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ANNALS OF
Musculoskeletal Medicine OPEN ACCESS JOURNAL

ISSN: 2640-8139 DOI: https://dx.doi.org/10.17352/amm

Research Article

Effects of postural control by personal mobility on human joint movements-prototype of a new alert system for personal mobility devices

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Received: 30 April 2024
Accepted: 10 May, 2024
Published: 11 May, 2024

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Keywords: Human-robot synchronous motion; Sensory feedback; Elderly rehabilitation; Motorized wheelchair

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Abstract

Purpose: This study aimed to develop a prototype Personal Mobility (PM) system with human-robot synchronous motion measurement and sensory feedback as an attention reminder to ensure the safe performance of sustained, step-by-step rehabilitation tailored to the daily living conditions of elderly individuals.

Methods: Five healthy adults were fitted with a simulation tool to experience the elderly, and inertial measurement unit sensors were placed on the subjects and the PM device to measure joint movements during two postural movements (sitting to supine and supine to standing). In addition, vibration stimulation and voice guidance were implemented as alerts at a certain set threshold of the joint motion angle. We analyzed the deviation of each joint motion between the subject and the PM device regarding the angle measurements of the trunk, hip, knee, and ankle joints.

Results: Trunk angle misalignment was high in the sitting-to-supine position. Hip angle misalignment was greater in the supine to standing position. As an alert system, vibration and voice guidance could be presented to the subject with a 0.3-second delay after the set threshold was reached.

Conclusion: The misalignment between a human and a motorized wheelchair in contact with the human is more than several tens of degrees when expressed as the angle change value of the joint motion. We believe that a system that can constantly sense and alert the user regarding whether the user and the PM device are in sync is necessary for PM devices being used in rehabilitation or as daily life support.

Introduction

The advancement of life innovation technology is anticipated to encompass the research, development, and commercialization of medical and nursing care robots, Personal Mobility (PM) devices for the elderly, and lifestyle support robots. In addition, the application of manufacturing technologies may facilitate the use of advanced medical technologies and information and communication technologies. In this context, the development of mobility support equipment for the elderly is anticipated but faced with challenges like the inadequate selection of mobility support devices based on the evaluation and analysis of the physical abilities of individual elderly people who require assistive technology. In addition, there is a lack of PM and robot suits that support normal human locomotion and a lack of an environment for their implementation in society, despite the fact that they are useful tools for both indoor and outdoor use. We previously conducted a research project, titled "Research and Study for the Development of Sustainable Equipment to Support the Mobility of the Elderly and Physically Challenged," and highlighted the technical issues related to PM and robot suits and how they should be implemented and commercialized

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in society in leading countries like Japan, Europe, and the United States.

Several studies have focused on intelligent powered wheelchairs [1,2], which are needed by patients or disabled persons who no longer have the physical capability to walk and the strength to use a manual wheelchair. Therefore, Personal mobility is an important assistive device for Activities of Daily Living (ADL) and Quality of Life (QO) in the elderly and people with disabilities [3,4]. However, few studies have shown that personal mobility can assist in controlling various postural impairments in people with disabilities. This study highlights the technological challenges of PM and robot suits and how they can be implemented and commercialized in society [5]. The study considered that it would be difficult to develop a locally accepted and sustainable assistive device unless it is commercialized by considering how it can be used in society, including a social science approach that considers the environment, in addition to simply developing mobility-assistive devices in cooperation with medical and engineering fields. The present study aimed to develop a prototype of a PM device that introduces synchronous motion measurement and sensory feedback as an attention reminder for humans and PM devices to safely perform continuous and step-by-step rehabilitation tailored to the daily living conditions of individual elderly persons.

Methods

Subjects

Five healthy adults (height, 174.4 ± 8.7 cm; weight, 66.0 ± 8.5 kg) participated in the study. The inclusion criteria were participants in their 20s who could independently provide written informed consent. The participants agreed to wear a simulation brace for the elderly and to participate in the experiment.

All participants received a verbal and written explanation of the study before providing informed consent and were assured that their participation was voluntary, that they would not be disadvantaged by non-participation, and that their personal information would be protected. This study was conducted with the approval of the institutional review board of The University of Tokyo (approval review No. 20-210).

Experimental equipment

This study utilized personal mobility F5 (power wheelchair F5 Corpus® VS, Permobill Co., Ltd.; weight, 196 kg), an electric wheelchair capable of controlling supine, seated, and standing postures.

Inertial measurement unit sensor (Figures 1-4): Inertial Measurement Unit (IMU) sensors (M5StickC Plus, M5Stack Technology Co., Ltd., weight: 21 g, sample frequency: 10 Hz) were placed at the seventh cervical spinous process, the fifth lumbar spinous process, the anteromedial surface of the thigh, the anteromedial surface of the lower thigh, and the dorsomedial surface of the ankle. The IMU was placed on the back support, seat surface, leg support, and foot support. The

Figure 1: Sitting position of a subject in a F5 wheelchair wearing the elderly experience simulation.

Figure 2: Supine postion of a subject in a F5 wheelchair wearing the elderly experience simulation.

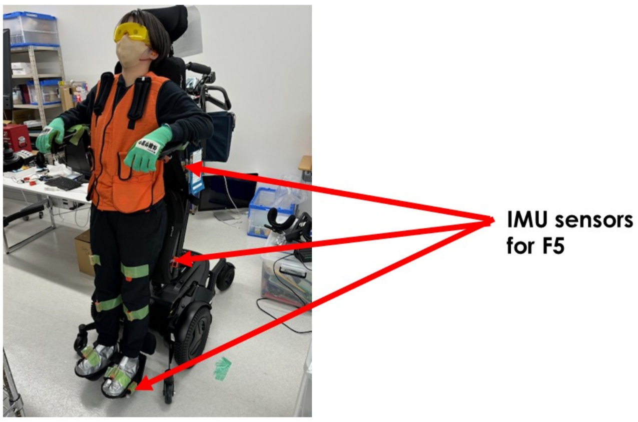
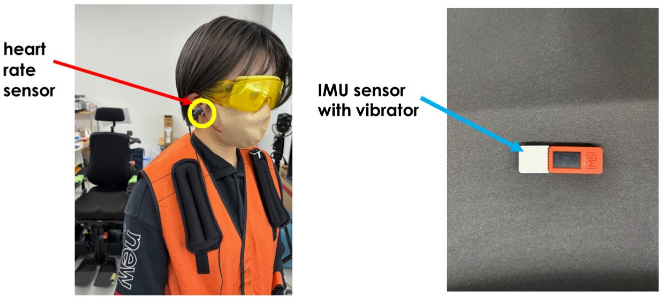


Figure 3: Standing postion of a subject in a F5 wheelchair wearing the elderly experience simulation.



(a) heart rate sensor

(b) IMU sensor with vibrator

Figure 4: New alert system for vibrator and heart rate devices.

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angles of the back support, seat surface, leg support, and foot support were measured.

Alert system: A system was developed using a vibrator (Figure 4) synchronized with the IMU and a voice guide to alert the subject when a misalignment angle between important joint sites was detected in the contact area between the human and F5. The vibration stimulus was 100 Hz for 2 s, and the voice guidance was presented as "Your body is far from the wheelchair." The heart rate was measured near the auricle, and a voice prompt ("Your heart rate is rising (falling)," "Your heart rate is rising (falling)," etc.) was used to alert the subject according to the deviation from the resting heart rate of each individual. Heart rate was measured near the ear perpendicular to it.

Experimental procedure

Subjects wore the Simulation Orthosis for the Elderly Experience (Figures 1-4), rode on F5, and performed two postural movements from sitting to supine and from supine to standing (Figures 2-4). The subjects were asked to maintain the position of their limbs by riding on F5. Three trials were conducted for each postural movement, which were performed randomly for each subject. The simulation equipment for the elderly consisted of a vest (2 kg), shoes (1 kg), gloves, glasses for visual disturbances, and earplugs.

Data analysis

The joint motions of the trunk (A1) and hip (A2), knee (A3), and ankle (A4) joints on the human side during the 2-action movement were measured; for F5, the angles of the back support (B1), seat surface (B2), leg support (B3), and foot support (B4) were measured. To confirm contact between the human and F5, the average and maximum minimum angles of the three trials for each two-position operation were calculated and analyzed for the angle difference (angle discrepancy between the human and F5) between A1 and B1, A2 and B2, A3 and B3, and A4 and B4.

Alert system: A threshold for the misalignment angle was determined, and the presentation time of the vibration stimulus and voice guidance were analyzed and examined as attention reminders. Participants were also examined for their comprehension of vibration and voice guidance.

Moreover, statistical analysis was performed using R version 4.12.

Results

According to the analysis, among all subjects, three out of five were able to obtain data on all variables. Therefore, a significant difference test was not performed. The lack of data was because the sensor was damaged during the process.

Misalignment angle value (degrees)

All five subjects had similar data, so a representative example is shown.

Regarding the misalignment values of the human trunk joint angle and F5 back support angle during the sitting-to-supine position, the average value was 18.7°, and the maximum value was 24.0° (Figure 5).

Regarding the misalignment values of the human hip joint angle and F5 sitting angle during the sitting-to-supine position, the average value was 6.5°, and the maximum value was 15.0° (Figure 6).

Regarding the misalignment values of the human knee joint angle and F5 leg support angle during the sitting-to-supine position, the average value was 13.4°, and the maximum value was 17.0° (Figure 7).

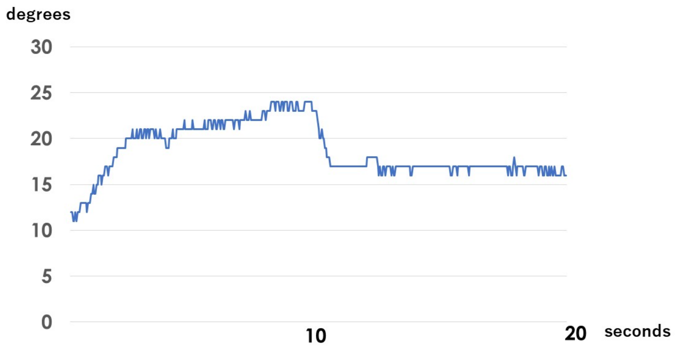

Figure 5: The angle difference between the trunk and back support from the sitting to supine position.

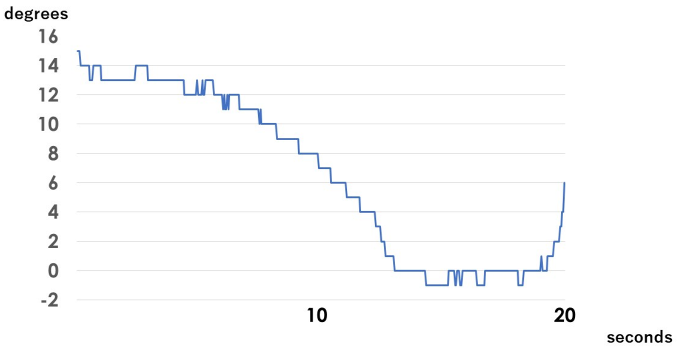

Figure 6: The angle difference between hip joint and seat surface from the sitting to supine position.

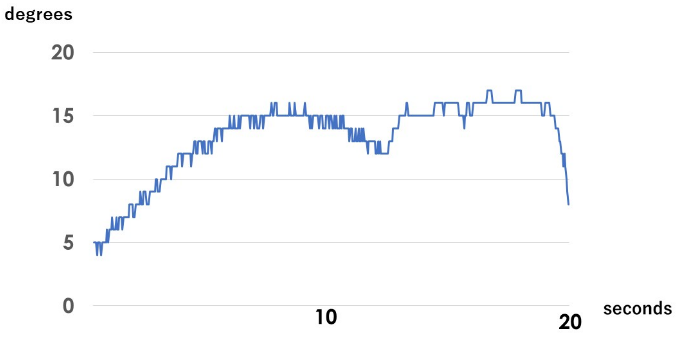

Figure 7: The angle difference between the knee joint and leg support from the sitting to supine position.

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Regarding the misalignment values of the human ankle joint angle and the F5 foot support angle during the sitting-to-supine position, the average value was 15.4°, and the maximum value was 20.0° (Figure 8).

Regarding the misalignment values of the human trunk joint angle and the back support angle of F5 in the supine to upright positions, the average value was 16.4 °, and the maximum value was 19.0° (Figure 9).

Regarding the misalignment values of the human hip joint angle and F5 sitting angle during the supine to standing position, the average misalignment value was 15.5 °, and the maximum value was 24.0° (Figure 10).

Regarding the misalignment values of the human knee joint angle and F5 leg support angle during the supine to upright position, the average misalignment value was 5.7 °, and the maximum value was 10.0° (Figure 11).

Regarding the misalignment values of the human ankle joint angle and the F5 foot support angle during the supine to upright position, the average value was 17.37 °, and the maximum value was 18.0° (Figure 12).

In summary, the misalignment value for the trunk was greater than for the hip and knee joints during the sitting-to-supine position. The misalignment value for the hip joint was larger than for the trunk and knee joint during the supine to standing position. This was greater than that of the ankle joint.

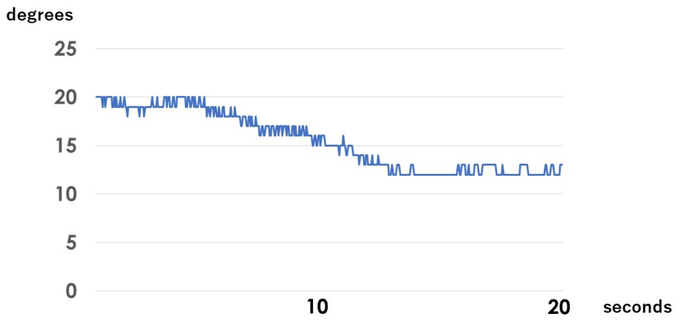

Figure 8: The angle difference between the ankle joint and foot support from the sitting to supine position.

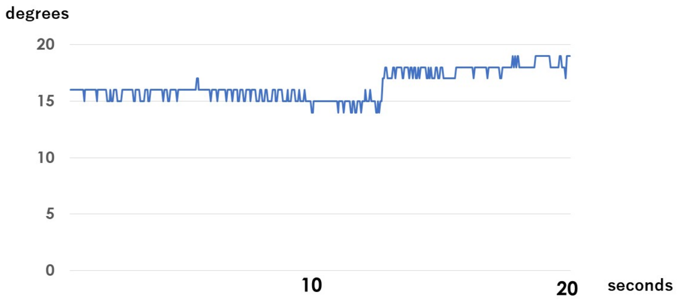

Figure 9: The angle difference between the trunk and back support from the supine to the standing postion.

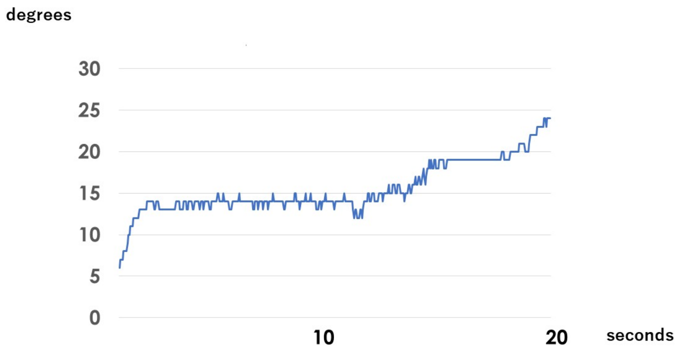

Figure 10: The angle difference between hip joint and seat surface from the supine to the standing position.

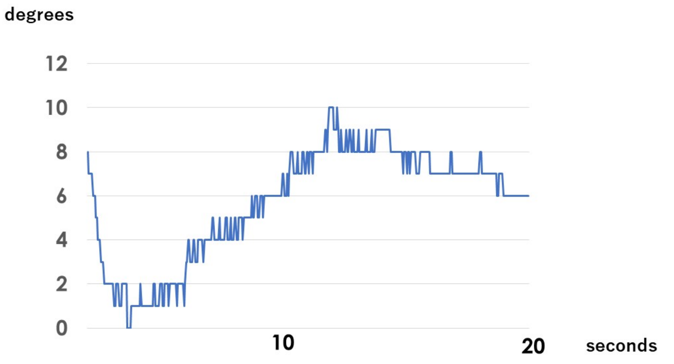

Figure 11: The angle difference between the knee joint and leg support from the supine to the standing position.

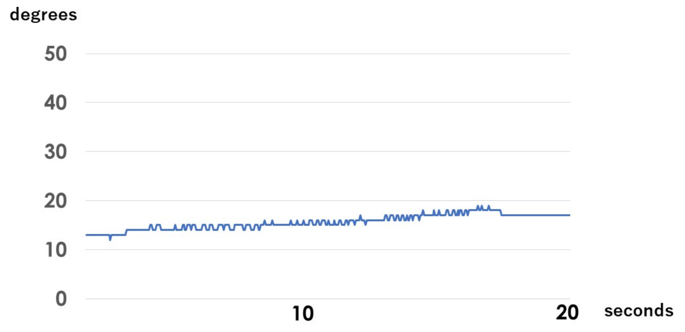

Figure 12: The angle difference between the ankle joint and foot support from the supine to the standing position.

Alert system

The vibration and voice-guided alert was presented with a 0.3-second delay to all patients when a certain set angular threshold was reached. All the subjects understood both the vibration stimulus and voice guidance.

Discussion

A few studies suggest that some misalignments between the user's anatomical and exoskeleton joints can cause undesired interaction forces, which in turn reduce comfort and safety [6-8]. Misalignments are considered a potential cause of lower limb fractures in powered exoskeletons [9].

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Dupuis [10] estimated that there are approximately 50 wheelchair-related deaths per year and approximately 36,000 nonfatal wheelchair-related accidents per year that require medical attention. An alert system (visual, vibratory, and auditory feedback system) to provide support for daily activities to patients with unilateral spatial neglect and cognitive impairment during wheelchair operations was developed [11]. Moreover, the versatile alert system might be effective in controlling misalignment between the movements of the PM and human mobility.

In the limb position change of F5, the misalignment value for the trunk was greater than for the hip and knee joints during the sitting-to-supine position. The misalignment value for the hip joint was larger than for the trunk and knee joint during the supine to standing position.

This was greater than that of the ankle joint. This suggests that trunk flexion movement in the sitting position is more likely to be induced by the movement of F5 than that of other joints. Therefore, the risk of falling with trunk movements in the sitting position should be fully considered. Hip motion, which is more multiaxial in joint motion, is more likely to be induced in the standing position. As a patient's lower limb muscles weaken, the patient may also be at risk for falls due to decreased support at the hip joint, and we believe that an average misalignment value > 15° in both positions would increase the risk of falls. Therefore, alerts should be used to reduce the misalignment of the contact surface between each joint and F5. Regarding the alerting system, it was possible to present an alert at a minimum of 0.3 s. Feedback at approximately 200–500 msec can be presented to humans as an alert [12,13]. Hardware and software improvements should be implemented to enable faster presentations.

As for the limitations of the research, in this study, we investigated whether it was possible to clarify the malalignment differences in movement between humans and PM using a sensor system with an alert that was prototyped using an elderly simulation device. Therefore, these data were not actual data for the elderly or people with disabilities. In addition, to resolve the lack of data, it is necessary to consider methods for fixing the sensor to humans and PM.

Conclusion

The present study found that the misalignment between a human and an electric wheelchair in contact with a human is more than several tens of degrees when expressed as an angular change value of joint motion. It has been previously reported that the misalignment between the joint motion of a human and a robotic suit is approximately 5 mm - 20 mm [14]. Thus, a system that constantly senses and alerts humans using PM devices and robot suits in rehabilitation or as daily life support is necessary. In addition, developing a safe and secure system for medical staff and family members to constantly monitor patients using ICT-based services is an important issue for current PM devices.

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