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관절 가동범위 향상을 위한 원격 모션 인식 재활 시스템

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

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요 약 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 참여를 권장 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 관절가동범위(Joint ROM; Joint Range of Motion)를 저장하여 신체 기능의 향상도를 확인한다. 이 논문에서는 시스템의 검증을 위하여 총 4명의 실험군이 참여하였으며, 총 3종류의 운동을 각 9회씩 반복한 데이터를 이용하여 각 실험군의 시작 및 마지막 운동의 관절가동범위의 차이를 비교하였다.

• 주제어 : 원격재활, 관절가동범위, 스테레오카메라, 포즈인식, 모션인식

Abstract Patients with disabilities from various reasons such as disasters, injuries or chronic illness or elderly with limited body motion range due to aging are recommended to participate in rehabilitation programs at hospitals. But typically, it's not as simple for them to commute without help as they have limited access outside of the home. Also, regarding the perspectives of hospitals, having to maintain the workforce and have them take care of the rehabilitation sessions leads them to more expenses in cost aspects. For those reasons, in this paper, a home-based remote rehabilitation system using motion recognition is developed without needing help from others. This system can be executed by a personal computer and a stereo camera at home, the real-time user motion status is monitored using motion recognition feature. The system tracks the joint range of motion(Joint ROM) of particular body parts of users to check the body function improvement. For demonstration, total of 4 subjects with various ages and health conditions participated in this project. Their motion data were collected during all 3 exercise sessions, and each session was repeated 9 times per person and was compared in the results.

• Key Words : Remote Rehabilitation, Range of Motion(ROM), Stereo Camera, Pose Detection, Motion Recognition

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Ⅰ. Introduction

1.1 Research Background

Rehabilitation includes processes that have aims to enhance and restore the functional abilities of life to a normal state for those with physical or mental impairments following an illness, injury or surgery, aging, etc[1]. To be specific, in physical rehabilitation, it is almost mandatory for patients to visit the hospital first, and then have care workers who can support their exercise sessions or external devices attached to them. However, in reality, patients and elderly with physical discomfort generally have limited access outside, so commuting to the hospital from their home can be one of the biggest hassles even before considering participating in rehabilitation activities. Besides, needing help from others and having to attach devices on their skin could cause discomfort. Hospitals running rehabilitation programs also find difficulties in maintaining employment for the programs from the economic perspective. To find solutions for both patients and hospitals, a few researchers, over time, have attempted to improve the rehabilitation systems requiring fewer supporters, or less external devices compared to the traditional method[2], and also to enable remote rehabilitation eliminating the need of commute.

There have been quite a few attempts to detect human body movements by using a variety of devices as sources of data such as wearable types of devices with gyroscopes and other sensors that could help obtain more accurate motion tracking data. According to the research done by Aizan Masdar et al., gyroscope and flex-sensors were used for Knee joint angle measurement in rehabilitation[3]. In another method, physiological and stereo sensors are used and ambulatory monitoring was enabled for physical rehabilitation[4]. And there are more researches such as joint angle estimation using inertial sensors and cameras[5]. A few researchers have proved that the motion data could be precise enough for industrial fields, but the concerns about having to set up and use multiple devices were still not able to be eliminated.

Therefore, in this paper, a remote rehabilitation system with no external wearable devices is introduced and it only requires a user to have a personal computer and a stereo camera installed at home. The human motion tracking method is used to capture poses in real-time and to measure the joint range of motion at specific poses to evaluate body performance. The design of the presented system and technical issues are discussed, also the concept of a range of motion(ROM) is explained and the result data from ROM measurement is shown to demonstrate the performance of the system.

Ⅱ. Experiment Methods

2.1 System Description

The diagram of the system procedure is briefly explained in Fig 1. The system consists of 3 divisions in order; System setup, exercise sessions, and results. For the system setup as preparation, a personal computer with a stereo camera needs to be installed in advance. The user stands in front of the camera and makes sure that the program can detect the full body of the user until the end of the program for proper motion tracking in Fig 2. The rehabilitation exercise program includes 3 exercises; swinging arms, side stretch and raising legs as mentioned with details in Table 1 and Fig 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 motions as instructed for 9 times, then begins the next exercises in order. During the sessions, the user information and exercise status such as specific joint angles in Fig 4 of the body and success/failure count also gets recorded simultaneously.

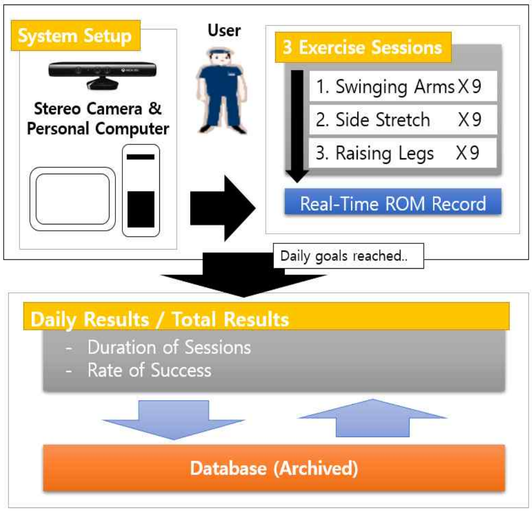

Fig. 1. System architecture of the rehabilitation exercise program

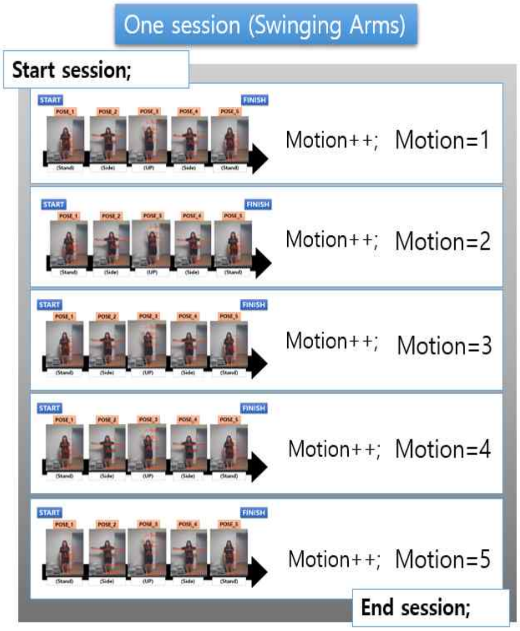

Fig. 2. The session flow of the suggested rehabilitation program

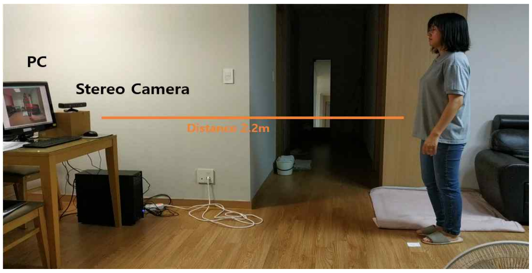

Fig. 3. System setup: A user is standing around 2.2m away from a stereo camera to reflect the full body

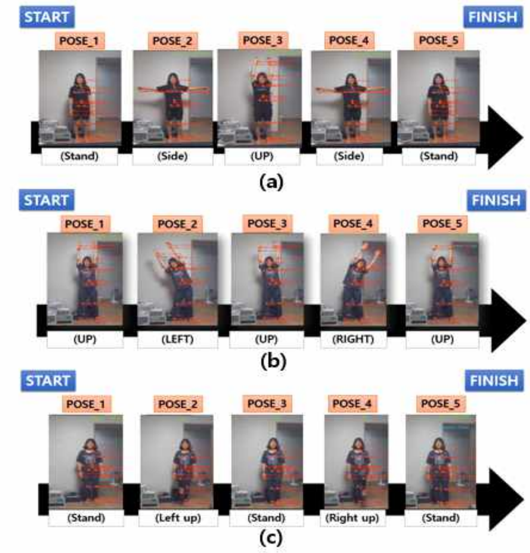

Fig. 4. Flow of a swinging arms(a), a side stretch(b) and a raising legs(c) motions

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

Exercise name	Angle1	Angle2	Angle3	Angle4
Swinging Arms	Joint no. 2, 5, 6 Left Armpit	Joint no. 5, 6, 7 Left Elbow	Joint no. 2, 9, 10 Right Armpit	Joint no. 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

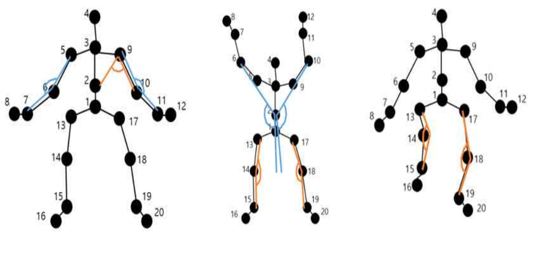

Fig. 5. Human skeletal data with joint angles detected for pose detection for each a swinging arms(a), a side stretch(b) and a raising legs(c) motions [6]

2.2 Experimental Setup

The hardware components consist of an all-in-one stereo camera with a color and depth camera in one device[7, 8, 9] (Microsoft Kinect v.1.8, 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).

2.3 User Motion Tracking

2.3.1 Pose Detection

First, all poses defined in the experimental as references are made with human joint positions in 3D and the joint angles. Thus, tracking user poses requires to read 3 adjacent joints each for the center joint angle among them. The angles calculated from 3 joint positions with x, y and z-axis are used to compare with the previous pose detected, and then judge if the user is taking the next pose as intended while all the joint angles are saved in the database in real-time.

2.3.2 Motion Recognition

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 in order, consistently. A threshold of time is set to distinguish success and failure from pose to pose, and if the user is not taking the next pose within a certain amount of time, it's considered as failure and restart the motion to the beginning step with the first pose of a motion. If the user completes the last pose through all in order, the system judges it as succeeded. 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.

2.4 Joint Range of Motion Assessment

Depending on the subject of the body control, ROM can be classified into 3 types; passive ROM, active ROM, and active-assistive ROM. Our system is designed and evaluates user motions for active ROM only which needs no support for moving the body, thus it supposes that the user exercises actively with no care supporters as the purpose of the system. In the experiment, the ROM assessment is executed from the user exercise sessions by reading and saving the joint angle data simultaneously and is analyzed to show improvement of user body performance with ROM data obtained in previous exercise attempts to be compared.

Ⅲ. Experimental Results

3.1 System Interface

The system hardware setup for the experiment was done as shown previously in Fig 3. The distance between the user and the stereo camera is about 2.2m and the height of the camera from the bottom to the camera lenses is about 1m. The camera can be set up lower or higher by tilting its body to the proper angle. The default ready pose before beginning sessions is set as a standing position. As the user moves the body to take the next pose, the system starts counting the duration of exercise time and finds the user pose correct or wrong as shown in Fig 6.

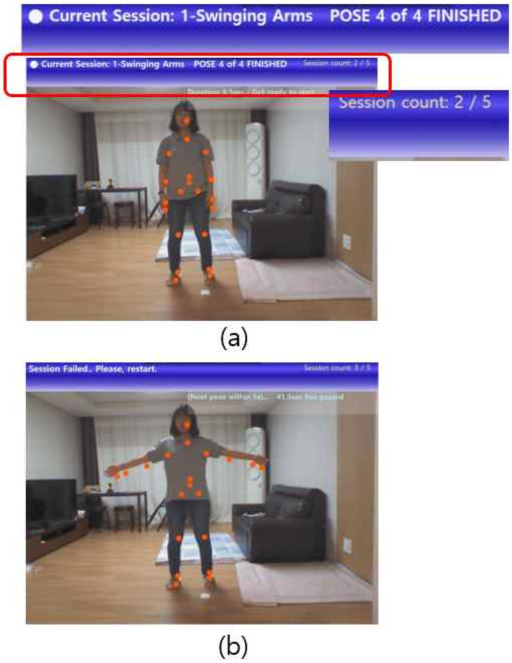

Fig. 6. An user interface for a success(a) and a failure(b) notifications of exercises during a rehabilitation exercise session

3.2 Data Analysis

Three subjects participated in the experiment, and the characteristics of each person are described in Table 2. 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 2. Basic personal information of all 4 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
D	F	Late-20s	162cm	55kg	None

Fig 7 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 in (a) of Fig 7. and it's mostly due to no enough pose changes to detect the next pose within 5 seconds(150 frames).

Fig 8 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 weren't able to 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.

Table 3 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).

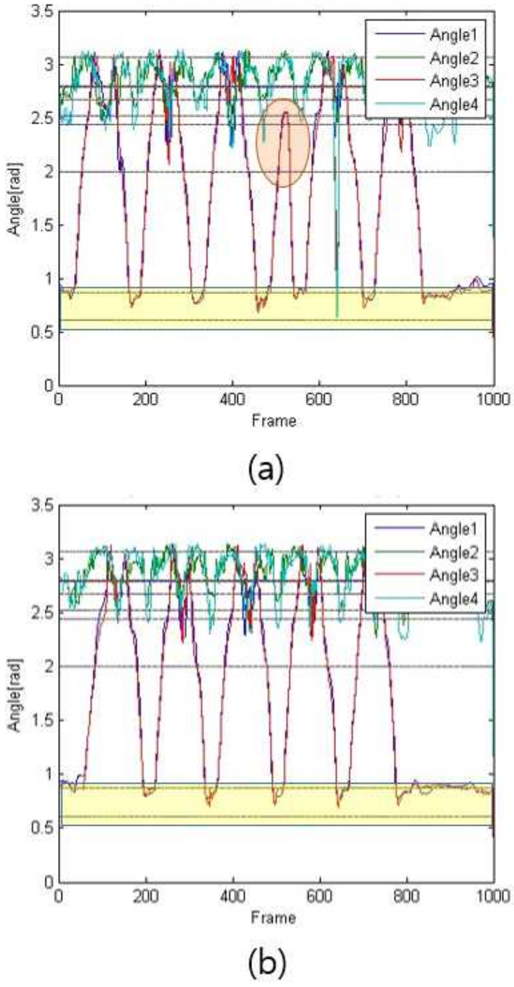

Fig. 7. Subject C's exercise data(specific joint angles from swinging arms), the graphs show raw values of 4 angles from the first exercise session(a), and the last(9th) exercise session(b)

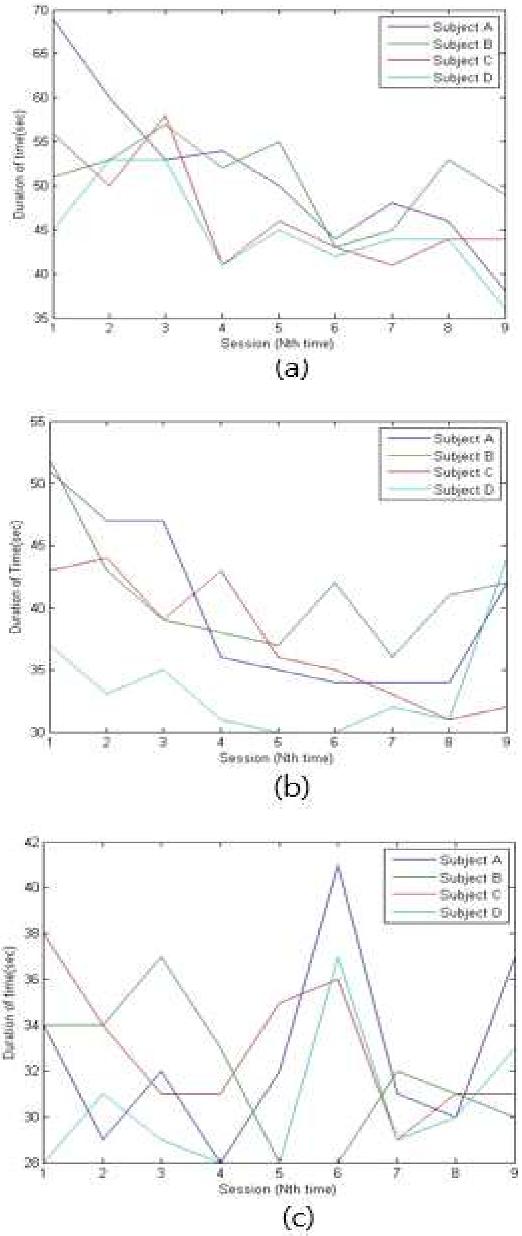

Fig. 8. The graphs show the change of exercise time duration per session; swinging arms(a), side stretch(b), and raising legs(c)

Table 3. 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
D	44.8	33.7	30.3

Ⅳ. Conclusions

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 augmented reality(AR) or virtual reality(VR) might attract more interest in the healthcare field.

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