Design and Implementation of Home Training System based on Personal Fitness Using Kinect Sensor

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Abstract

In this paper, we implemented and developed a home training program using sensors. The implemented program grasps the user's athletic ability and suggests personalized exercise program. In modern society, the aging population is growing rapidly, and most of them are working and living in the interior. For this reason, health management of the aging population is becoming an important social issue, and it is recognized that muscle strength is an important factor. In this paper, we designed and developed a home training program for aged people to exercise in a comfortable environment like natural environment. In the developed program, we extract the skeletal feature points of the user using Microsoft's Kinect sensor and generate feature vectors to check the user's motion state. The proposed algorithm measures the user's athletic ability and suggests a suitable exercise based on the information. As a result of applying kinematic sensor measurements to the proposed algorithm, it showed up to 97% accuracy. We measured the user's athletic ability through the program using the proposed algorithm and suggested the exercise suitable for the individual ability based on this information.

Keywords
Body Strength, Aging, Home Training, Kinect Sensor, Motion Detection

Introduction

Recently, home training has emerged as a new exercise that solves the problem of shortage of time and the burden of spending. Home training is an effective exercise method for the elderly in the aging society in terms of safety and relieves the risk of injuries that may occur in health promotion aspects and external activities (Kenshi et al., 2017; Christopher et al.,
In addition, when exercising with a sensory-type exercise game, more than 40% of the exercise effect is more than general game (Sudip & Subhadeep, 2015; Andrea et al., 2018; Leigh et al., 2020). Therefore, more effective exercise can be achieved when the user watches his/her own state and performs the exercise using a TV screen or the like.

As a result of investigating the causes of death of elderly people, deaths due to falls were the first place except traffic accidents. Elderly people with reduced strength due to aging of the body have a maximum risk of death within 1 year of a fracture due to falls, and older people aged 65 and older are 15 times as likely to die from falls regardless of their health status. In order to prevent fall and improve health, it is necessary to strengthen the lower body strength of the elderly. The elderly has different athletic ability according to various factors such as sex, age, and living environment (Melchor et al., 2016; Muhammad et al., 2019).

Home training guide videos for the general public abound, and coaching apps for professional trainers are popping up. However, non-face-to-face coaching also has limitations in terms of immersion and motivation. One-sided follow-up will quickly give up. A stumbling block is that it is difficult to expose the house to a large number of people in an interactive program of a video conferencing method. In addition, home training videos and related software for the elderly, not the general public, have not yet been released to the market. For this reason, it is a reality that home training software for the elderly is needed (Weiwei et al., 2021; Jing & Aiguo, 2019; Yan et al. 2020).

Therefore, it is necessary to improve the safety of users who use different exercise prescription according to the difference of athletic ability of each elderly person and those who are judged to lack exercise capacity according to the test. For this reason, this paper designs and implements a sensor-based home training program for the elderly. The composition of this paper is as follows. In Section 2, related research is described. In Section 3, we describe the structure of the proposed implementation system. Section 4 describes the system implementation and algorithm. Finally, Section 5 describes the conclusion and future expectations.

**System Architecture**

This section describes gestures and motion recognition that are needed in elderly home training content. In addition, we describe Kinect-based gesture algorithm, motion recognition algorithm and image synthesis for image synthesis.
Motion Detection Algorithm

For human gestures and motion recognition algorithms, it is necessary to extract features from human postures. Figure 1 shows the 25 major body joints provided by the Kinect SDK. The proposed algorithm uses 10 joints information of both hands to grasp the user’s gesture and motion. Kinetic sensor data based gestures and motion algorithms are defined to accurately determine whether the user is performing gesture and motion operations required by the system (An-Ti et al., 2018; Lin et al., 2019; Lina et al., 2019).

Figure 1. Skeleton recognition by Kinect Sensor

The gesture algorithm uses the skeleton data input through the sensor to check whether the user has performed a specific gesture. The gesture used in this paper is a fist grip. The hand state of the user uses HandData provided by Kinect SDK 2.0.

The motion algorithm calculates the angle using the position information of the skeleton data input from the sensor and the vector generated from the position information. As the user proceeds the exercise program, the user checks the positional information change of the skeleton data corresponding to each exercise posture. Then, the degree of bending of the joint is checked using the angle calculated from the generated vector. Using this information, it is determined whether or not the exercise operation is performed, and appropriate feedback is given to the user in the exercise program according to the result.
Motion Recognition Model

The vector is generated from the position information and the position information of the skeleton data, and then the angle is calculated and used for the exercise posture inspection. For example, the right knee lift posture checks whether the right knee is bent if the user lifts the right knee. It is determined whether or not the user has raised the knee by using the height information of the right knee. In this case, Kalman filter was used to reduce the deviation of the input value in real time and increase the reliability.

The right knee, right hip, and ankle coordinate information are used to calculate the degree of bending of the knee. At this time, the reference point of angle calculation is used as the contact point of the left and right knees. The angle is obtained by using the dot product of the vector. First, the direction vector of two straight lines is obtained using the following equation (1).

\[
\vec{a} = (x_2 - x_1, y_2 - y_1, z_2 - z_1)
\]
\[
\vec{b} = (x_2 - x_1, y_2 - y_1, z_2 - z_1)
\]

Where \( \vec{a} \) is the direction vector of the knee joint position coordinate and the ankle position coordinate, and \( \vec{b} \) is the direction vector of the knee joint position coordinate and the hip position coordinate. This equation is solved and substituted into equation (2) to calculate the final angle of intersection.

\[
\theta = \cos^{-1}\frac{\vec{a} \cdot \vec{b}}{|\vec{a}| \cdot |\vec{b}|}
\]

The angle calculated above means the knee angle of the user, thereby determining whether the user has bent the knee.

Image Synthesis

The vector is generated from the position information and the position information of the It recognizes the user through the sensorData recognized through Kinect, and removes the entire background excluding the recognized user using the bodyTexture of the sensorData. The color image corresponding to the image of the user whose background is removed is
obtained through sensorData. A color image with the entire background removed except the user is displayed on the user object as shown in Figure 2.

The program renders the Main Camera, which captures the image and background image displayed on the user object, and the Background Camera screen, which captures the background. Figure 3 shows the result of compositing user's actual image and background image.

Figure 2. User Object in Unity

Figure 3. Result image of synthesized image and object

Program Contents

The proposed lower extremity muscular strengthening exercise program selected the top 3 elderly persons as the main users among the elderly group divided into 6 stages according to their physical ability, in which the elderly group at the 3rd stage can live independently, it represents the elderly who need exercise in order to prevent disease. In addition, in this program, the exercise prescription was changed according to the user's athletic ability in
order to provide a personalized program of the elderly individual, and the choice of the natural background and the exercise teacher which the user desired was widened.

In order to improve the health and strengthen the muscles in the elderly, the stretching before the start of the program is carried out. In order to propose a personalized exercise program, the exercise program consists of evaluation of lower body strength and a total of 6 exercises that constitute the program. Considering the stability of the elderly, all exercise except the lower body strength evaluation is not limited to time.

Elderly users receive exercise prescription according to individual ability through lower body strength evaluation and exercise ability evaluation. At this time, in the lower body strength evaluation, after sitting for 30 seconds and repeating the standing motion, the user is classified into 1 and 2 according to Figure. 4.

Using this information, it is determined whether or not the chair, which is an auxiliary tool for the exercise of the lower body strength strengthening motion, is going to proceed in the future. The users whose average evaluation results are above average are classified into two stages, and the users who do not use the chair during the exercise and the average and the average are classified into the first stage and use the chair. This is a necessary part of the elderly exercise program as a way to secure the safety of the user.

Next, in the exercise capacity evaluation, the personal fitting strength of the lower body strength strengthening exercise is determined through the six kinds of exercise operations.
The program consisted of six motions based on the criteria of the elderly exercise program reflecting the opinions of professional books and experts. The elderly performs six exercise programs according to the prescribed exercise intensity according to the thesis. Exercise using muscle strength requires at least 24 hours of muscle recovery time, so we recommend using this program three times a week.

Finally, when the elderly has completed all exercises in this program, feedback on the exercise results of the day is provided. This result shows a total of three pieces of information about the exercise performed by the elderly. First, the user can check how many times each motion was performed on the day of the exercise. Second, you can check the result of the most recent exercise by comparing it with today's exercise result. Third, it is possible to check the exercise result of the day compared with the result of the exercise ability evaluation test performed when the program is used for the first time. As shown in Figure 5, it is possible to grasp the number of exercises performed and the degree of muscle improvement. In addition, it provides motivation to the elderly through different cheering feedbacks according to the exercise results.

![Figure 5. Dialog windows of exercise results](image)

This program provides a variety of contents by allowing the elderly to choose an exercise teacher who instructs them on the natural background and posture in which they exercise themselves. Through this, it can help the elderly to be immersed in the exercise program, lead to continuous exercise participation, and maximize the effect of the customized exercise program.
Experiemnt and Evalution

To evaluate the performance of the motion recognition model developed in this study, hardware was tested using a computer with i5-7700 3.6GHz CPU, 16GB RAM, Windows 10 operating system and Kinect 2.0 sensor. Kinect-based motion recognition model was implemented to be usable in Unity 3D game implementation using C# language. In this program, before the user's exercise begins, the movement is explained and demonstrated through the exercise teacher, a 3D content created with Blender. After checking the movement of the exercise teacher displayed on the screen, the user proceeds with the exercise by himself. At this time, the user image recognized by Kinect is synthesized with a pre-made 3D background using Unity. This gives the user the effect of exercising in a real natural environment, and has the effect of recognizing the user's own exercise posture by recognizing his or her movements. In addition, information input and program interruption are possible through hand gestures. To do this, Kinect must be used to receive the user's skeletal data and understand the user's movement.

Eleven people participated in this experiment. Participants performed one evaluation exercise and exercise capacity evaluation and six exercise activities required in this application. For the same operation, 10 movements were performed 2.5 meters away from the Kinect sensor. Exercise was performed on the chair from the Eccentric heel drop to the Half squat posture. Figure 6 shows the average of 11 experiments performed by 10 users. Experimental results showed that the sitting and standing movement of the chair were the highest with 97.2%. The recognition rate of the five motions except the eccentric heel drop motion was higher than 95%. On the other hand, Eccentric heel drop operation showed the lowest recognition rate of 82.7%. These results suggest that the recognition rate of movement motion with less change of joint position information such as eccentric heel drop motion is low.

Figure 6. Rate of Motion Recognition
Conclusion

In this paper, we propose a lower body muscle strengthening exercise program tailored to the abilities of elderly users. In order to verify the proposed program, it was implemented and tested from the user UI to the actual program. The created program increases safety by controlling the user's exercise stage and intensity through exercise tests. In addition, a natural background was provided so that the user could feel comfortable, and using Kinect, the user could check their exercise posture in real time. By integrating sensor-based equipment and exercise contents, it is possible to conduct exercise in an easy and fun way. Utilizing the created program will help the elderly to improve muscle strength.

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