the subject's muscle activation to control the magnitude of joint torque for the powered device, which may be more beneficial in lower-limb control[53].But most of the previous work proposes complex mechanisms or systems of sensors. Meanwhile, many researchers also use the EMG directly to *generate machine control commands for robot*[54]. However, most of the previous works decode only finite lower limb postures from surface electromyography (sEMG) signals, which can cause many problems regarding smoothness of motion, especially in the cases where the robot performs everyday life tasks .Therefore, effective controller entails the necessity for continuous and smooth control. Besides, studies have shown that active involvement for operators in the production of a motor pattern results in *greater motor learning and retention than passive movement*[55-57].So in our system design, in order to make the patient actively participate in the task specific training, sEMG is adopted to decode intent of operator.

In the work, we construct a hybrid control scheme that combines the model-based control system and sensor-based control system. For the design of sensor-based control system, you can complete the design by referring to the design methods of control system of traditional robots. Therefore, the work mainly talk about the other sub-control system of model-based control system. In the system, Neuro-Musculo-Skeletal model is adopted. The sub-control system is an intuitive interactive interface between exoskeleton and operator. Compared to the traditional control by way of an external device, for example, a keypad or a wheel and so on that has to be manipulated, intuitive interface can reduce operator's mental load, that is, the operator can focus on fulfilling a task with the exoskeleton rather than focus on *mere* *control of the device*[58]. This chapter is organized as follows: Section 5.2 introduce an application of muscle activity signal. Section 5.3 provides a brief description of physiology of Neuro-Musculo-Skeletal and human motion control; Section 5.4 focus on the description about the control framework based on Neuro-Musculo-Skeletal model developed in the work.

5.2 Application of Muscle Activity Signal

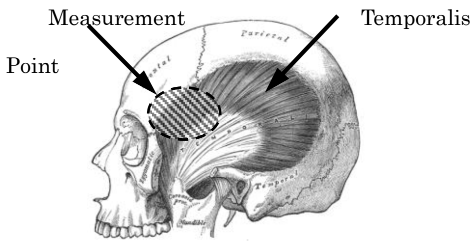


Fig. 5.1 Pressure sensor measurement point

The proposed device detects chewing action by measuring the activation of the temporal muscle which is one of the muscles used to actuate the jaw. The location of the temporal muscle is shown in **Fig. 5.1**. It can be located easily as while chewing the temporal muscle contracts resulting in a slight swelling near the temple. When relaxed, for example when the mouth is open the temple flattens. Thus the swelling of the temple is significant while chewing. Therefore, this chewing action can be detected by monitoring the level of swelling of the temporal muscle. In the proposed device, a capacitive pressure sensor is placed in direct contact with the temple and is fixed in place by a head band as shown in **Fig. 5.2**. This head band is adjusted with a Velcro fastener to provide the light level of tension required. **Fig. 5.3** shows the pressure sensor output where five chewing actions can be readily recognized from the seven second point.

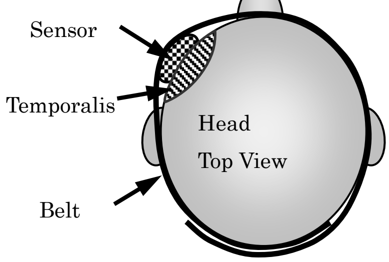


Fig. 5.2 Pressure sensor head band

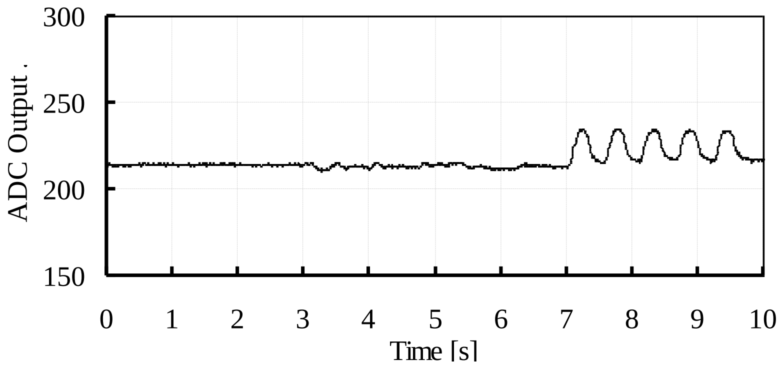


Fig. 5.3 Pressure data obtained from monitoring chewing action

5.3 sEMG-driven musculoskeletal model to control exoskeleton robot used in lower extremity rehabilitation

5.3.1 Physiology of Neuro-Musculo-Skeletal And Human Motion Control

Movements of the body are brought about by the harmonious contraction and relaxation of selectedmuscles. Rehabilitation referred in this article is mainly to rebuild human limbs motor function such as walking gait, so as to maximize the patient's *quality of life* (QOL)[59].

In Neuro-Musculo-Skeletal model, the connection of the nervous and muscular system is the so called α-motor neurons originating from the spinal cord or brain stem. Neurons create an electrical impulse (nerve impulses or an action potential (AP)) that transmitted across neuromuscular junctions to the motor endplates sitting on top of the muscle fibers. At this time, the muscle is activated to contract by the nerve signal and human movement is finally driven by skeletal muscle contraction force.

The α-motor neuron, together with the axon, motor endplate, and the muscle fibers they connect to make up the fundamental block of motor control and are called a *motor unit*[60]. In general, motor units are fired in a random pattern and are not synchronized when a motor unit action potential (MUAP) is evoked .Studies on single motor units revealed that one stimulation pulse creates a single twitch response from the muscle. With increasing frequency of those pulses, the twitches start to merge and the force production of the muscle becomes continuous and increases. When the stimulation frequency is further increased, the twitches come closer to a permanent maximum contraction of the muscle at which point no further force can be generated. If this contraction is performed voluntary (no reflex, no spasm) it is called maximum voluntary contraction.

In my control scheme of the exoskeleton, the surface electromyography (sEMG) have been used as nerve control signal to identify voluntary movement from a patient. sEMG signal of a muscle is the summation of MUAPs evoked at the same time and can be directly measured invasively with surface electrodes located on top of the skin. **Fig. 5.4** shows the *main hardware composition* that completes the process from the sEMG signal generation to the controlled object, whose details can refer to[61].

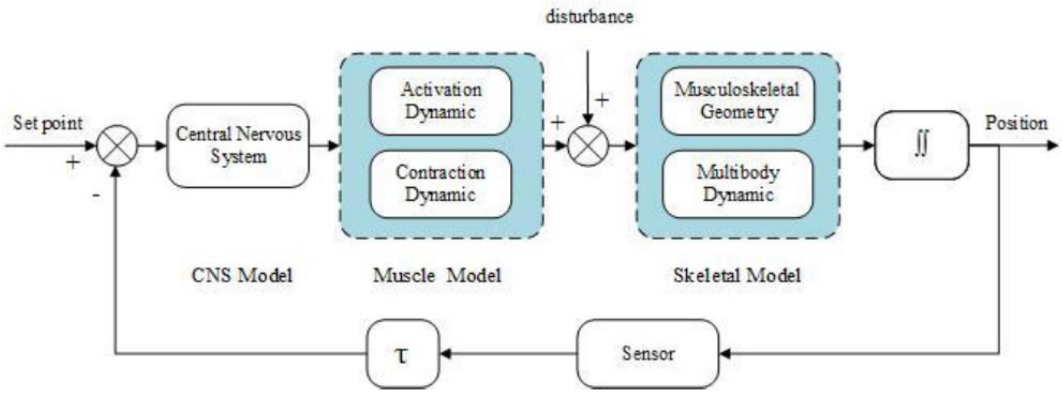


Fig. 5.4 A conceptual scheme of the Neuro-Musculo-Skeletal system

The time between the emission and detection of the sEMG signal can be neglected in the context of this work. But there is also a time between emission and force production. This time, called the electromechanical delay, is reported to be *about 50–80ms*[62, 63]1, mainly due to low muscle fiber conduction velocity and the chemical processes which lead to contraction. It allows the signal evaluation process to start before the force production begins, reducing the latency of control systems coupled to EMG signals. Effects of muscle fatigue are not taken into account in this work. *An analysis* of these effects can be found in[64]. So the control scheme is the ability to detect the user's intention prior to the actual contraction of the muscle .However, one of problems by using sEMG is the system will not work properly if it is applied to the user with muscle disorder. This is also why a hybrid control scheme is used. **Fig. 5.4** is a conceptual scheme of the Neuro-Musculo-Skeletal system from the perspective of control. The scheme shows a feedback control system.

During the whole process from the creation of nerve impulses that is based on feedback signal from sensor such as eyes to movement generation, the essential characteristic of human biological system is that it is converged in nature. About four levels of integration are included in the *Neuro-Musculo-Skeletal system*[65-67].But they are mainly divided into three parts from the perspective of biomechanical modeling and control in the work, that is, the central nervous system (CNS) model, muscle dynamics (activation and contraction dynamic) and skeletal dynamic model.

The construction of musculo-skeletal model requires an understanding of the anatomy of musculoskeletal systems. According to[68],anatomy is the study of the structure of the human body and provides essential labels for musculoskeletal structures and joint motions relevant to human movement.

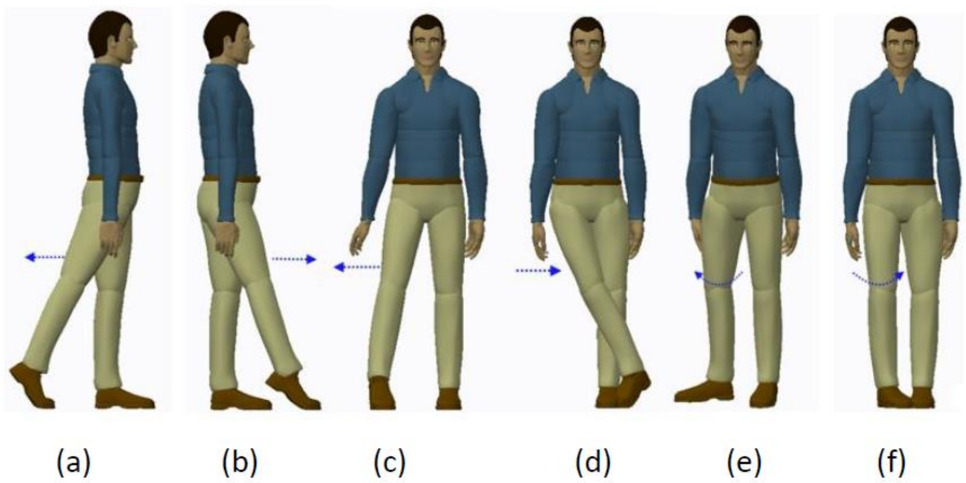


Fig. 5.5 Possible hip joint movements and their corresponding types are: (a)Extension(b) Flexion(c) Abduction(d) Adduction(e) External rotation(f) Internal Rotation.

In anatomy, each bone is a complex living organ that provides attachment points for muscles to allow movements at the joints. For human joints, according to predominant tissues that supports the articular elements together, joints typically have three major types, that is, *fibrous, cartilaginous, or synovial*[69] joints. Among of them, the synovial joint is the main joint type associated with lower limb movement. Mobility varies considerably and a number of subcategories are defined based on the specific architecture and topology of the surfaces involved (e.g. planar, saddle, ball and socket). For different categories of joints, corresponding movements are permitted, e.g. flexion and extension, medial and lateral rotation and so on. For example, hip joint that is the link between the pelvis/trunk and the lower limbs is a ball-and-socket joint and has several kinds of movement, as shown in **Fig. 5.5**.

5.3.2 Control Framework Based on Neuro-Musculo-Skeletal Model

The work aims to develop an innovative neuromuscular control theoretic formulation to control a exoskeleton rehabilitation robot for the lower limb. The approach adopted here in developing the interface of human-robot sensorimotor control is based on an inverse model (dynamic and kinematics) coupled with nonlinear feedback. As the nervous system plans and regulates movement, it does so by taking into account the mechanical properties of the muscles, the mass and inertial properties of the body segments, and the external forces arising from contact with the environment. The overall system can be represented schematically as in **Fig. 5.6**, which is subdivided into three distinct parts: the motion intent parser, lower-level controller and controlled object. Among of them, the motion intent parser that computes the suitable support torque is the most important composition part .So the following mainly give a description for it.

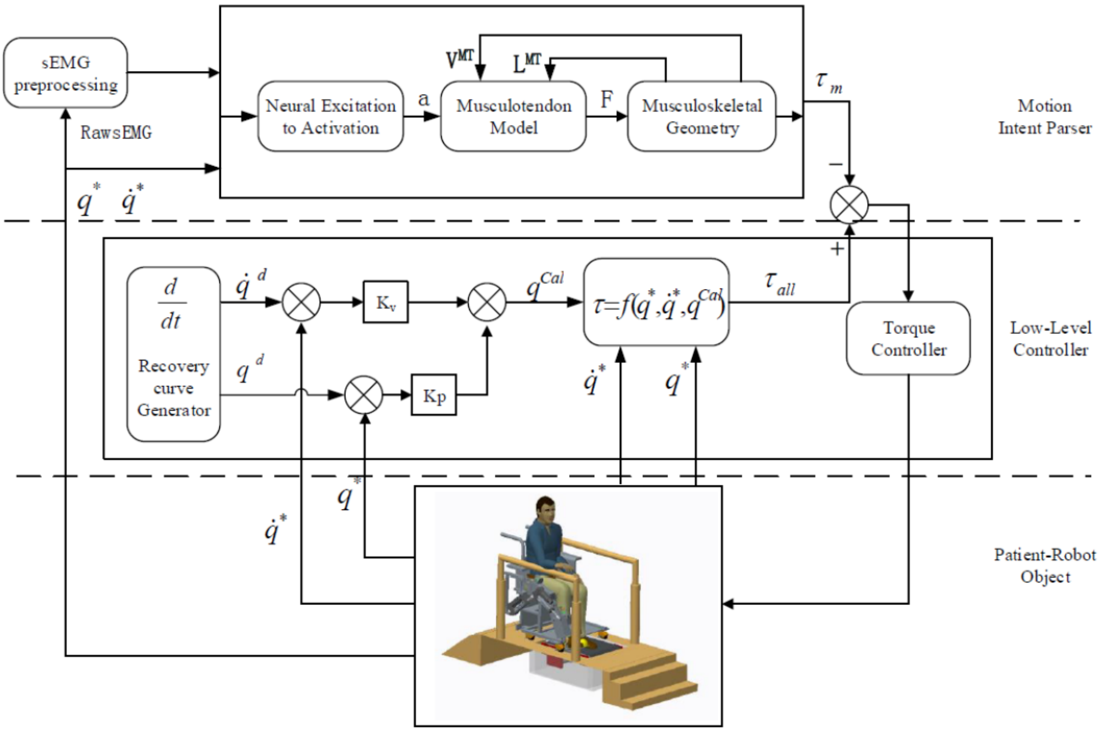


Fig. 5.6 The framework of overall control system

The part of the motion intent parser mainly comprises of three distinct parts, which are signal acquisition of surface electromyography (sEMG), muscle dynamic model and skeletal dynamic model.

sEMG is the summation of motor unit action potential (MUAP) starting from central nervous system (CNS).So that it can be used to decode action intent of operator to make the patient actively participate in specific training .Figure 4 is a sEMG signal acquisition system adopted in our experiment. It is a multi-channel wireless telemetry system that is a product of NIHON KOHDEN Corporation in japan. Before starting to obtain signal, a lot of preparations must be done, which is very important if a good quality signal is to be obtained. In my experiment, it includes (1) shaving the excess hair to obtain even lower skin resistance;(2) Using alcohol to removal of dirt, oil, and dead skin in order to reduce any skin resistance and allow electrodes to be attached without coming loose;(3) a part of subjects whose skin surface are dry use electrode gel (Elefix Z-181BE made in NIHON KOHDEN corporation in japan) rubbed into the skin, which can dramatically improve the quality of the recorded signal;(4)In the decision of the specific site for the electrode, in order to assure repeatability for different subjects, various bony landmarks are used as a reference .After finding the position for one subject, marks are made so as to assure that the electrodes are over the same muscle fibers in different trials; (5)The inter-electrode distance is an important parameters and you should make sure that this distance is consistent throughout all subjects and trials. In my experiment, this step is skipped because the electrodes has fixed electrode geometries.

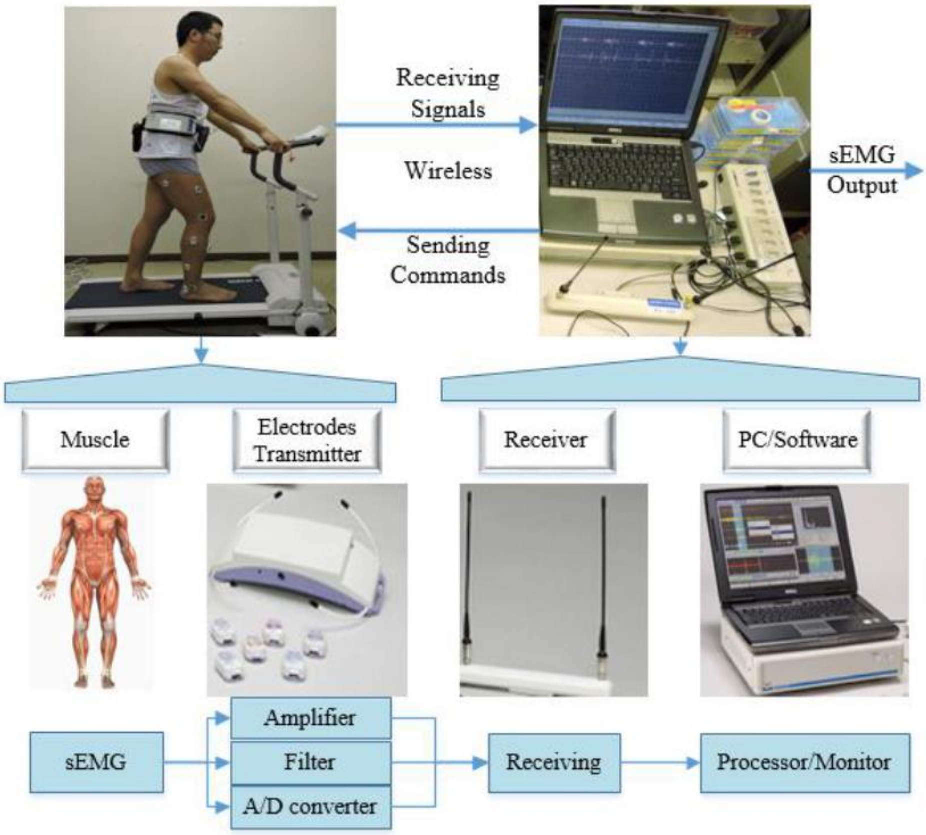


Fig. 5.7 The key elements of the system from SEMG to robot

Act as the input, sEMG signals get into the muscle dynamics and estimate the current joint moment contribution of the operator based on the resulting muscular forces. The module consists of activation dynamic and contraction dynamic model. Activation dynamic corresponds to the transformation $u\,t$ of sEMG to activation $a\,t$ of contractile and *a modified non-linear first-order dynamic model*[70, 71] is used in the system, as shown in Equ(viii),(ix).

$$\frac{da}{at} = \frac{u-a}{\tau_a(a,u)} \quad \text{(viii)}$$

Where, u is excitation, a is activation, $\tau_a(a, u)$is a variable time constant that varies with activation level and whether the muscle activation level is increasing or decreasing.

$$\tau_a(a,u)=\begin{cases}\tau_{act}(0.5+1.5a)\\ \dfrac{\tau_{deact}}{0.5+1.5a}\end{cases} \quad \text{(ix)}$$

Where, τ_{act} is the activation time constant and τ_{deact} is the deactivation time constant. Typical values for activation τ_{act} and deactivation τ_{deact} time constants are 10 ms and 40 ms, respectively.

The raw sEMG signals are acquired and need to do some preprocessing before calculating a (t). The preprocessing mainly includes rectification, filter, smoothing. And during the process of modeling, all parameters are derived through scaling values found in the literature. And in order to do analysis for different persons and muscles conveniently, no dimensional method is implemented, that is, all parameters used in the calculation is normalization value .For instance, all forces and length quantities are normalized to maximum isometric muscle force (F0M) and optimal muscle fiber length (L0M).

Once we have obtained the activation of the muscle, we can compute the resulting force exerted by the muscle using a muscle model. In this work, *a type of Hill-type*[72] muscle model that is based on the work of is used to model muscle contraction dynamics. This type of hill muscle tendon model consists of three components: *an active contractile element (CE), a passive parallel element (PE) and a passive series element (SE)*[73].

The skeletal dynamic model is simplified as a Linked Segment Digital Human Model (LS-DHM) in the work. For the sake of generality, *the template model LS-DHM* is developed firstly, which is based on the model presented in[74],as illustrated in Figure 5(side view and front view).There are three branches in the body frame. The first branch is the right leg, the second is the left leg, and the third is the spine. In the spine branch, there are child branches and so on. So the topological structure of presented LS-DHM is a tree-structure.

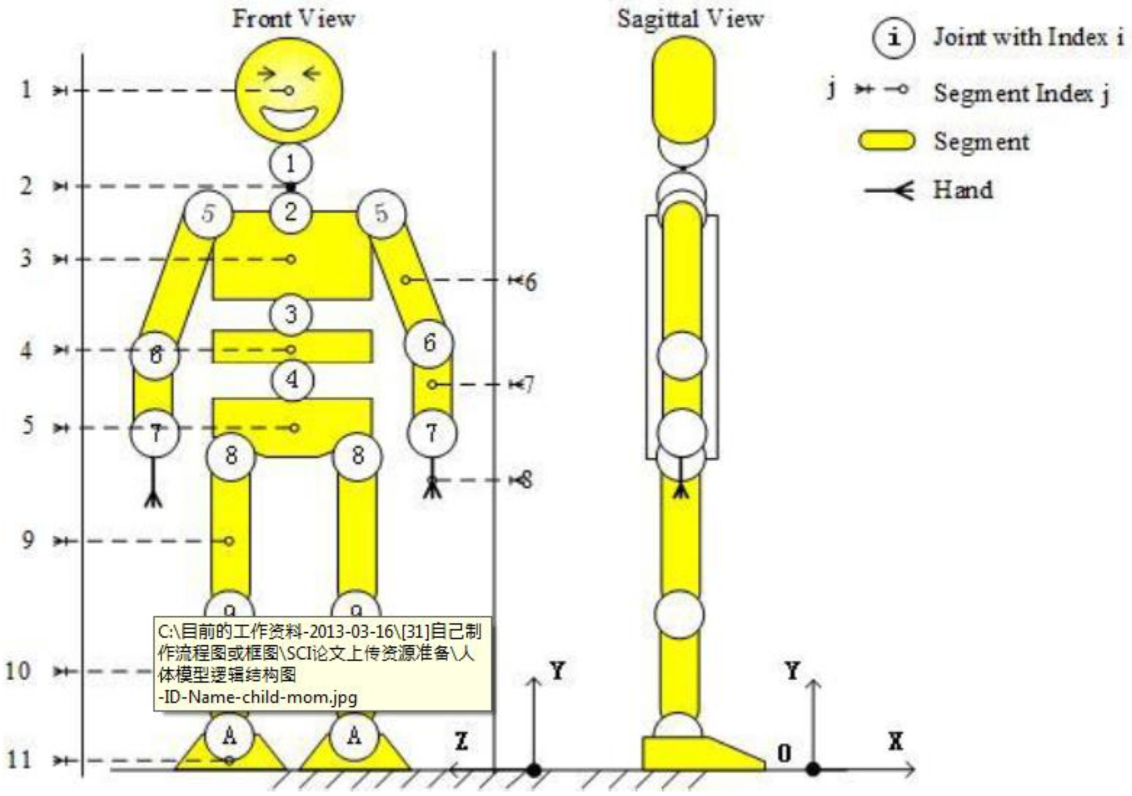


Fig. 5.8 Illustrative view of human body decomposition and labeling

In **Fig. 5.8**,yellow parts are simplified as rigid segments and assigned unique numbers to index them in program, as shown in **Table 5.1**. Circles with numbers represent kinematic joints in **Fig. 5.8**. Their joint type and degrees of freedom are shown in **Table 5.2**. It should be note that the ground is also viewed as the segment in the work, in order to model.

Table 5.1 Segment Information

Name	**Segment Label**	**Index Id in program**
Static ground(SG)	S0	1
Dynamic ground(DG)	D0	2
Head	1	301
Neck	2	300
Thorax	3	31
Abdomen	4	30
Pelvis	5	3
Upper arm	6R/6L	100/200
Forearm	7R/7L	101/201

L/R Hand	8R/8L	102/202
L/R Thigh	9R/9L	10/20
L/R Shank	10R/10L	11/21
L/R Foot	11R/11L	12/22

And process data conveniently, the ground is broken into static ground (SG) and virtual dynamic ground (DG)whose index Id are assigned to 1 and 2, respectively. Based on **Table 5.1** and **Table 5.2**, it is known that the template LS-DHM comprises 19 segments and 46 DOFs.

Table 5.2 Joint Information

Joint Label	Joint Type(Name)	DOF	Mom Segment Index	Child Segment Index	Id in program
S0	Translation(SG-DG)	3	S0	D0	2
D0	Spherical(DG-Pelvis)	3	D0	5	3
1	Spherical(Neck -Head)	3	2	1	301
2	Spherical(Thorax- Neck)	3	3	2	300
3	Spherical(Abdomen- Thorax)	3	4	3	31
4	Spherical(Pelvis - Abdomen)	3	5	4	30
5R/5L	Spherical(Shoulder)	3×2	3/3	6R/6L	100/200
6R/6L	Revolute(Elbow)	1×2	6R/6L	7R/7L	101/201
7R/7L	Spherical(Hand)	3×2	7R/7L	8R/8L	102/202
8R/8L	Spherical(Hip)	3×2	5/5	9R/9L	10/20
9R/9L	Revolute(Knee)	1×2	9R/9L	10R/10L	11/21
AR/AL	Spherical(Ankle)	3×2	10R/10L	11R/11L	12/22

Combined with muscle dynamic model, the joint torque exerted by internal muscles can be exported by Equ(x) .Using an inverse dynamic model of LS-DHM derived from equations of motion, a exoskeleton controller can be designed.

$$M_k(t) = \sum_{i=1}^{Ne} F_e^i(t) \times d_e^i(t) - \sum_{j=1}^{Nf} F_f^j(t) \times d_f^j(t) \quad \text{(x)}$$

Where, $k$is the joint identifier.for lower limb,$k$could be hip ,knee ,ankle and other joint indetifier.Ne is the number of extensor muscles for k joint;Nf is the number of flexor muscles for k joint;$F_{ei}(t)$ is the force produced by$i-th$ extensor muscle at time$t$; $F_{ej}(t)$ is force produced by $j-th$ flexor muscle at time$t$;$d_{ei}(t)$ and$d_{fj}t$ are moment arm of $i-th$ extensor and $j-th$ flexor muscle at time t, respectively.

The equation of motion is formulated by using *Lagrangian dynamics*[75], as shown in Equ(xi).

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) = Q_{nc} \quad \text{(xi)}$$

Where, $\boldsymbol{q}, \boldsymbol{q}, \boldsymbol{q}$ are n × 1 vectors of displacement, velocity and acceleration; $\boldsymbol{M}$ is a pose-dependent n × n inertia matrix comprising body anthropometry, and comes from taking the second derivative the kinetic energy. The next factor$\boldsymbol{C}$ represents what are called the coriolis and centrifugal or coupling effects of the manipulator system on joint torques, which is a n × 1 vector. Note it includes both angular position and velocity terms. The n × 1 $\boldsymbol{G}$ matrix includes forces based on the influence of gravity. $\boldsymbol{Q}_{nc}$ is non-conservative force (internal dissipative forces, any external forces).

Chapter 6　Research conclusion

Serious disability may result in patients living in a bed ridden state with little ability of voluntary movement. For example their intentional muscular abilities maybe limited only to slight head movements, fingers movements and eye movements. Their daily lives are dependent on family members and care-givers. Interaction of these patients with society is extremely limited. Even if they lose their independence and communication abilities, they should enjoy their lives as individual human beings. In order to improve their quality of life, an environmental control system has been proposed and is efficient at enabling the control of home electric appliances as well as providing a computer interface. Usability and adaptability of the control system are important problems to be solved for such people with serious disabilities. Due to recent developments of information and computer technology, this environmental control system with advanced usability and adaptability has been achieved. Considering that the recovering of independence and communication abilities for such patients with serious disabilities is top priority, an environmental control system employing the recent information technologies has been developed.

This thesis consists of five chapters. In chapter 1, the situation of people with serious disabilities is considered and two patients are introduced to clarify the target patients of this research. One patient suffering from an incurable neurological disease (amyotrophic lateral sclerosis: ALS), his remaining muscular ability is significantly limited to slight finger movements and eye and head movement. He can make faint vocal utterances. His daily life is dependent on his wife and care givers. Another patient injured his spinal cord by accidentally falling. His remaining abilities are limited to movement above his neck. He needs an artificial respirator. His daily life is also dependent on the care givers. In order to improve these patients' quality of life, an environmental control system and input devices are discussed. This is purpose of this thesis.

In chapter 2, an environmental control system using a tablet computer with blue tooth communication function is proposed. The environmental control system consists of four parts, the tablet computer, input devices, an infrared controller to control home electric appliances and a bed controller.

The efficacy of one proposed input device is operated by slight finger movement and is evaluated by ALS patients. Based on the evaluation, the efficacy of the proposed input device was confirmed.

In chapter 3, a vision-based computer input device is proposed. The user of the proposed input device can move the computer cursor by head movement and activate the click button by mouth opening and closing actions. A feature of the input device is robustness to the hazardous environment by introducing a multiple template matching method and an orientation code matching algorithm (OCM). The advantage of the proposed method over a conventional method was evaluated by experiments.

In Chapter 4, an input device using a joystick is introduced. The proposed input device enables wheelchair users to operate the computer settled apart from the wheelchair. A feature of the device is that the joystick control can be achieved by mounting a sensor unit on the wheelchair joystick without any modification of the wheelchair joystick controller. The principle of the sensing unit is to measure the inclination angle and the direction of the joystick with an acceleration and gyro sensors. The applicability of the proposed input device was tested by a wheel chair user.

In chapter 5, a SEMG (surface electromyography)-driven musculoskeletal model is proposed. The model is used to control an exoskeleton robot which is designed for lower body rehabilitation. This control framework of the exoskeleton rehabilitation robot has been successfully applied to assist rehabilitation by guiding motions to correct training, rehabilitation trajectories, or to provide additional force to support perform certain motions.

In chapter 6, the conclusions and future of this thesis are described. Firstly, an environmental control system using a tablet computer was proposed to assist people with serious disabilities towards been more independent. In addition, efficiency of an input device for people with slight remaining abilities on their fingers was proposed. The usability of the proposed environmental control system and input devices were confirmed by experiments.

Secondly, a vision-based input device using multiple template matching and orientation code matching algorithm was proposed as an effective device for people with serious disabilities. Comparison tests revealed the usability and robustness feature of the proposed device. Thirdly, an input device using a joystick mounted on a conventional wheelchair was proposed and the usability was confirmed.

In the final part, a control system framework based on a neuromusculoskeletal model was proposed. SEMG was used to sense the operator's voluntary intention and proved to provide an intuitive control for the exoskeletal device. Compared with current control systems this would be significantly more intuitive user friendly and effective.

Acknowledgments

How time flies, in the blink of an eye, my Japanese learning life is coming to its close, thanks to the careful guidance of my professor Ishimatsu, my doctoral dissertation would be able to complete. The ages in Japan mean a lot to me, and I can't help looking back the dribs and drabs of life. In the year of 2011, I arrived in Japan with an uneasy heart, when I arrived at the airport, Prof. Ishimatsu had arrived and was waiting for me. Staring at the Japanese teacher who was smiling at me and so kind, instantly, a warm current came to my whole body, a deep respect from my heart came out. The strangeness and lonely sense of far away from home in a foreign land was instantly disappeared. From the moment I secretly made up my mind to follow this person to study well, and never live up to what the teacher barrels.

In the days that learning following Prof. Ishimatsu, I deeply understand Prof. Ishimatsu.

Speaking of work, Prof. Ishimatsu is the most dedicated teacher I have ever seen. Prof. Ishimatsu is often absorbed in working. Once Prof. Ishimatsu begins to work, Prof. Ishimatsu often forgets time, often forgets to have meals and his attitude towards the work is up to a fascinating degree. Nowadays I truly got the meaning of two Chinese proverb called "vomit one's heart and shed one's blood" and "disregard meal times and go without sleep". In terms of guiding students, Prof. Ishimatsu is also very patient, never gives up the students because of students' dullness, but teach us what we cannot understand. Also, Prof. Ishimatsu gives the students some advice about how to find a job and guides us to write a good resume. Prof. Ishimatsu not only has a broad mind in the research field but also has a heart of benevolence in the life. In the weekends, Prof. Ishimatsu often takes us to visit the serious patient with incurable diseases who is in bedridden status, and cannot speak and cannot lead a life by themselves. After returning school, considering the situations of the patients, Prof. Ishimatsu immediately think about some ideals and guides us to do the experiment in order to help the patients in largest extent.

Once, in the conversation with Prof. Ishimatsu, I knew the fact that Prof. Ishimatsu chose the rehabilitation research because he wanted to help these patients in paralysis to lead a life by themselves. Here, I express the highest respect and deepest gratitude to my professor Ishimatsu. “Enjoy work, enjoy life.” The working and living values of Prof. Ishimatsu is what I respect and want to learn. I must thank Prof. Ishimatsu again for teaching me these values, it will charge my future.

Next, I want to thank Dr. Muromigi and Dr. Tanaka. Dr. Muromigi and Dr. Tanaka are assistant of my professor Ishimatsu. Dr. Muromigi is very responsible for the work. When professor Ishimatsu is busy with work or meeting, Dr. Muromigi was always enthusiastic to teach us how to do the experiment and gave us much good advice about our research. In his most busy time, he also made a special trip to accompany me to go abroad to take part in the international conference for addressing a paper. When I recalled the time spent with Dr. Muromigi together, I cannot help holding my feelings of thanks. Dr. Tanaka often gave me a big hand in writing program. When I made a mistake in my program and do not know how to correct, Dr. Tanaka was always earnest to come to help. Frankly speaking, thanks to the help of Tanaka a sir, my experiment could go smoothly. Dr. Tanaka is now working in other school, but also often squeeze time to Nagasaki University to help us to solve the problems on research and experiment. Although Dr. Muromigi and Dr. Tanaka are not working in Nagasaki University, but the respect to them always stay in my heart. Here I express deep gratitude to Dr. Muromigi and Dr. Tanaka.

Also, thanks to the secretary Ms. Matsuo and technician Imai sir of my laboratory. Ms. Matsuo often helped us in the details of life, such as remind us about information time, and how to apply for some information, how to fill in, and so on. So we avoided many troubles and saved much time to our experiment. Imai sir often helped us to design the experiment device, buy devices of our experiment online, silently help us clean the laboratory, truly speaking, that our experiment can goes well has a close relation with Imai sir. Here express the most sincere gratitude to Ms. Matsuo and Imai sir.

Dr. Lawn is an English teacher who comes from New Zealand, he often helps us to speak English, to correct our pronunciation, and help us to modify the English papers, he is a very rare good teacher. Here I express my deep gratitude to Dr. Lawn.

Jiangli Yu, a Doctor student from China, I express the depth of my gratitude to her. She supported my research and daily life several times. And she is a trustworthy research mate. I hope she could find a great place for herself.

Dr. Lei Shi, Dr. Longxi Luo, two research mates of mine. Thanks them to carry my headstrong. It a great pleasure for me to do a same job with them.

Prof. Liu, thanks him for guiding me to study in Japanese. And also thanks him to warm my heart when I was homesick.

Thanks students researching together, because they brought me the joy of living and learning motivation, so I cannot sense any loneliness in the alien land. Much appreciation to you, my lovely friends.

Finally, thanks Hisako Yamaguchi, my wife. When I became crestfallen, she encourage me and handled the problem together. Thus I could concentrate on completing this paper.

Last, I bow to teachers and friends deeply who kelp me all the time and give my most sincere gratitude to you.

Reference

[1] WHO. (2014). *WHO Director General's message on the International Day of Persons with Disabilities 2014*. Available: http://www.who.int/disabilities/media/news/2014/idpd_dg/en/

[2] "Ministry of Health, Labour and Welfare's report in 2015," Ministry of Health, Labour and Welfare2015.

[3] "Investigation about difficulty of lifes in 2011," Ministry of Health, Labour and Welfare2011.

[4] P. Gonzalez-Perez, U. Woehlbier, R.-J. Chian, P. Sapp, G. A. Rouleau, C. S. Leblond*, et al.*, "Identification of rare protein disulfide isomerase gene variants in amyotrophic lateral sclerosis patients," *Gene,* vol. 566, pp. 158-165, 7/25/ 2015.

[5] Available: http://taiwanspinecenter.com.tw/tsc_e/education/levels_of_injury.htm

[6] *ECS-16L*. Available: http://www.interphonestore.com/hinban/10/ECS-16L.html

[7] *Breating action to control ECS*. Available: http://www.interphonestore.com/catalog/10_12/460.html

[8] *Environmental control sytem*. Available: http://www.interphonestore.com/catalog/10_12/461.html

[9] *Environment control system e-612-s*. Available: http://www1.s3.starcat.ne.jp/fukushi/E612_S.htm

[10] *Dennosinn*. Available: http://www.p-supply.co.jp/products/217

[11] *Hearty ladder*. Available: http://heartyladder.net/xoops/

[12] *Nanndemo IR*. Available: http://www.ttools.co.jp/product/hand/ircenter/

[13] *Push switch*. Available:

https://sv40.wadax.ne.jp/~amor-co-jp/4_301.html

[14] *Push switch common type*. Available: http://life-support.me/communication/

[15] *Touch switch*. Available: https://sv40.wadax.ne.jp/~amor-co-jp/103_54.html

[16] *Breathing switch*. Available: https://sv40.wadax.ne.jp/~amor-co-jp/105_61.html

[17] *Pressure sensor*. Available: https://sv40.wadax.ne.jp/~amor-co-jp/106_321.html

[18] *SmartNav4*. Available: http://www.naturalpoint.com/smartnav/products/4-at/

[19] *SmartNav4 working technology*. Available: http://www.naturalpoint.com/smartnav/products/howitworks.html

[20] *Tobii EyeX*. Available: http://www.tobii.com/xperience/

[21] C. Zhang, T. Ishimatsu, J. Yu, M. Lawn, and L. Shi, "Vision-Based Displacement Sensor for People with Serious Spinal Cord Injury," *The 2015 IEEE International Conference on Mechatronics and Automation (ICMA 2015),* 2015.

[22] O.Takami, K.Morimoto, T.Ochiai, and T. Ishimatsu, "Computer Interface to use head and eyeball movement for handicapped people," presented at the 1995 IEEE International Conference of System,Man and Cybernetics, Vancouver, Canada, 1995.

[23] J. Yu, C. Zhang, N. Shiraishi, T. Ishimatsu, M. Lawn, and M. Tanaka, "Pillow-type Computer Input Device for Serious Spinal Cord Injury," *Journal of Modern Mechanical Engineering,* 2015.

[24] J. Ramachandran, Abrams(Edt.),Kohei Arai et al., "Communication Aid with Human Eyes Only," *Electronics and Communications in japan,* vol. 93, pp. 1-9, 2010.

[25] M.Mizuta, S.Moromugi, and T.Ishimatsu, "Measuring of Number-of-

Chewing using Flexible Capacitive Sensor,," *Proc. of 4th Asia International Symposium on Mechatronics,* vol. TP2-A-5-P221 in CD-ROM, 2010.

[26] Kohei Arai and M. Yamaura, "Computer input with human eyes only using two Purkinje images which works in a real time basis without calibration," *International Journal of Human Computer Interaction,* vol. 1, pp. 71-82, 2010.

[27] Y.Fukuda, M.Tanaka, S. Moromugi, and T. Ishimatsu, "A Communication device for disabled slight movement capabilities," *International Journal of HWRS,* vol. 4, pp. 7-12, December 2003.

[28] T. Ochiai and T. Ishimatsu, "Computer Input device for handicapped using vision sensor," *in Proc.3rd Int. symposium on artificial life and robotics,* vol. 2, pp. 634-637, 1997.

[29] Kohei Arai and R. Mardiyanto, "Real time blinking detection based on Gabor filter," *International Journal of Human Computer Interaction,* vol. 1, pp. 33-45, 2010.

[30] Kohei Arai and R. Mardiyanto, "Camera mouse and keyboard for handicap person with trouble shooting capability, recovery and complete mouse events," *International Journal of Human Computer Interaction,* vol. 1, pp. 46-56, 2010.

[31] M. M. Gorkani and R. W. Picard, "Texture orientation for sorting photos at a glance," *ACM Comput.Surveys,* vol. 24, pp. 325–376, 1992.

[32] W. Freeman and M. Roth, "Orentation histograms for hand gesture recognition," *Proc. IEEE Int. Workshop Face Gesture Recog,* pp. 296–301, 1995.

[33] S. Kaneko, I. Murase, and S. Igarashi, "Robust image registration by increment sign correlation," *Pattern Recog,* vol. 35, pp. 2223–2234, 2002.

[34] F. Ullah and S. Kaneko, "Using orientation codes for rotation-invariant template matching," *Pattern Recognit,* vol. 37, pp. 201–209, 2004.

[35] F. Ullah and S. Kaneko, "Orientation code matching for robust object search," *IEICE Trans. Inf. Syst,* vol. E84-D, pp. 999–1006, Aug. 2001.

[36] Y. Li, H. Takauji, S. Kaneko, T. Tanaka, and I. Ohmura, "Robust focusing using orientation code matching," *Electron. Lett. Comput. Vis. Image Anal,* vol. 7, pp. 101–114, 2008.

[37] Bernstein and Jonathan. (2003, February 1) An overview of MEMS inertial sensing technology. *Sensors Weekly*.

[38] J. Yu, T. Ishimatsu, and N. Shiraishi, "Face mount computer input device for serious disabled," in *2015 IEEE Fifth International Conference on Big Data and Cloud Computing*, Dalian, 2015, pp. 195-198.

[39] Jezernik.S, "Robotic orthosis lokomat: A rehabilitation and research tool," *Neuromodulation: Technology at the neural interface,* vol. 6, pp. 102-115, 2003.

[40] Riener.R, "Technology of the Robotic Gait Orthosis Lokomat," *Neurorehabilitation Technology,* vol. Springer, pp. 221-232, 2012.

[41] Husemann.B, "Effects of locomotion training with assistance of a robot-driven gait orthosis in hemiparetic patients after stroke a randomized controlled pilot study," *Stroke,* vol. 38, pp. 349-354, 2007.

[42] Westlake.K.P and C. Patten, "Pilot study of Lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke," *Journal of neuroengineering and rehabilitation,* vol. 6, p. 18, 2009.

[43] Veneman.JF, Kruidhof.R, Hekman.EE, Ekkelenkamp.R, Van.Asseldonk.EH, and Van.der.Kooij.H, "Design and evaluation of the LOPES exoskeleton robot for interactive gait rehabilitation," presented at the Neural Systems and Rehabilitation Engineering, 2007.

[44] V. Asseldonk, E.H, and H. v. d. Kooij, "Robot-Aided Gait Training with LOPES," *Neurorehabilitation Technology,* vol. Springer, pp. 379-396, 2012.

[45] S. K. Banala, "Robot assisted gait training with active leg exoskeleton,"

Neural Systems and Rehabilitation Engineering, vol. IEEE Transactions on, pp. p. 2-8., 2009.

[46] O. Unluhisarcikli, "Design and control of a robotic lower extremity exoskeleton for gait rehabilitation," in *Intelligent Robots and Systems (IROS)*, 2011 IEEE/RSJ International Conference on, 2011.

[47]Y. Sankai, "Hybrid assistive limb based on cybernics,," *Robotics Research,* vol. Springer, pp. 25-34, 2011.

[48] K. Kong and D. Jeon, "Design and control of an exoskeleton for the elderly and patients," *Mechatronics,* vol. IEEE/ASME Transactions on, pp. 428-432, 2006.

[49] Farris, R.J, H. A. Quintero, and M. Goldfarb, "Preliminary evaluation of a powered lower limb orthosis to aid walking in paraplegic individuals," *Neural Systems and Rehabilitation Engineering,* vol. IEEE Transactions on, pp. 652-659, 2011.

[50] Pons and J.L., *Wearable robots: biomechatronic exoskeletons* vol. 70: Wiley Online Library, 2008.

[51] Schultz, A.E, and T. A. Kuiken, "Neural interfaces for control of upper limb prostheses: the state of the art and future possibilities," *PM R,* pp. 55-67, 2011.

[52] J. Park and O. Khatib, "A haptic teleoperation approach based on contact force control," *The International Journal of Robotics Research,* vol. 25(5-6), pp. 575-591, 2006.

[53] Ferris, D.P., and C. L. Lewis, "Robotic lower limb exoskeletons using proportional myoelectric control," in *IEEE Eng Med Biol Soc*, 2009, pp. 2119-24.

[54] J.-W. Lee and G.-K. Lee, "Gait angle prediction for lower limb orthotics and prostheses using an EMG signal and neural networks," *International Journal of Control, Automation, and Systems,* vol. 3(2), pp. 152-158, 2005.

[55] M. Lotze and e. al, "Motor learning elicited by voluntary drive," *Brain,*

vol. 126(4), pp. 866-872, 2003.

[56] J. Schouenborg, "Learning in sensorimotor circuits," *Current opinion in neurobiology,* vol. 14(6), pp. 693-697, 2004.

[57] Kaelin-Lang, L. S. A., and L. G. Cohen, "Role of voluntary drive in encoding an elementary motor memory," *Journal of neurophysiology,* 2004.

[58] C. Fleischer, "Controlling exoskeletons with EMG signals and a biomechanical body model," *Scuola Superiore Sant'Anna.,* 2007.

[59] L. Shi and Z. Liu, "Design of Soft Human-Robot Interface Based on Neuro-Muscular-Skeletal Model. in Dependable," in *Dependable, Autonomic and Secure Computing (DASC)*, 2014.

[60] R. Merletti and P. A. Parker, *Electromyography: physiology, engineering, and non-invasive applications* vol. 11: John Wiley & Sons, 2004.

[61] L. Shi, Z. Liu, and Q. Wang, "A Novel Method of sEMG Signal Segmentation," in *Mobile Ad-hoc and Sensor Networks (MSN)*, 2013.

[62] P. Cavanagh and P. Komi, "Electromechanical delay in human skeletal muscle under concentric and eccentric contractions," *European journal of applied physiology and occupational physiology,* vol. 42(3), pp. 159-163, 1979.

[63] S. Zhou and e. al., "Electromechanical delay in isometric muscle contractions evoked by voluntary, reflex and electrical stimulation," *European journal of applied physiology and occupational physiology,* vol. 70(2), pp. 138-145, 1995.

[64] K. Petersen and e. al., "Muscle mechanical characteristics in fatigue and recovery from a marathon race in highly trained runners.," *European journal of applied physiology and occupational physiology,* vol. 101(3), pp. 385-396, 2007.

[65] C. De Luca and e. al, "Control scheme governing concurrently active human motor units during voluntary contractions," *The Journal of*

physiology, vol. 329(1), pp. 129-142, 1982.

[66] Winter.D.A., "Overall principle of lower limb support during stance phase of gait," *Journal of biomechanics,* vol. 13(11), pp. 923-927, 1980.

[67] Winter.D.A., "Kinematic and kinetic patterns in human gait: variability and compensating effects," *Human Movement Science,* vol. 3(1), pp. 51-76, 1984.

[68] Duane.V.Knudson, *Fundamentals of biomechanics*: Springer Science & Business Media, 2007.

[69] L. Kun, "Research on Wearable Sensor system for 3D lower limb kinematics analysis," Doctor, Kochi University of Technology, Kochi, 2010.

[70] D. G. Thelen, "Adjustment of Muscle Mechanics Model Parameters to Simulate Dynamic Contractions in Older Adults," *Journal of Biomechanical Engineering,* vol. 125(1), p. 70, 2003.

[71] W. JM, "An improved muscle-reflex actuator for use in large-scale neuromusculoskeletal models," *Annals of biomedical engineering,* vol. 23(4), pp. 359-374, 1995.

[72] Hill.A., "The heat of shortening and the dynamic constants of muscle.," in *Proceedings of the Royal Society of London B: Biological Sciences*, 1938, pp. 136-195.

[73] Rosen.J, M. B. Fuchs, and M. Arcan, "Performances of Hill-type and neural network muscle models—Toward a myosignal-based exoskeleton," *Computers and Biomedical Research,* vol. 32(5), pp. 415-439, 1999.

[74] D. H. Laananen. (1991, Computer simulation of an Aircraft Seat and Occupant (s) in a Crash Environment-Program SOM-LA/SOM-TA (User Manual).

[75] Greenwood.D.T., *Classical dynamics*, 1997.