Thesis for the Degree of Master of Engineering

A Home-Based Remote Rehabilitation System for Joint Range of Motion Improvement

by

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관절 가동범위 향상을 위한

가정용 원격 재활 시스템

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by

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List of Abbreviations

A-AROM	Active-Assistive Range of Motion
AR	Augmented Reality
AROM	Assistive Range of Motion
B.C.	Before Christ
CPU	Central Processing Unit
FPS	Frame Per Second
HW	Hardware
IR	Infrared
OS	Operating System
PC	Personal Computer
PROM	Passive Rang of Motion
RAM	Random Access Memory
RGB	Red, Green, Blue
ROM	Range of Motion
SDK	Software Development Tool
UI	User Interface
VR	Virtual Reality

관절 가동범위 향상을 위한 가정용 원격 재활 시스템

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요약

재해로 인한 부상 및 만성 질환 등의 다양한 요인으로 신체적 장애를 가진 환자, 혹은 신체의 노화로 인하여 몸의 움직임의 범위가 제한된 노인과 같은 경우, 치료의 일종으로 병원에서의 재활 프로그램의 참여 권장을 받는 경우가 있다. 그러나 이들은 신체의 거동이 불편하므로 보호자의 동행 없이 재활 프로그램의 참여를 위한 이동이 쉽지 않다. 또한, 병원에서는 각각의 환자 및 노인들에게 재활 운동을 지도해주어야 하는 불편함이 존재한다. 이러한 이유로, 이 논문에서는 모션 인식을 통하여 집에서도 타인의 도움 없이 재활 운동이 가능한 원격 재활 프로그램을 개발하였다. 해당 시스템은 사용자 집의 스테레오 카메라와 컴퓨터를 이용하여 구동할 수 있으며, 모션 인식 기능을 통하여 사용자의 실시간 운동 상태 확인이 가능하다. 사용자가 재활 운동에 참여하는 동안, 시스템은 사용자의 특정 부위의 관절가동범위를 저장하여 신체 기능의 향상도를 확인한다. 이 논문에서는 시스템의 검증을 위하여 총 3 명의 실험군이 참여하였으며, 총 3 종류의 운동을 각 9 회씩 반복한 데이터를 이용하여 각 실험군의 시작 및 마지막 운동의 관절가동범위의 차이를 비교하였다. 또한, 관절가동범위에 제약이 있어 제안된 운동들을 수행하기 어려운 환자들을 위하여 특정 관절 운동을 반복하는 세션이 소개되었으며, 운동 반복 횟수에 따른 관절가동범위 향상도를 제시한 그래프가 포함되었다.

Chapter 1

1 Introduction

Rehabilitation is described as the action of restoring someone to health or normal life through training and therapy after imprisonment, addiction, or illness [1][2]. There are various products and services in the market such as general aids, support devices, physical therapy, drug rehabilitation and others to help people wishing to improve their body conditions through rehabilitation. Also, due to rise in geriatric population, as elders are more exposed to strokes, heart attacks, injuries and other chronic conditions that require physical therapy for rehabilitation, the rehabilitation market was expected to grow rapidly [3]. However, in real life, the hospital-based rehabilitation is generally placed, which gives elderly or patients with physical disabilities limited access commuting without their supporters. This is a cause of discomfort in the conventional rehabilitation method. Not only do the patients have to visit the hospitals, but it is also required for the hospitals to maintain their employees to assist them in rehabilitation programs. Thus, it's high cost and low efficiency in economic perspective.

To meet the increasing demand for both, comfort and cost-effectiveness in the rehabilitation field, there have been several researches, including remote rehabilitation exercises: A robot for assisting in rehabilitation training for patients [4][5][6] and a sensor attached to an arm to sense motions [7][8]. Also, there are more researches regarding motion sensing for physical rehabilitation using body area network [9] and by inertial sensors and a stereo camera for joint angle estimation [10]. Others focused on using the strength of a stereo camera in motion tracking to build healthcare monitoring systems [11][12][13].

1.1 Motivations

To eliminate the need of commute to the hospitals for rehabilitation, researchers attached wearable devices to patients' skin or installed extra hardware for better motion tracking performance as mentioned above. However, having to attach multiple sensors to patients' skin every time they run rehabilitation sessions causes discomfort.

In this dissertation, a home-based rehabilitation system is introduced which can be accessed only using a stereo camera and a personal computer (Microsoft Windows OS-based). The system leads users to follow exercises as instructed in the program, while the system reads the user's skeletal joints to measure the joint angle range of motion (ROM) as data for body performance evaluation.

1.2 Challenges

There are a few challenges aroused when implementing the system. Constraints concerned are:

(a) Low frame rate and low quality of videos causing inaccurate data extraction from videos

(b) Motion artifacts affecting the system robustness

(c) Windows OS based PC and Kinect camera needed to run the program

1.3 Research Objectives

In this research, a home-based remote rehabilitation system with real-time motion tracking for joint range of motion was developed. The proposed system aims are:

(a) To develop a system to help patients do the rehabilitation exercises with instructions and get feedbacks about their exercise status

(b) To develop a real-time motion tracking feature via a stereo camera without any wearable devices.

(c) To improve the accuracy of the motion tracking algorithm for joint range measurement.

(d) To merge those features into one system

1.4 Chapter Organization

This chapter of dissertation discussed the motivation, challenges faced, and research aims in developing a home-based remote physical healthcare system with motion recognition for range of motion improvement. Chapter 2 briefly introduces the literature reviews and related works that inspired this research work. Chapter 3 introduces the system design of the main system and the overview of the sub systems. Chapter 4 explained about the motion tracking algorithms for motion recognition feature in the system and range of motion evaluation. Chapter 5 describes the user interface of rehabilitation application. Chapter 6 contains the experimental results and finally, chapter 7 summarized the thesis works and discussions of the potentials for system enhancement in the future.

Chapter 2

2 Background and Related Work

In this chapter, previous researches related to the main topic of the dissertation are discussed which include rehabilitation system, a stereo camera, motion tracking and motion recognition, and joint range of motion (ROM) evaluation.

2.1 Conventional Physical Rehabilitation Activities

Physical rehabilitation is not a new concept as it had been mentioned in various areas for a long period in history. Hippocrates of Kos (460-370 B.C.) reportedly advocated exercise as an important factor in the healing of injured ligaments, and the Hindus and Chinese used therapeutic exercise in the treatment of athletic injuries as early as 1000 B.C. [14].

In other perspectives of medication, regarding the medical ethics influenced by religious traditions during medical practice through the Middle Ages, Catholics incorporated principles of medical decision making into their moral theology. Protestants, too, have examined specific ethical topics in detail and integrated concepts of medical ethics into a larger, systematic theology. Orthodox Jews have linked Talmudic and rabbinical teachings to the practice of medicine, with emphasis on the preservation and sanctity of life.

The concepts forming the basis for therapeutic exercise come from studies in basic physiologic science and applied exercise physiology. In recent years, epidemiologic investigations have provided additional insight into the importance of exercise in prevention of disease.

Fig. 2-1 The conventional physical rehabilitation therapy for elderly [15].

2.2 Stereo Camera for Motion Tracking

A commercialized stereo camera (Kinect v.1 for Windows, Microsoft, USA) is used as one of important components in this research. The Kinect is a device developed by Microsoft, with multiple vision sensors, which enables remote movement tracking of users originally for the X-box 360 gaming console. The use of the device is expanded to not only gaming purposes, but also applications for multiple purposes by releasing the development tools such as SDK for personal computer. The technical specifications and features of Kinect are as shown in Table 2-1.

Table. 2-1 Specifications of Microsoft Kinect v.1 [16].

Features	Kinect v1
Depth sensor type	Structured light
RGB camera resolution	640 x 480, 30fps
IR camera resolution	320 x 240, 30fps
Field of view of RGB image	62° x 48.6°
Field of view of depth image	57° x 43°
Operative measuring range	0.8m - 4m (Default) 0.4m - 3.5m (Near)
Skeleton joints defined	20 joints
Maximum skeletal tracking	2

2.3 Motion Recognition Methods

In this paper, the basic concept of a motion is defined as a group of poses in order. Thus, a motion can be recognized by detecting user's poses one by one consistently, in the time sequence. Motion recognition process starts from detecting user poses in time sequence using the method which will be described in chapter 2.3.1. A motion is found when it completes counting all poses for a motion within the certain thresholds set as the definition of each pose as in chapter 2.3.2.

2.3.1 Pose Detection

A human body in this system consists of total 20 joint points as drawn in Fig. 2-2. Thus, value of specific joint points in the 3D space must be stored for detecting user poses and figuring the current user pose status. And then, each joint angle is calculated by reading 3 adjacent joints, which will be described with details in chapter 4.

2.3.2 Motion Recognition

The basic concept of a motion is a group of poses in order. Thus, a motion can be recognized by detecting user's poses one by one consistently, in the time sequence. The thresholds of time and joint angles are set to distinguish the success and failure of poses. With similar concepts using a commercialized stereo camera, many researchers have found it useful for patients who are physically disabled [17] [18] [19] [20].

A commercialized stereo camera with two sensors; color and depth sensors, called Kinect (manufactured by Microsoft) has commonly been used for obtaining skeleton data frames in 3D coordinates with 20 body joint points.

The equation of the joint points data is shown as $C_t^j = [x, y, z]^T$ at every frame t [21].

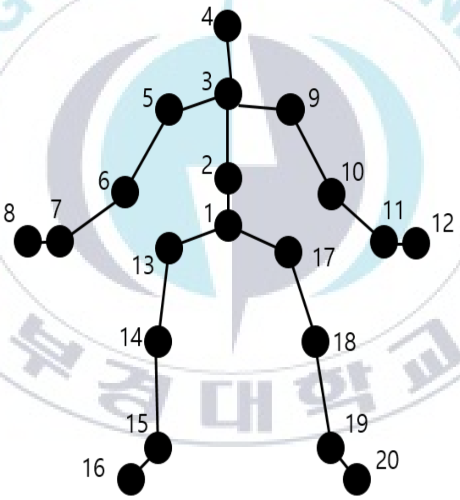

Fig. 2-2 Human skeleton data with 20 joint points tracked in this system.

2.4 Joint Range of Motion Evaluation

2.4.1 Evaluation of Body Function

Before beginning with range of motion evaluation and physical treatments for rehabilitation, the diagnosis procedure of disease identification for examiners and physiatrist must be mentioned in advance. Medical diagnosis focuses on two factors; the historical clues and physical findings that lead the examiner to the correct identification of disease. After a medical diagnosis is established, the physiatrist is expected to ascertain functional consequences of the disease. Appropriate clinical evaluation requires the examiner to have a clear understanding of the distinctions among the disease, body functions, activity limitations, and participation restrictions, etc.

For successful rehabilitation, the physiatrist not only must address the consequences of impaired functioning directly but also must identify intact functional capabilities. When the intact capabilities and their use are augmented and adapted to new uses, functional independence can be enhanced.

2.4.2 Range of Motion

Range of Motion is a basic technique used for the examination of movement and for initiating movement into a program of therapeutic intervention. Thus, the full motion possible is called range of motion. the ROM activities can easily be described in terms of joint range and muscle range, and the ranges of available joint motion are usually measured with a goniometer and recorded in degrees. In case to describe joint range, terms such as flexion, extension, and rotation are used, and muscle range is related to the functional excursion of muscles [22] [23].

The range of motion can be decreased by many factors, such as systemic, joint, neurological or muscular diseases; surgical or traumatic insults; or simply inactivity or immobilization for any reason.

The ROM exercises can be classified into 3 types by the subject of the body control; passive ROM, active ROM, and active-assistive ROM, as in Table 2-2.

The passive ROM, also called as PROM, is movement of a segment within unrestricted ROM that is produced entirely by an external force, such as gravity, a machine or another individual and there is little to no voluntary muscle contraction. Unlike PROM, the Active ROM, also called as AROM, is produced by active contraction of the muscles crossing that joint. Last, Active-assistive ROM (A-AROM) is a type of AROM with assistance provided by outside force because the prime mover muscles need assistance to complete the motion [24].

In our system, it is designed for evaluations of AROM, thus, the user practices ROM exercises actively with no help as intended. The ROM evaluation session was executed while the user practices rehabilitation exercises throughout the application. The ROM data scanned from the user activity was analyzed to show the change in body performance.

Table. 2-2 Three different types of range of motion and their description.

ROM type	Subject of motion control
Passive Range of Motion (PROM)	Therapist or equipment
Active Assisted Range of Motion (A-AROM)	Patient with some help from the therapist or equipment (such as a strap)
Active Range of Motion (AROM)	Patient (without any assistance)

Chapter 3

3 System Design and Conceptualization

3.1 System Overview

The diagram of the system procedure is briefly explained in Figure 3.1. The system is consisted of 3 divisions in order; System setup, exercise sessions, and ROM recording as results.

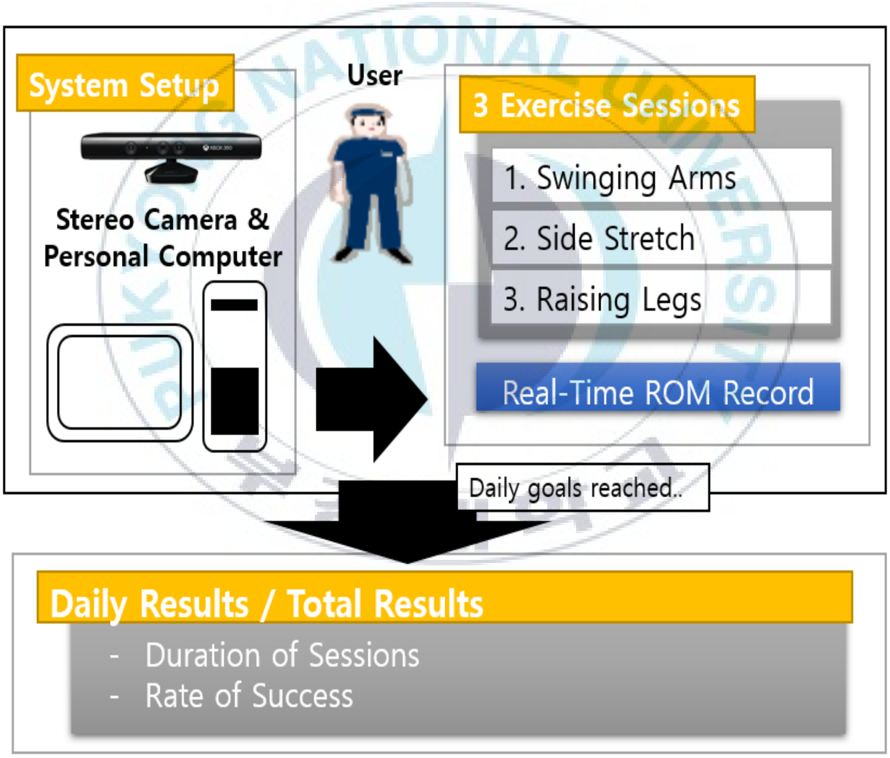

Fig. 3-1 System architecture of the home-based rehabilitation exercises.

3.2 System Setup

First, the system setup requires a personal computer with a stereo camera installed in advance, and the user needs to stand in front of the camera and make sure that the program can detect the full body of the user until the end of the program for proper motion tracking.

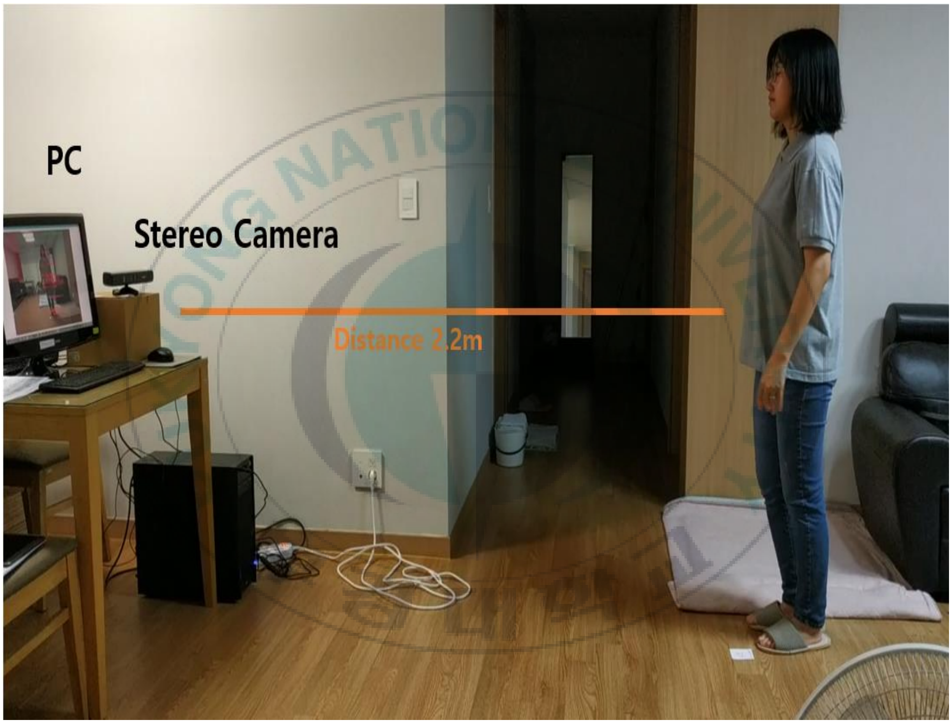

Fig. 3-2 System setup: A user is standing around 2.2m away from a stereo camera to reflect the full body.

3.2.1 Exercise Session

The exercise session for rehabilitation includes 3 motions; swinging arms, side stretch and raising legs as mentioned with details in Fig. 3-3 and Fig. 3-4. Those are common exercises selected among various rehabilitation exercises for the user's better understanding of exercises and less time consuming for materialization.

The user takes one motion as instructed for 5 times continuously, then take a short break within a minute and then, it is considered as one session completed. The user repeats the session 3 times (total 15 times of motions; 5 motions × 3 sessions, Fig. 3-4), then begins the next exercises in order.

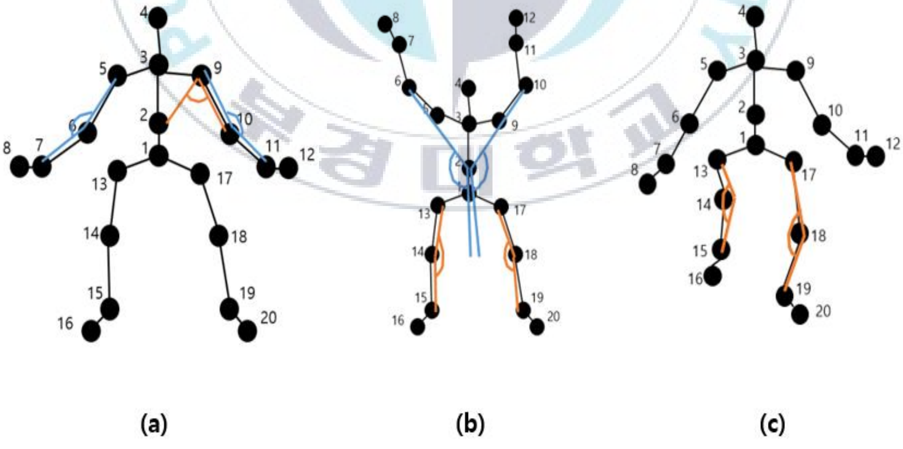

Fig. 3-3 Human skeletal data with joint angles detected for pose detection for each a swinging arms(a), a side stretch(b) and a raising legs(c) motions [17].

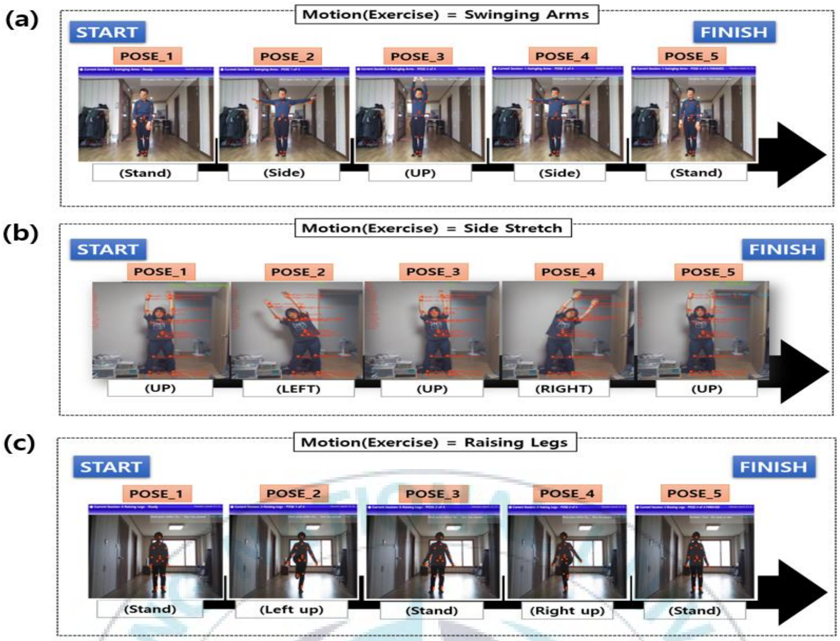

Fig. 3-4 Sequence of a swinging arms(a), a side stretch(b) and a raising legs(c) motions

Fig. 3-5 The session flowchart of the suggested rehabilitation program.

Each session contains 5 motions.

3.2.2 ROM Recording

During sessions, the user information and exercise status such as specific joint angles of the body and success/failure count also gets recorded simultaneously.

3.2.3 Repeated Motion for ROM Improvement

A special session for disabled who aren't able to move to make the intended poses due to injuries is implemented in the system, which is briefly explained in Fig. 3-6. Among various common stretching exercises, we picked to measure the joints of shoulders with arms stretched to the back. The session will be presented separately in results.

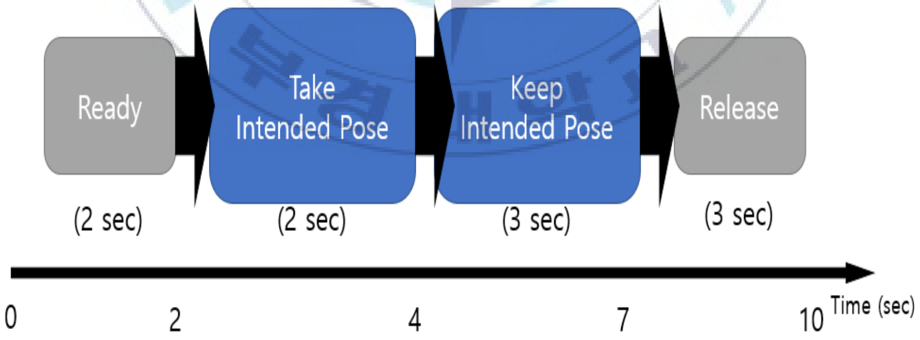

Fig. 3-6 Procedure of repeated motion for the disabled.

Chapter 4

4 Motion Tracking and ROM Evaluation

4.1 Pose Detection

The principle of the pose detection feature was briefly introduced in the previous chapter. Fig. 4-1 shows the procedure of pose detection with details.

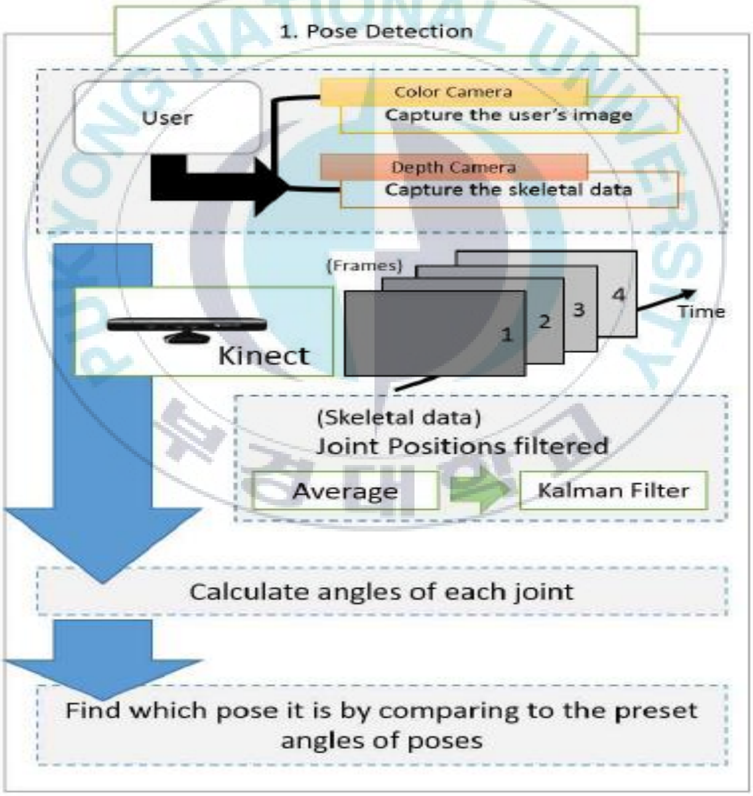

Fig. 4-1 The diagram of pose detection feature

As the user stands in front of the stereo camera, the system senses total 20 joints from the human body in 3D coordinate. While the depth sensor of the stereo camera is used for detecting the skeletal data, the color sensor projects the scenery on the monitor with the joints over the scenery. The coordinate data (x, y and z axis) of each joint is obtained from the depth camera, and we pick a set of 3 specific adjacent joints as in Fig. 4-2, for example, $J_1(x_1, y_1, z_1)$, $J_2(x_2, y_2, z_2)$, $J_3(x_3, y_3, z_3)$, as mentioned in Table 4-1. Then the joint angle of J_2 between J_1 and J_3 can be calculated as follow.

$$\theta = \cos^{-1}\frac{\overline{J_1J_2} \bullet \overline{J_2J_3}}{\overline{J_1J_2} \times \overline{J_2J_3}}$$

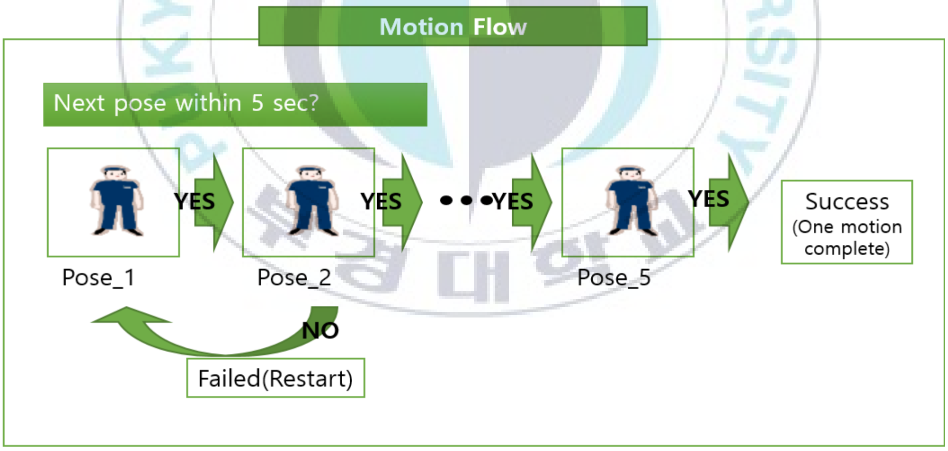

Fig. 4-2 An example of a motion flow with poses in order. If the next pose is not detected within 5 seconds from the time recorded when the last pose was shown, it is defined as failure of a motion and it resets the motion to the very first pose.

Table. 4-1 Body parts with the 3 joint points to measure the specific joint angles to track user exercises.

Exercise Name	[3 adjacent joint number]			
	Angle_1	**Angle_2**	**Angle_3**	**Angle_4**
Swinging Arms	[2,5,6] (Left Armpit)	[5,6,7] (Left Elbow)	[2,9,10] (Right Armpit)	[9,10,11] (Right Elbow)
Side Stretch	[(14+18)/2, 2, 6] (Left side)	[(14+18)/2, 2, 10] (Right side)	[13, 14, 15] (Left knee)	[17, 18, 19] (Right knee)
Raising Legs	[13, 14, 15] Left knee	[17, 18, 19] Right knee	(None)	(None)

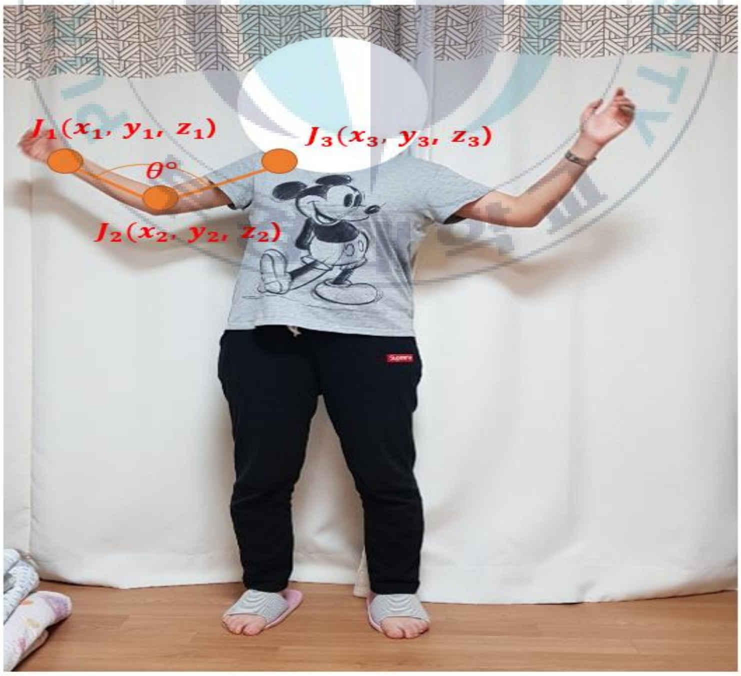

Fig. 4-3 Example of 3 adjacent joints selected for measuring the joint range of motion.

Fig. 4-4 Detected joints for first exercise, named as swinging arms.

Fig. 4-5 Detected joints for second exercise, named as side stretch.

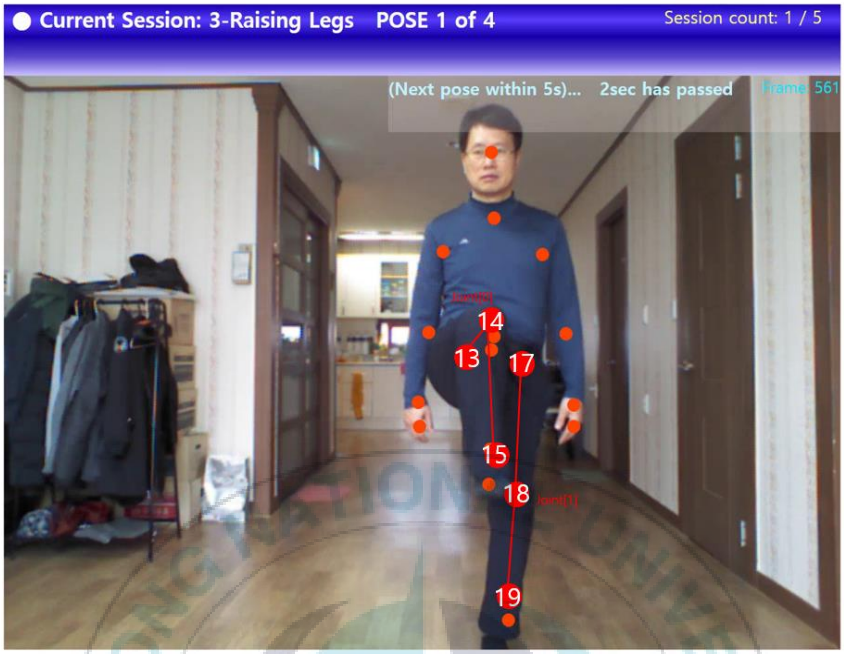

Fig. 4-6. Detected joints for the last (third) exercise, named as raising legs.

The joint angles, calculated from the adjacent joints, are to be compared with the pre-defined joint values to judge if the user's pose is what the system is intended at the time. The principle of ROM session is the same as the pose detecting method.

4.2 Motion Recognition

4.2.1 Basic Operation

In this research, the basic concept of one motion is a group of poses in time sequence. Thus, a motion gets recognized by detecting user's poses one by one consistently in the time sequence. A threshold of time between 2 poses is set to distinguish success and failure of a motion. Thus, if the user is not taking the next pose within the threshold time, it's considered as failure and the session restarts to the beginning step of a motion. If the user completes the last pose through all steps in order, the system judges that the user succeeded the exercise. User attempts of sessions and success and failure are also counted and saved in the system.

For patients and elderly having difficulties moving their body parts as intended might not be able to reach the normal poses, therefore, with the same method mentioned above cannot always work in a different condition. So, we compare the angles from the next intended pose and the previous pose, and then subtract them to find if the angles are increasing or decreasing as vectors. Those vectors will be compared with the patients' data in real-time and find if the users are moving to the intended directions.

4.2.2 Feature Enhancement

The built-in joint detecting feature in the Kinect v1.8 SDK can recognize 20 joint points of a human body as explained previously.

Each joint point contains 3 numbers which are from its x, y and z axis and those values change every frame. However, the accuracy of the values can become suspicious due to the motion noise interfering the original data we like to obtain.

There are 2 filters used for more accurate motion data in this research: the averaging filter and the Kalman filter. The averaging filter is used as follows:

$$x_{avg} = \frac{\sum_{n=1}^{N} x_n}{N} \qquad (2)$$

N in the equation is the number of frames, and the x is the values from x, y or z axis for the N frames.

The basic equations of the Kalman filter are explained as below:

$$\hat{x}_k^- = A\hat{x}_{k-1} \qquad (2)$$

$$P_k^- = AP_{k-1}A^T - Q \qquad (3)$$

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1} \qquad (4)$$

$$\hat{x}_k = \hat{x}_k^- + K_k(Z_k - H\hat{x}_k^-) \qquad (5)$$

$$P_k = (I - K_k H)P_k^- \qquad (6)$$

The equation (2)-(3) are the estimation session, and the equation (4)-(6) are called the measurement session of the Kalman filter.

4.3 Real-Time ROM Evaluation

As mentioned previously in Chapter 4.1, the same algorithm for pose detection is used to materialize the ROM evaluation in real-time. The ROM values of specific joints being tracked for pose detection are compared with the pre-defined joint values as proper ROM for specific positions.

The comparison for the pre-defined joint values and the measured values in real-time can be described as pseudo code in Fig. 4-7.

```
double joint_value_rad = new double[4];
int j = 0;        //check if all 4 joint values are matching
for(int i=1;i<=4;i++)
{
    if((double_joint_value_rad[i] >= threshold[i]-0.13) &&
      (double_joint_value_rad[i] <= threshold[i]-0.13))
    {
          detected[i] == true;
          j++;
    }
    else
    {
         detected[i] == false;
    }
}
if(j == 4)
{
     return 1;
}
else
{
     return -1;
}
```

Fig. 4-7 Pseudo code to check if all 4 joints are close to the pre-defined values (radian unit) set as thresholds.

Chapter 5

5 User Interface of Rehabilitation Application

5.1 Architecture of User Interface

The user interface of the rehabilitation application will be explained based on the architecture of the system described earlier in chapter 3. Fig. 5-1 includes the user interface shown step by step.

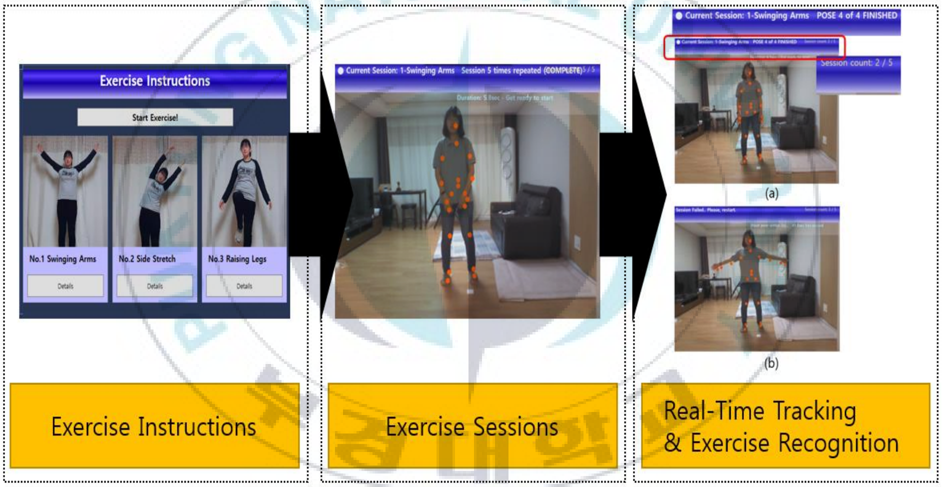

Fig. 5-1 The diagram of the presented application's user interface in this paper.

5.2 Available Exercises for Rehabilitation

The exercise instructions page pops up before beginning the exercise session in the application as shown in Fig. 5-2. Total 3 types of exercises can be executed by the system, and when user hovers over the details button, text descriptions will show up as a dialog.

Once the user figures out the exercise method in this system, the user can move on to the next stage by clicking "Start Exercise!" button. Then the exercise session just as Fig. 5-3 will pop up. As highlighted, the interface of the exercise session includes various information.

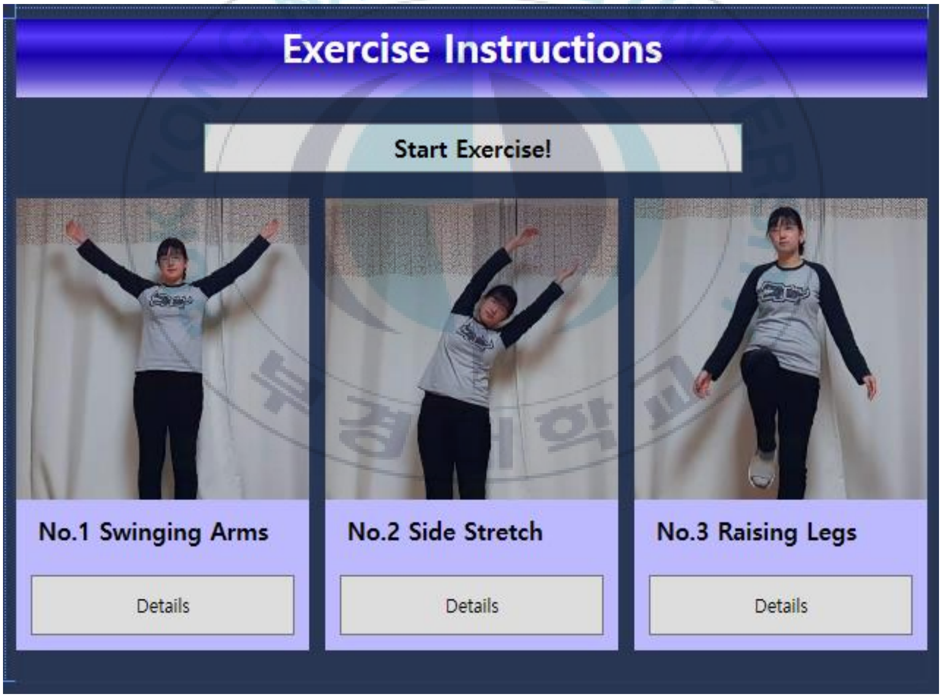

Fig. 5-2 Exercise instructions window before user begins exercise.

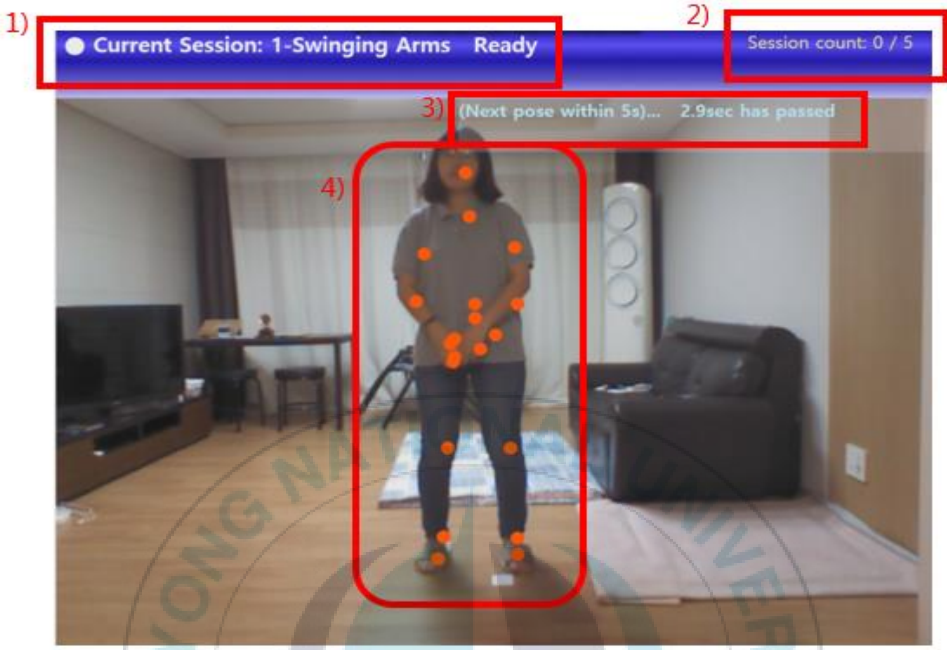

Fig. 5-3 The user interface of the rehabilitation program, and the user is standing with hands down before beginning an exercise session. 1) Current exercise status, 2) Session count (5 times repeated to finish one session), 3) Time duration of exercise and 4) Human body joint detection.

While the user exercises along as led by the system, ROM is simultaneously recognized to judge if the user is taking motions as intended and also track the user's ROM values as a reference of body function performance. Fig. 5-4 shows the interface with the information mentioned.

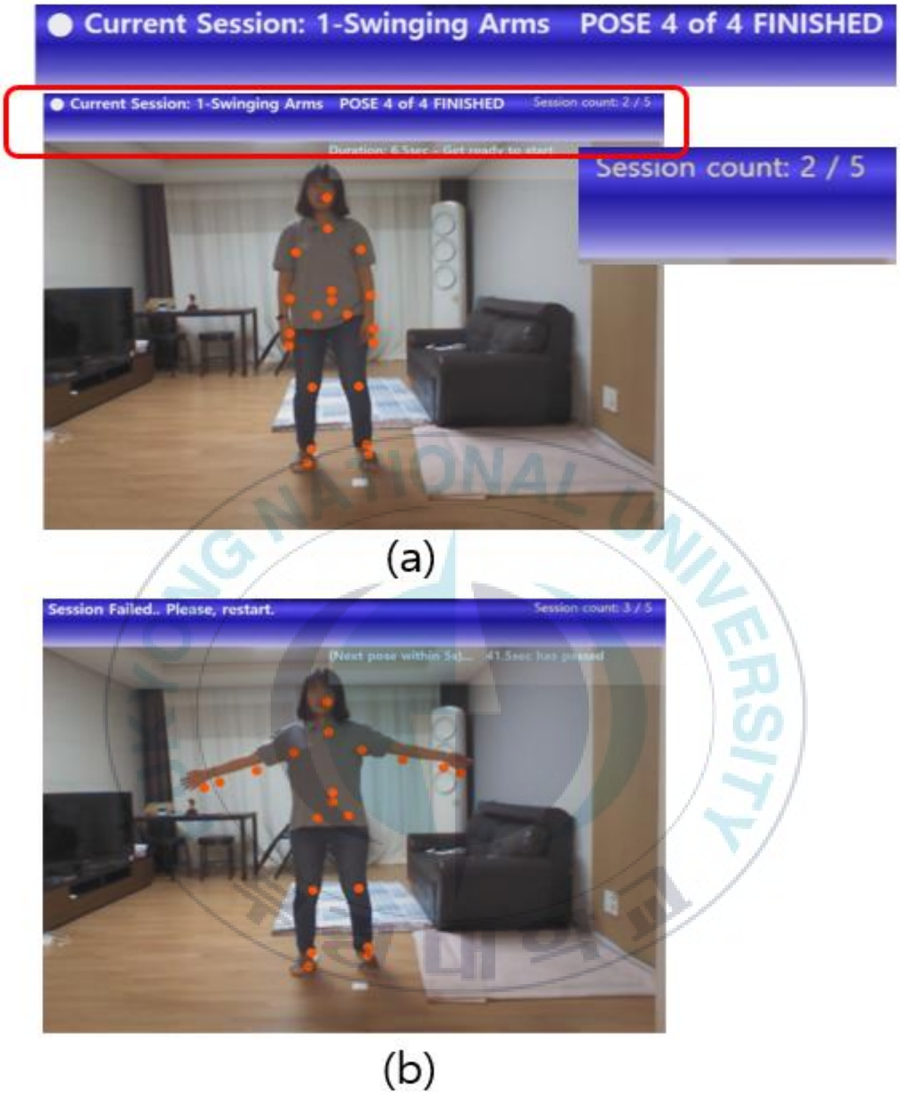

Fig. 5-4 A user interface for a success(a) and a failure(b) notifications of exercises during a rehabilitation exercise session.

Chapter 6

6 Results and Discussion

6.1 Experiment Initialization

The hardware components consist of an all-in-one stereo camera with a color and depth camera in one device (Kinect v.1, Microsoft, USA), and a personal computer with Windows OS installed. The stereo camera has the color resolution of 1240×860 pixels and the depth resolution of 640×480 pixels. The frame rate set in the paper is 30 frame-per-second. The 'Kinect for Windows SDK' is used to build part of the Windows Application for the system with its basic skeletal tracking feature included. To execute the Windows Application of the system, a personal computer running the Microsoft Windows OS version 8.1 was used on a personal computer in this experiment. (Intel Core i5-4690 CPU at 3.50Hz, 8GB of RAM, and the Microsoft Windows 8.1 for the 64-bit operating system). With the system described, a user stands around 2.2 meters to 3 meters away from a stereo camera so it can read the full body properly.

6.2 Real-Time Motion Recognition and Rehabilitation Exercises

As mentioned earlier, in the exercise session of the application introduced in the paper, the user’s motion is recognized in real-time. The real-time motion recognition in 3D coordinate is shown in a 3D space in Fig. 6-1.

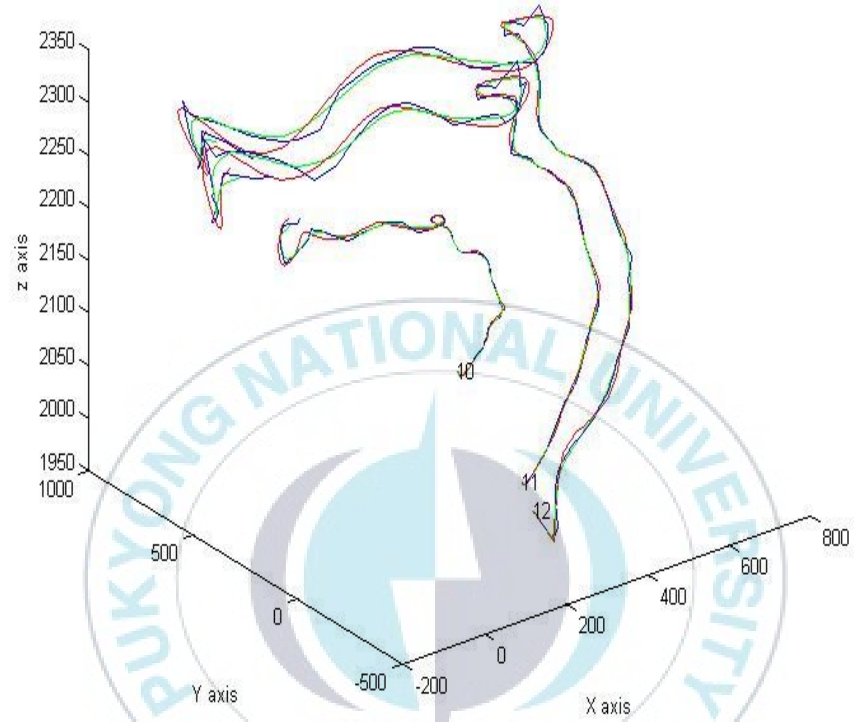

Fig. 6-1 Motions of 10th, 11th and 12th joints in 3D coordinate when raising an arm (3 attempts each).

6.3 Subject Data Analysis

Three subjects participated in the experiment, and the characteristics of each person are described in Table 6-1. Each person was instructed about 3 rehabilitation exercises in advance and practiced once before the beginning of each session. Each exercise was repeated 9 times in a row with a break time between sessions for less than 1 minute, and as soon as one exercise was done by repeating 9 times, the system led the subject to the next exercise session.

Table. 6-1 Basic personal information of all 3 subjects participated in the experiment.

Subject	Sex	Age	Height	Weight	Chronic Disease
A	F	Mid-50s	160cm	66kg	None
B	M	Late-50s	175cm	72kg	Hyperpiesia
C	F	Late-20s	160cm	60kg	None

Fig. 6-1 is the data recorded from exercises; swinging arms and raising legs as references to show data processing the raw angle data in radian unit and the thresholds which distinguish between the previous pose and the next pose. The highlighted parts are the borders to the next pose. However, there are some failures which couldn't reach to the end of the motion (to the last pose) as intended. and it's mostly due to lack of enough pose changes to detect the next pose within 5 seconds (150 frames).

Fig. 6-2 shows the difference in time duration per session. In average, it consumes less time as the users execute the same exercises. It abnormally takes more time when the subjects made mistakes taking wrong poses and couldn’t fix them within 5 seconds. The duration of sessions seemed to decrease as repeating the same motions made them adjusted but around 6th-

7th sessions, the graphs show that it's more time consuming on average as physically, their bodies got tired.

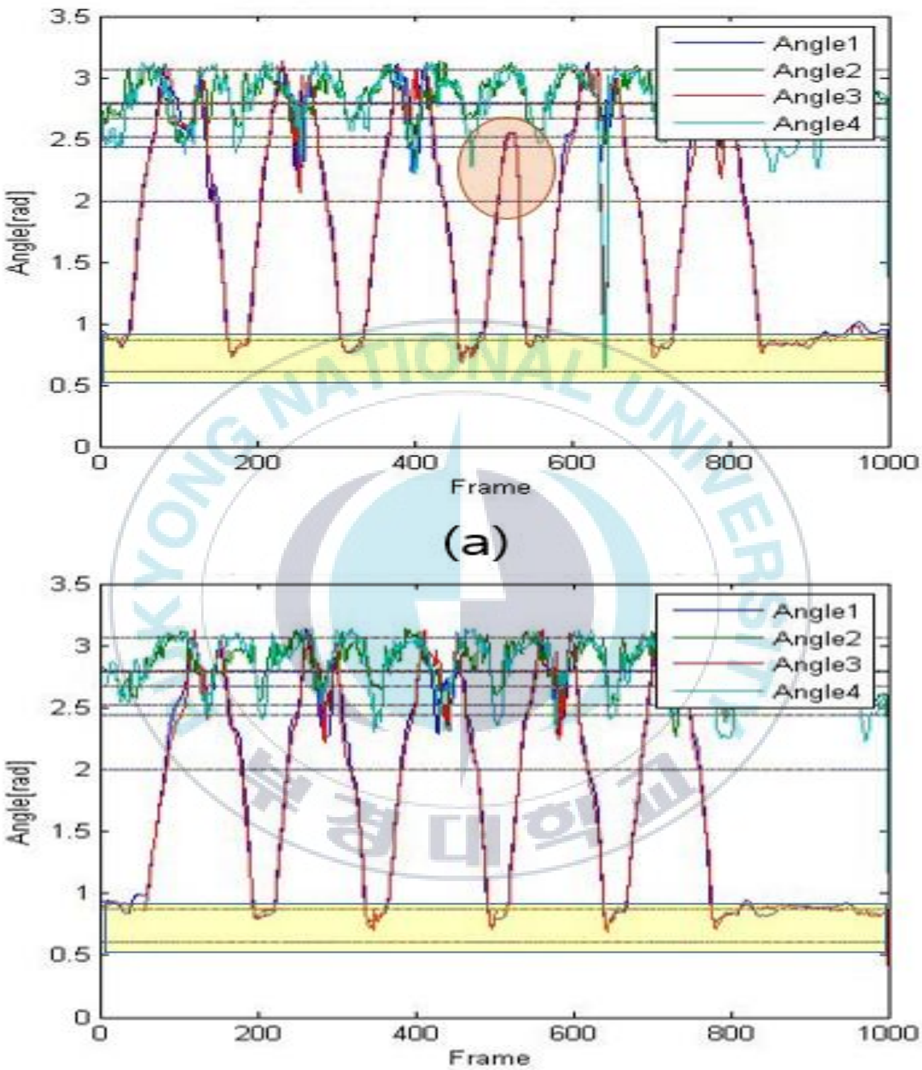

Fig. 6-2 Subject C`s exercise data (specific joint angles from swinging arms), the graphs show raw values of 4 angles from the first exercise session(a), and the last(9th) exercise session(b).

Table 6-2 presents to compare the average exercise time depending on subjects, and subject C's results overall were outstanding while the other two subjects in the 50's consumed a maximum of 4.3 minutes in exercise 1(Swinging arms).

Table. 6-2 The average time consumption of exercises by subject.

Subject	Exercise_1 (Swinging Arms)	Exercise_2 (Side Stretch)	Exercise_3 (Raising Legs)
A	51.3	40.0	32.7
B	50.9	41.1	31.9
C	47.0	37.3	32.9

In the exclusive, repeated motion session for disabled, a motion of raising arms backward was repeated 7 times continuously without a break. The extracted data from a subject is presented in Fig. 6-4 and Table 6-3.

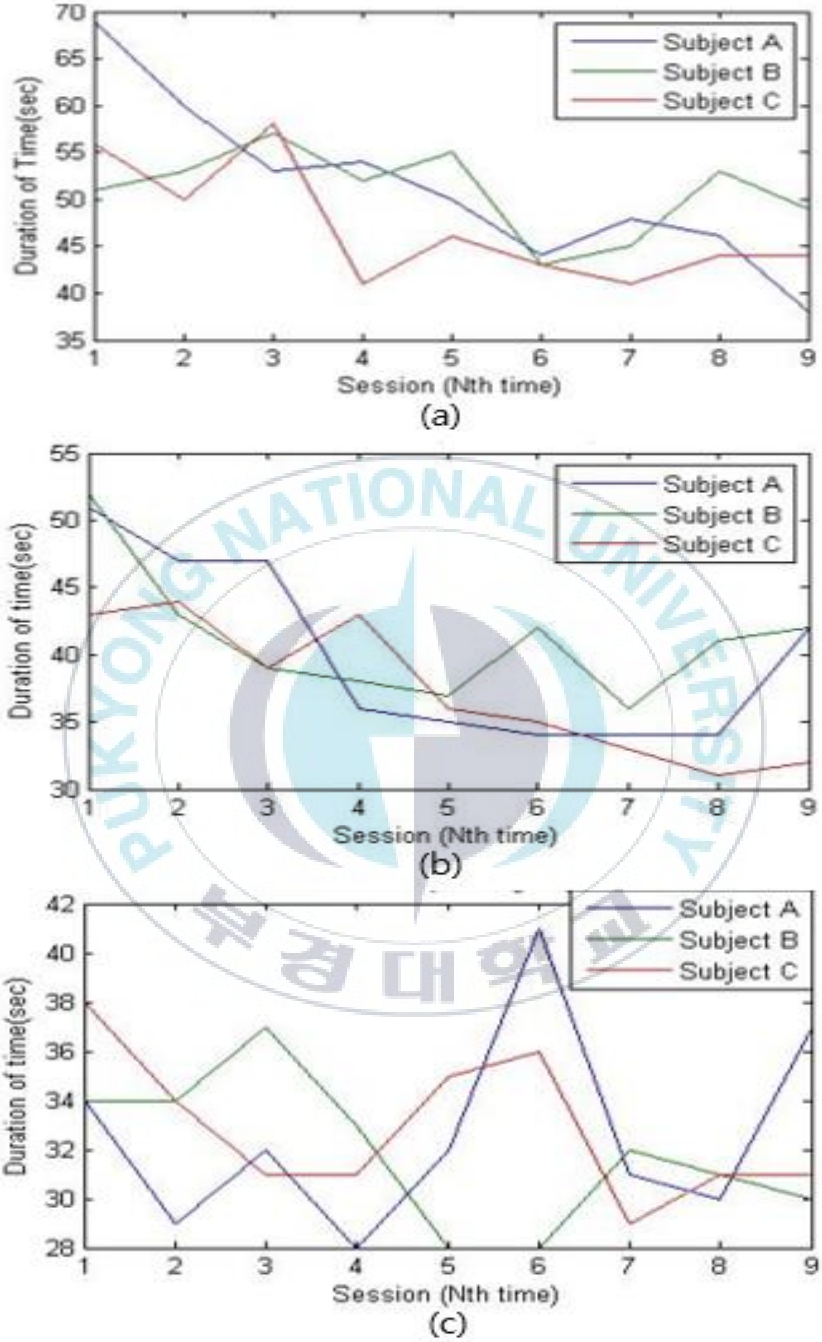

Fig. 6-3 The graphs show the change of exercise time duration per session, swinging arms(a), side stretch(b), and raising legs(c).

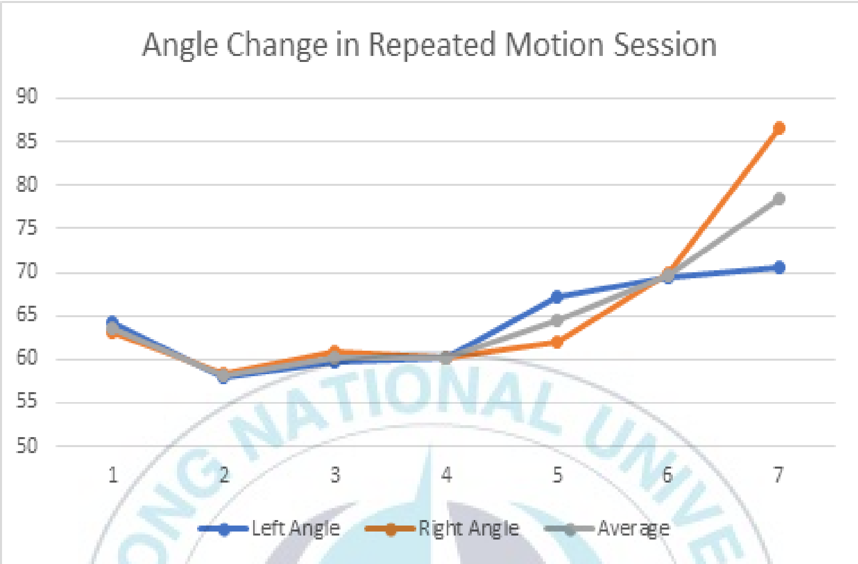

Fig. 6-4 The graph is presented to show how angles are improved over time as the subject A moves arms stretching backwards 7 times repeatedly. The average value implies that arms tend to further as intended.

Table. 6-3 Subject A's exercise data from repeated motion session (raising arms backward).

Repeat Count	Left Angle [rad]	Right Angle[rad]	Left Angle[°]	Right Angle[°]	Average of left/right angles[°]
1	1.12	1.10	64.20382	63.05732	63.63057
2	1.01	1.02	57.89809	58.47134	58.18471
3	1.04	1.06	59.61783	60.76433	60.19108
4	1.05	1.05	60.19108	60.19108	60.19108
5	1.17	1.08	67.07006	61.91083	64.49045
6	1.21	1.22	69.36306	69.93631	69.64968
7	1.23	1.51	70.50955	86.56051	78.53503

Chapter 7

7 Conclusion

The remote rehabilitation system with motion tracking for ROM improvement was introduced. The user interface for an exercise session is presented as well as the results in ROM of users analyzed, and the performance for simple motions selected for rehabilitation exercises is acceptable without needing external devices other than the suggested stereo camera. However, the system might not be able to read the body information of patients with a physical disability from serious damage or amputation which is critical for the accuracy of the motion tracking features in the system. Also, the design of the program can be boring with limited interaction with a user. In the next research, fabrication of rehabilitation exercise systems with more content or games applying AR or VR might attract more interest in the healthcare field.

References

[1] Rehabilitation, [Online], Available: https://english.oxforddictionaries.com/rehabilitation

[2] H. Zhou and H. Hu, "Human motion tracking for rehabilitation-A survey", Biomedical Signal Processing and Control, Volume 3, Issue 3, 2006, pp. 343-351.

[3] Home Rehabilitation Products and Services Market, [Online]. Available: http://www.transparencymarketresearch.com/home-healthcare-market.html

[4] C. Wang, L. Wang, J. Qin, Z. Wu, L. Duan, Z. Li, X. Ou, Weiguangli, Z. Lu, M. Li, Y. Wang, J. Long, M. Huang and Q. Wang, "Development of a novel finger and wrist rehabilitation robot for finger and wrist training", TENCON 2015-2015 IEEE Region 10 Conf., pp. 1-5, Macao, China, 2015.

[5] A. Koenig, A. Caruso, M. Bolliger, L. Somaini, X. Omlin, M. Morari and R. Riener, "Model-based heart rate control during robot-assisted gait training", 2011 IEEE International Conf. on Robotics and Automation, pp. 4151-4156, Shanghai, China, 2011.

[6] X.-K. Fang, B. Han and J.-H. Wang, "Adaptive velocity field control of upper-limb rehabilitation robot," 2016 Chinese Control and Decision Conference (CCDC), pp. 5438-5443, Yinchuan, China, May 2016.

[7] R.Li, X.Sha and K.Lin, "Smart greenhouse: A real-time mobile intelligent monitoring system based on WSN," in Wireless Communications and Mobile Computing Conference (IWCMC), 2014 International ,pp. 1152-1156, 4-8 Aug. 2014.

[8] A. Masdar B. S. K. K. Ibrahim, D. Hanafi, M. M. A. Jamil, and K. A. A. Rahman, "Knee joint angle measurement system using gyroscope and flex-sensors for rehabillitation", The 6th 2013 Biomedical Engineering International Conference, 2013.

[9] E. Jovanov, A. Milekovic, C. Otto and P. C de Groen, "A wireless body area network of intelligent motion sensors for computer assisted

physical rehabilitation", Journal of NeuroEngineering and Rehabilitation, 2005.

[10] A. P. L. Bo, M. Hayashibe and P. Poignet, "Joint angle estimation in rehabilitation with intertial sensors and its integration with Kinect", 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2011.

[11] C.-K. Tey, Y.-S. Lee and Y.-W. Chung, "Healthcare monitoring system combined with noncontact Kinect-based rehabilitation for outpaitnets", KISPS Summer Conf. 2014, pp. 27-28, Gyengsan, Korea, 2014.

[12] C.-L. Lai, Y.-L. Huang, T.-K. Liao, C.-M. Tseng, Y.-F. Chen and D. Erdenetsogt, "A microsoft Kinect-based virtual rehabilitation system to train balance ability for stroke patients", 2015 International Conference on Cyberworlds(CW), pp. 54-60, Gotland, Sweden, 2015

[13] C.-M. Tseng, C.-L. Lai, D. Erdenetsogt and Y.-F. Chen, "Microsoft Kinect based virtual rehabillitation system", 2014 International Symposium on Computer, Consumer and Control (IS3C), pp. 934-937, Taichung, Taiwan, 2014.

[14] J. A. DeLisa, B. M. Gans and N. E. Walsh, "Physical Medicine and Rehabilitation: Principles and Practice", Volume 1, Lippincott Williams & Wilkins, 2005, pp. 389.

[15] Physical Rehabilitation, [Online], Available: https://www.pennmedicine.org/for-patients-and-visitors/find-a-program-or-service/physical-medicine-and-rehabilitation

[16] A. Al-Naji, K. Gibson, S.-H. Lee and J. Chahl, "Real Time Apnoea Monitoring of Children Using the Microsoft Kinect Sensor: A Pilot Study", Sensors(Basel), Feb. 2017.

[17] B. Galna, G. Barry, D. Jackson, D. Mhiripiri, P. Olivier and L. Rochester, "Accuracy of the Microsoft Kinect Sensor for Measuring movement in people with parkinson's disease", Gait & posture, vol. 39, no. 4, pp. 1062-1068, 2014.

[18] A. Mobini, S. Behzadipour, and M. Saadat, "Test-retest reliability of kinects measurements for the evaluation of upper body recovery of stroke patients", Biomedical Engineering Online, vol. 14, no. 1, pp. 75, 2015.

[19] W.-S. Kim, S. Cho, D. Baek, H. Bang, and N.-J. Paik, "Upper extremity functional evaluation by fugl-meyer assessment scoring using depth-sensing camera in hemiplegic stroke patients," Plos one, vol. 11, no. 7, pp. e0158640, 2016.

[20] Y. Hirano, D. Kushida, and H. Matsumoto, "Contactless Motion Analysis System Using a Kinect and Musculoskeletal Model", 2017 IEEE Life Sciences Conference (LSC), 2017.

[21] S. Sinha, B. Bhowmick, A. Sinha, and A. Das, "Accurate Estimation of Joint Motion Trajectories for Rehabilitation Using Kinect", 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2017

[22] Range of Motion, [Online], Available: https://www.sciencedirect.com/topics/medicine-and-dentistry/range-of-motion

[23] D. C. Boone and S. P. Azen, "Normal range of motion of joints in male subjects", The Journal of Bone and Joint Surgery, Vol. 61, Issue 5, pp. 756-759, 1979.

[24] C. Kisner, L. A. Colby and B. John, “Therapeutic Exercise Foundations and Techniques (Therapeudic Exercise: Foundations and Techniques)”, 7th Edition, F A Davis, Oct. 2017.

List of Publications

Domestic Journals

1. K. Kim, W.-Y. Chung and J.-J. Kim, "A Remote Rehabilitation System using Kinect Stereo Camera", *Journal of Sensor Science and Technology*, Vol. 25, No. 3, pp. 196-201, 2016.
2. K. Kim and W.-Y. Chung "A Home-Based Remote Rehabilitation System with Motion Recognition for Joint Range of Motion Improvement", *Journal of the Institute of Convergence Signal Processing*, Vol. 20, No. 3, pp. 151-158, 2019.

Domestic Conferences

3. K. Kim, W.-Y. Chung, "Stereo Camera Based Bio-Signal Recognizable Remote Rehabilitation System", *Proceedings of the Korea Institute of Signal Processing and Systems Conference (KISPS)*, pp. 41, 2015.
4. K. Kim, W.-Y. Chung, "Stereo Camera-based Skeleton Recognizing Rehabilitation Exercise System", *Proceedings of the Korea Institute of Signal Processing and Systems Conference (KISPS)*, 2019.