Posture Detection for Enhancing Elderly Daily Exercise via Reclining Chair

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Abstract. Research shows that regular physical exercise is essential to improving the overall health of older adults. However, many older adults find it difficult to stick to a dedicated exercise program. To address this problem, this paper selects reclining chairs that are common in daily life in order to integrate exercise into daily life. Combined with an intelligent system, the posture of the person is inferred and the intensity of the exercise is adjusted according to the different strength and physical state of each elderly user. This paper generates a digital twin system by using pressure sensors and IMU (inertial measurement unit) sensors embedded in the reclining chair to detect the posture of the elderly in the reclining chair. Compared with traditional visual methods, visual methods have the risk of privacy issues, and the amount of force exerted by the elderly on the reclining chair is difficult to judge visually. By adjusting the difficulty of the exercise according to the user's current physical strength, this system can help the elderly maintain their fitness habits and improve their quality of life.

Keywords: posture detection, digital twin, health promotion, Sensor-based, Adaptive design.

1 Introduction

Entering the 21st century, with the advancement of medical technology, improvement of health conditions and improvement of people's living standards, the global elderly population continues to grow. Statistics show that many countries are facing the challenge of an aging society. The proportion of the population over 65 years old is gradually increasing. By 2050, the elderly will account for 25% of the global population [1]. This trend has put forward new requirements for society in terms of medical care, social security and public services, and the health of the elderly has become an increasingly important issue [2].

In this context, participating in exercise is considered an effective way to improve the health of older adults. Exercising as an older adult has multiple health benefits and can reduce some of the negative effects of aging [3]. Physical activity is defined as any body movement produced by skeletal muscles that results in the expenditure of energy. In contrast, the term “exercise” refers to a regular program of physical activity that seeks optimal levels of fitness [4]. Exercise is defined here as "planned, structured, and repetitive physical activity."

However, convincing older adults to exercise is a difficult task. While the importance of an active lifestyle is well known, older adults often believe they are too old or too frail to engage in physical activity [5]. Exercise is rarely considered a necessary prescription.

In this context, the concept of integrating exercise into daily life becomes crucial [6]. Encouraging older adults to engage in physical activity without disrupting their daily lives is expected to enhance their overall health and well-being. One possible way to achieve this is to design recliners that facilitate exercise without requiring dedicated time slots [7]. At the same time, incorporating exercise into daily activities can also promote better adherence to exercise among the elderly.

The purpose of this study was to explore the potential of using a recliner as a means of promoting daily exercise in older adults. Through pressure sensors and IMU sensors, the posture of the elderly is judged, a digital twin is generated, and the physical status of the elderly is obtained in real time. And perform exercises or standing support based on sensor information.

2 Relevant Work

Home exercise is a vital component of maintaining health and fitness, especially for the elderly. As individuals age, their physical capabilities often diminish, making it crucial to engage in regular activity to preserve muscle strength, endurance, and balance [8]. Home-based workouts offer a convenient and accessible means to achieve this, particularly during times when outdoor activities or gym visits are not feasible, such as during pandemics. However, while the benefits of home exercise are clear, the elderly may face challenges in adhering to a routine without supervision. The lack of technical skill in per-forming exercises correctly can lead to reduced effectiveness or even injury [9]. Therefore, it's essential that older adults receive some form of guidance, whether through weekly visits or phone calls from trainers, to ensure they are exercising safely and effectively.

Both visual motion detection and wearable devices have some limitations in detecting a person's sitting posture. In the case of visual motion detection, it typically relies on a camera to capture human movement, but in low light or in the presence of occlusions, the vision system may not be able to accurately capture a person's sitting posture, resulting in inaccurate detection. And visual motion detection limited in some locations, such as places with high privacy requirements or places lacking space for camera installation.

For wearable devices, the location and accuracy of the sensors may have an impact on sitting posture detection, and placement on the wrist may not accurately capture the seat in relation to the floor. Comfort and wearability of wearable devices are also considerations. The design of certain sensors may limit the user's freedom of movement and reduce the acceptance of the device [10], thus affecting the usefulness of sitting posture detection. Therefore, while addressing these issues, a combination of sensors and technologies may be an effective way to improve the accuracy and useful-ness of sitting posture detection.

There has been growing interest in exploring innovative and unobtrusive methods to incorporate exercise into daily life for older adults. Smart home technology and assistive devices have emerged as potential solutions for promoting seamless and continuous physical activity.

3 Method

3.1 Type of exercise

For exercise in daily life, reducing the duration of a single session of exercise allows older adults to stick with it better. And High-Intensity Interval Training (HIIT) is a workout method characterized by alternating short, high-intensity phases of exercise with relatively short rest phases to achieve an intensity level at or near maximum heart rate. The goal of this type of workout is to provide efficient training results in a short period of time. HIIT has garnered extensive research and attention in exercise for older adults. For older adults, moderate and careful implementation of HIIT can provide a range of physical and psychological benefits: Cardiovascular Health, Metabolic rate enhancement, Muscle Strength and Endurance, Blood Sugar Control, Cognitive Function, Emotional and Mental Health [11-13]. Choose the following two typical HIIT exercises for exercises via recliners:

(1) Seated Back Extension: An exercise movement that targets the muscles of the back. The seated back extension can be performed with minimal equipment or solely through the use of one's own body weight, making it a suitable exercise for individuals of all fitness levels. The fundamental stages of the exercise comprise seating oneself in a chair, adjusting one's posture, and then slowly leaning back, employing the strength of the back muscles to complete the movement. The upper body should be extended and the backrest should be leaned backward. Maintain the extended position for a brief period before returning to the starting position in a controlled manner. The benefits of this exercise include the strengthening of the back muscles, the improvement of posture, the prevention of back pain and the promotion of back flexibility. Incorporate it into a base unit, sit with your back against the backrest and transition to a reclined position while keeping your back extended.

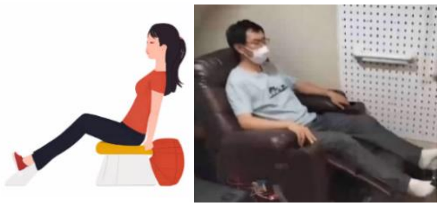


Fig. 1. Seated Back Extension

(2) Reverse Pushups: An exercise movement that emphasizes the engagement of the back and lumbar muscles and is designed to improve strength in the upper body and

core area. In this movement, the individual begins by lying flat on the ground with their legs straight and their arms stretched out on either side of their body, palms facing down. By utilizing the strength of the back and hips, the upper body is lifted off the ground to form an arch, and then slowly lowers the body back to the starting position. This move focuses on strengthening the upper back, lumbar and core muscles, helping to improve postural stability and strengthen the back muscles while building core strength.

Incorporate it into a base unit, A reclining chair with the ability to adjust angles can be used to maintain positions such as lying down or rising up. By performing repetitions, it can provide support for standing up.

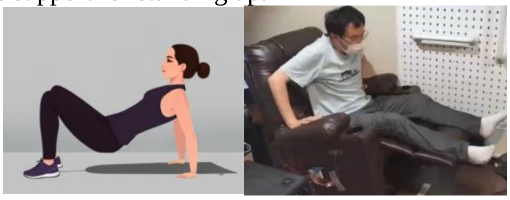


Fig. 2. Reverse Pushups

3.2 System process

As HIIT (High-Intensity Interval Training) is considered effective for older adults' exercise, the method proposed in this paper includes integrating weight sensors into the backrest and seat cushion of the reclining chair to detect the elderly individual's state while sitting on the chair. IMU (Inertial Measurement Unit) sensors are used to detect the reclining chair's posture for system control.

Among them, the sensor in the backrest detects the force exerted by the elderly on the backrest. The seat does not transform into a recliner until a threshold set by the system is reached. During this process, the elderly need to continue to exert force on the backrest. When the force is small, the deformation process will stop. The force level is restored, and the deformation will continue. This process is intended to strengthen the back of the elderly and is integrated into the daily exercise of the elderly before the seat is transformed into a recliner.

After being transformed into a recliner, the elderly can use it as common. This process is not adding any workout content. It can be used by the elderly for rest and other daily use.

When the elderly want to get up, they need to lift their body vigorously, leave the cushion as much as possible, and keep it for five seconds (or other set time). At this time, the weight sensor in the cushion will change. The system will record the previous normal sitting sensor value and compare it with the value when the body is raised. The difference between the two reflects the strength of the elderly to lift their own body weight.

When the deformation of the seat is in the reclining chair state, this posture makes it difficult for people to get up, and it is necessary to adjust the angle to become a seat. Adjust the angle according to the body strength ability detected by the system. After adjusting the angle, repeat the above process, the system re-records the sensor person when sitting and standing normally, and the elderly repeatedly lift their body for five seconds. Gradually adjusting the angle in this process makes getting up easier until the older person leaves the seat.

The maximum deformation angle of the seat is not only the posture of ordinary seats, but also supports the standing of the elderly, making it easier for the elderly to use.

3.3 Posture recognition using pressure sensors

IMU sensors are used to detect the posture of the power recliner for adjustment. Pressure sensors are used to obtain the pressure values of various parts of the elderly's body on the motorized recliner, and this is used for motion detection. When the elderly person uses the recliner, the Seated Back Extension action is performed to change the recliner to relax mode. When in relax mode, the elderly person wants to stand up from the recliner and performs the Reverse Pushups action. The action is detected, and the motorized recliner is controlled by the system to provide feedback to the older person.

(a) For Seated Back Extension:

The use of pressure sensors to detect a person's backward movement have advantages over visual methods. This technology helps protect personal privacy, as it typically does not involve the capture and processing of image or video data. Pressure sensors are usually relatively inexpensive, whereas vision methods may require more expensive hardware and software.

Multiple pressure sensors are combined with cushions and placed on the backrest of a power recliner to increase the detection range and allow for easy installation and replacement. Using the pressure sensors.

I) Read the value every $10 \ ms$ and use the maximum value of the multiple pressure sensors as a valid input.

II) Compare the value with the saved historical maximum, if it is greater than 50% of the historical maximum, proceed to the next step, otherwise return to i). If there is no historical maximum, record the value as historical maximum and proceed to the next step.

III) Continuously record the valid input for 500ms, calculate the average value, and when it reaches 80% of the historical maximum value, proceed to the next step. Return to i) if not reached. This step is to prevent the user from triggering by mistake.

IV) The backrest of the recliner is gradually tilted down, gradually changing to relax mode. During this process, the valid inputs for 500ms are continuously recorded in segments, the average value is calculated, and if it exceeds the historical maximum value, the historical maximum value is updated to that value. If it is lower than 80% of the historical maximum value, the deformation will stop and return to I)

V) After changing to relax mode, there will be no more feedback on the sensor value.

(b) For Reverse Pushups:

Similar to the backrest, multiple sensors are combined with a cushion and placed on the seat of the recliner. The pressure of the buttocks against the motorized recliner is detected.

I) A value is read every $10 \ ms$, with the maximum value from the multiple pressure sensors as a valid input.

II) Continuous recording, with the option to analyze the most recent value of 10 seconds. The average value for that time period is compared to the historical maximum average value, and if there is no historical maximum average value, that value is taken as the historical maximum average value. If it is 15% below the historical value large average, proceed to the next step. Return I) for the remaining cases.

III) Calculate the length of the consecutive time period during which the value is 15% below the grand average of the historical values. If the final value of the last recording is still below the threshold, continue recording until the real-time data is 15% above the grand average of the historical values. This time period is considered to be the time the older adult is performing Reverse Pushups. The total duration is considered to be the time it takes the older adult to complete a Reverse Pushup. The next step is performed if the duration is higher than $5000\ ms$. For the rest of the cases return to I)

IV) The average value of the combined time and Reverse Pushups time period for the recliner to gradually deform from Relax Mode to Rise Support Mode is considered as the coefficient of physical functioning of the elderly. The higher the coefficient of physical functioning, the shorter the duration of a single deformation. That is, older adults who are in better shape are provided with more exercise. After a single deformation revert back to I). Going through multiple I)~IV), i.e., performing the Reverse Pushups maneuver multiple times, causes the recliner to return to a posture where it can stand up

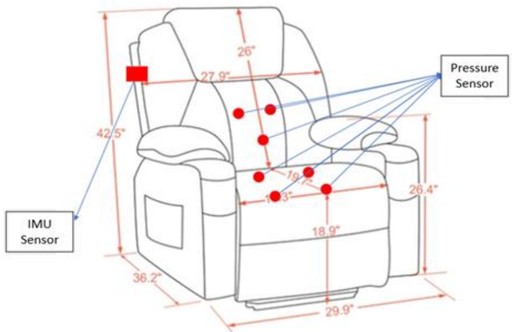


Fig. 3. Device Composition

3.4 Exercise volume analysis

(a) Seated Back Extension:

In this exercise, the amount of exercise E is proportional to the value F of the 3 pressure sensors on the backrest:

$$E \propto F \tag{1}$$

The values of the pressure sensors of the backrest were obtained as F_1, F_2, F_3 and the values of the pressure sensors were read every $10ms$ to calculate the average pressure value in 0.1 seconds as F:

$$F = \frac{\sum F_1 + F_2 + F_3}{10} \tag{2}$$

The pressure sensor used in this paper has a value range of $[0, 4096]$. The amount of motion E in time t is defined by the empirical formula:

$$E = t \times F/100 \tag{3}$$

(b) Reverse Pushups:

Read the pressure sensor value every 10ms, calculate the average value F_{ave} every 0.1 seconds, record the sum F_{sum} of the pressure sensor values F_{ave} for the cushion every 5 seconds.

$$F_{sum} = 50 \times \frac{\sum F_1 + F_2 + F_3}{10} \tag{4}$$

The maximum F_{sum} in 30 seconds is used as the baseline value F_{base} for the weight applied to the recliner when the older person sits normally in the chair.

During the Reverse Pushups exercise, the older person raises his body and the corresponding value on the cushion decreases. The ratio of the reduced value to F_{base} is used to obtain the physical capacity A by the empirical equation:

$$A = 100 \times \frac{F_{base} - F_{sum}}{F_{base}} \tag{5}$$

A threshold x is established, and when physical ability A is greater than the threshold, the older person is judged to have performed one Reverse Pushups to exclude noise from the older person's normal activities in the recliner.

Reverse Pushups is a multiple workout in which the recliner guides the older adult to perform the appropriate amount of exercise based on physical ability A. The older the person, the better the physical ability A, the more exercise the recliner performs. The greater the physical ability, the smaller the angle at which the recliner deforms after each Reverse Pushups. The total time for the recliner to change from relax to normal is about 30s, and the single running time T of the actuator motor is controlled to control the single deformation angle of the recliner to provide a reasonable number of Reverse Pushups exercises to change from relax to normal:

$$T = 10 \times (1 - A) \tag{6}$$

4 Experiments and Results

4.1 Equipment

The pressure sensor is placed under the fabric cushion and placed on the power recliner. The IMU sensor is placed on the backrest section. The overall finished power recliner looks similar to the ordinary power recliner. It creates a sense of familiarity for the elderly. The pressure-voltage value obtained from the pressure sensor is approximately linear and can be well analyzed as an input.

Fig. 4. (Left) Motorized recliner with sensors (Right) Cushion with pressure sensors

4.2 Experimental results

During the reclining exercise process, the weight sensors accurately detect the force exerted by the participants' back against the backrest, enabling the reclining mechanism to activate. The system's real-time feedback loop effectively adjusts the reclining angle based on individual force patterns, providing personalized motion support.

From the initial sitting position to the complete transformation into a reclined chair, it takes approximately 30 seconds of continuous force applied to the back. During this process, the participants distinctly feel the use of their muscles.

During normal usage, the system is designed not to undergo any deformation due to minor variations in sensor values caused by regular user movements. Actions such as using a smart phone, reading, or making slight adjustments to body posture will not trigger the standing phase inadvertently.

In the standing phase, participants need to exert force to lift their body off the cushion and maintain this position for 5 seconds. Participants feel the use of their muscles during this phase. This process is repeated multiple times as participants perform the action repeatedly. The entire process lasts for approximately 50 seconds, ending when the participants leave the seat.

Fig. 5. The tester is pushing hard on his back (left) The tester is pushing his body off the cushion (right)

4.3 Posture recognition and digital twin

Posture of elderly people successfully obtained based on sensors on a recliner. Classify all states of being on a recliner and shown as table 1.

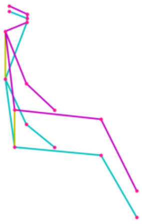
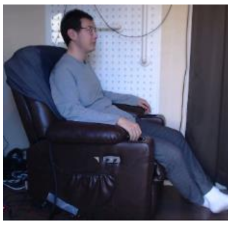
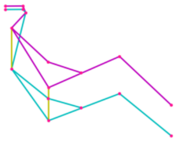
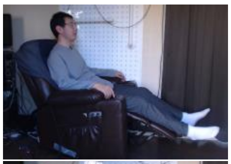
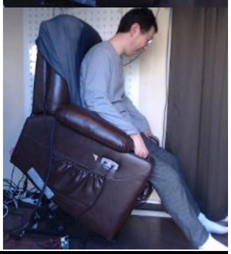
Sit: The IMU determines the current status of the recliner. Determine whether the person is on the recliner based on the seat pressure sensor. According to the backrest pressure sensor, it is determined that the person (a) leans lightly on the backrest and relaxes (b) does not touch the backrest (c) squeezes the backrest hard to perform Seated Back Extension

Sit-relax: It is the process of state change from sit to relax or relax to sit. The IMU determines the current status of the recliner.

Relax: After the recliner changes to relax, the seat surface sensor is used to determine whether the elderly are doing Reverse Pushups.

Stand: In the sit state, if the elderly continue to do reverse pushups, or simply have difficulty standing, the value of the pressure sensor on the seat surface will decrease and then increase. It is judged that the elderly person has not left the seat at this time and needs standing support. Continue to raise the recliner to help the senior stand.

Table 1. states in recliner

States	Digital twin	Reality
Sit		
Sit-relax		
Relax		
Stand		

4.4 Compare with general methods

Compared with general visual methods, using visual methods to determine the posture of the elderly will not only cause the elderly to worry about privacy, but also make it difficult to detect subtle changes. Taking the sitting posture as an example, the visual method (Movenet, etc.) can only obtain the approximate posture but cannot obtain whether the elderly exert force on the backrest, that is, it cannot provide help for the elderly's exercise. This study uses sensors on the recliner to determine whether force is exerted on the back while obtaining the posture of the elderly. If the sensor data of the backrest does not feel pressure, the upper body angle of the digital twin will increase accordingly by 5 degrees. Note that this is just an intuitive external representation of the untouched state of the backrest for the elderly. In subsequent exercises and standing support, the calculation is still based on the original angle.

Fig. 6. Using Movenet detection, the backrest and seat surface cannot be obtained

Compared with visual algorithms for target recognition and classification, such as yolo et al. Also because the human movement characteristics are not obvious under different forces, it is not as accurate as using a pressure sensor. It is difficult for algorithms such as yolo to distinguish between a person leaning lightly on the backrest or performing a Seated Back Extension. The recognition rate when performing Reverse Pushups is slightly better, but the overall accuracy is lower than 35%, and the amount of exercise cannot be analyzed. After experiments, this article believes that the digital twin system using pressure sensors can already identify the movements of the elderly and analyze the amount of exercise, which is better than traditional visual methods.

From a privacy perspective, it is more advantageous to use sensors such as pressure sensors that do not directly capture visual audio images. Related studies have shown that people are more resistant to using vision-based sensors due to privacy concerns [14]. Our approach, which uses IMUs and pressure sensors to detect the state of the elderly, is more advantageous in terms of privacy protection.

Table 2. comparison

Items \ Methods	Depth method	Visual method	ours
Body movements detection	√	√	√
Force condition detection	×	×	√
Privacy protection	×	×	√

5 Conclusion and future work

In conclusion, this study has demonstrated the potential of utilizing a smart reclining chair and exercise assistance system to promote unobtrusive exercise among older adults. The integration of weight sensors and intelligent technology enabled a personalized and user-friendly exercise experience, seamlessly incorporating physical activity into their daily routines.

The smart reclining chair's ability to adapt its reclining angle based on real-time force feedback. The system's automated assistance during standing exercises effectively supported those with reduced support capacity, gradually enhancing their physical abilities over time. The user-friendly design and seamless integration of exercise into daily activities contributed to high levels of participant engagement and acceptance.

The smart reclining chair and exercise assistance system offer a novel approach to encouraging regular physical activity without requiring explicit effort or dedicated time, addressing barriers commonly faced by older individuals in engaging in exercise.

It is essential to recognize that this study's limitations include a relatively small sample size and a specific age range of participants. Future research could involve larger and more diverse participant groups to further validate and generalize the findings. And will use more sensors and CNN (Convolutional Neural Network) algorithm. Through the value of the sensor, the current state of the user is identified, and the adjustment is more precise and personalized, so that the user can be better exercised in daily life.

The integration of innovative technology into furniture design presents a promising avenue for promoting exercise and supporting healthy aging among older adults. By leveraging smart reclining chairs and exercise assistance systems, we can create a more active and vibrant aging population, enhancing their well-being and independence throughout their later years.

Acknowledgments. This work was (partially) supported by JST, [Moonshot R&D][Grant Number JPMJMS2034] and TMU local 5G research support.

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