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An AR-based mobile robot system for gait training

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Abstract

Gait training is an important rehabilitation exercise for lower-extremity patients to recover their ability to walk. However, existing gait training that makes use of treadmills or robotic assistive systems differs from the actual walking environment on the ground because they repeat similar treatments in restricted treatment rooms. Therefore, in this paper, we propose a new type of gait training system that combines a mobile robot with virtual reality. The proposed system is a mobile system that augments virtual content for gait training on real ground. Our proposed system differs from conventional robotic-assisted gait training in terms of making a patient interact with the content. In addition, there is another advantage in that the space is not limited during gait training because a mobile robot is used. Two experiments were conducted, and the results were used to examine the performance of our proposed system.

Keywords: Mobile Robot, Gait training, Virtual Reality, Augmented Reality, Rehabilitation

1. Introduction

Gait training (including stroke patients and sports injuries) is an important rehabilitation exercise for the recovery of gait abilities in patients with lower extremities. The traditional gait training system is a training system based on treadmills and robots (technology) [1,2,3]. Gait training systems based on a treadmill provide symmetrical gait patterns to improve gait ability [4]. In addition, a gait training system based on robots (technology) improves gait ability by manually moving joints so that a patient can experience normal gait with the assistance of at least one trainer per patient [5].

Virtual reality (VR) gait training content has recently been added to these traditional gait training systems to increase the interest and immersion of trainees [6,7]. It helps patients walk through a treadmill and gait training robot system and provides higher immersion to patients through VR gait training contents.

Lokomat [8] is a state-of-the-art, customized rehabilitation robot that deviates from the traditional method of holding patients directly and practicing gait due to partial paralysis and massage. It allows patients to walk on treadmills and provides feedback on the VR content through the screen. Similarly, C-Mill [9] is a rehabilitation robot that uses VR content and a treadmill to adapt to everyday life. It provides VR content and helps training depending on various situations such as avoiding obstacles or gaiting in crowded areas. Training can also be designed to fit the trainer's plan so that the environmental elements of the VR content can be changed as needed. Walkbot [10] is a robot used for the recovery of patients with gait disabilities. As it is a wearable robot, it supports rehabilitation training focusing on patient joints (knee joints, hip joints, and ankle joints) and child rehabilitation, especially with low ages. The G-EO robot [11] provides a variety of gait experiences to patients by simulating gait on flat lands, slopes, and stairs, and allows trainers to provide efficient training within a short time by easy setup for each patient.

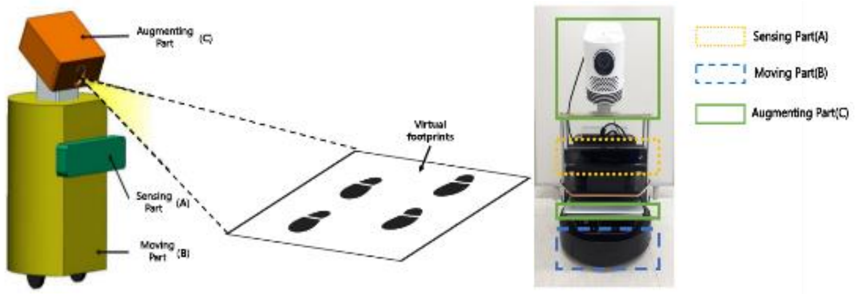
However, the above-mentioned conventional gait training systems (using treadmill gait, robot-assisted gait therapy, among others) have the following limitations: 1) There is a difference from the actual gait environment conducted on the ground because they repeat similar treatments in a restricted treatment room. 2) As robot equipment is used, there are restrictions on wearing it depending on the age and the body. 3) Even though training contents using VR are provided, there are limitations on continuous interest and immersion due to the lack of real-time interaction.

Therefore, we propose a new type of gait training system that combines a mobile robot with virtual reality. Our proposed system is a system wherein robots augment virtual content for gait training on real ground while keeping distance from patients. In addition, the main difference from conventional gait training is that the proposed method provides a real-time interaction between patients and virtual content on real ground.

The remainder of this paper is organized as follows. The gait training system is reviewed in Section 2, including a system overview. Two experiments were conducted, and the results are presented to examine the performance of the proposed system in Section 3, followed by the concluding statements and future work in Section 4.

2. Proposed system for gait training

The proposed system comprises a sensing part (A), a moving part (B), and an augmenting part (C). The sensing part takes charge of gait recognition and is composed of Kinect [12] and OpenNi trackers. The moving part is in charge of keeping the distance with patients and is made up of a robot. The augmenting part takes charge of augmenting virtual content for gait training and is composed of a projector and a computer.



(a) (b)

Fig.1: Proposed system: (a) conceptual system and (b) actual system

2.1 Sensing Part

The sensing part recognizes one's gait in real time based on image processing and is composed of the Kinect and OpenNi trackers.

The sensing part collects 3D point-cloud depth information to analyze patient movements. A 3D point-cloud is a collection of points belonging to 3D coordinates, and it has the advantage of collecting large amounts of data and representing the surface of an object. In this study, Kinect was used to collect the 3D point-cloud.

Based on the obtained depth information, the OpenNi tracker, which is an open source tracker, is used to recognize the posture of the patient.

Once the patient holds a calibration pose, the sensing part synchronizes the patient with the skeleton model shown in Figure 2 and collects 3D point-cloud information on the patient's joints in accordance with the movement of the synchronized skeleton model.

It converts the collected 3D point-cloud depth information into a 3D coordinate system [13]. These patient coordinate data are used to keep a certain distance between the patient and the moving part, and to synchronize the coordinates for the augmenting part

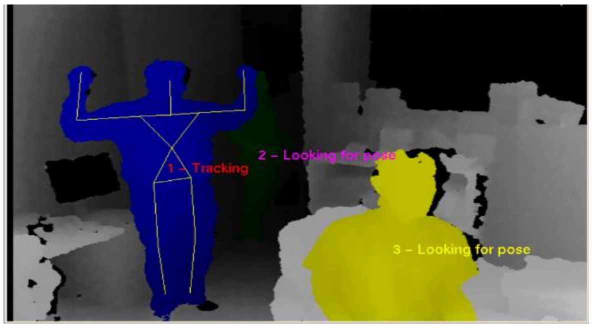


Fig.2: Snapshot of the OpenNi Tracker [14]

2.2 Moving Part

The moving part, which is a mobile robot, takes charge of keeping a certain distance between the patient and the robot in real time.

The moving part receives the patient's coordinate data from the sensing part through the robot operation system (ROS) to keep a certain distance between the patient and the robot in real time. ROS is an operating system (OS) used for sending and receiving data with robots. Using this ROS, patient coordinate data are sent from the sensing part to the moving part.

After receiving the coordinate value (distance between patient and robot) of the patient's center point (torso) from the moving part, the mobile robot is commanded to move. Once a mobile robot (receiving an order) reaches a certain velocity, the moving parts keep that velocity to keep the distance between the robot and the patient. Figure 3 shows that the moving part helps keep the distance between the mobile robot and the patients.

The robot saves its own coordinates to keep the distance between itself and the patient as data called Odometry, as shown in Eq. (1),

$$Odometry = x, y, z, \theta_x, \theta_y, \theta_z \qquad - (1)$$

where x, y, z and $\theta_x, \theta_y, \theta_z$ denote the coordinates of the 3D position and rotation, respectively.

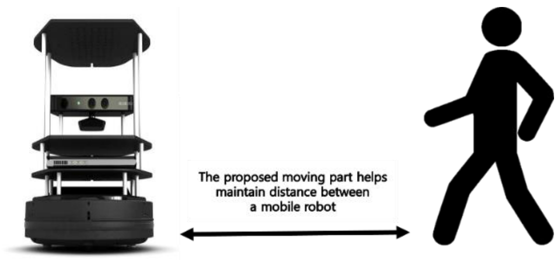


Fig.3: Distance-keeping between a patient and robot by the moving part

2.3 Augmenting Part

The augmenting part takes charge of augmenting the virtual content on the real ground for gait training and is composed of a projector and computer (PC).

Coordinate synchronization is required to use the patient's coordinate information and the robot's coordinate information in content (such as virtual footprint)

Coordinate synchronization is performed in sequence, as shown in Figure 4.

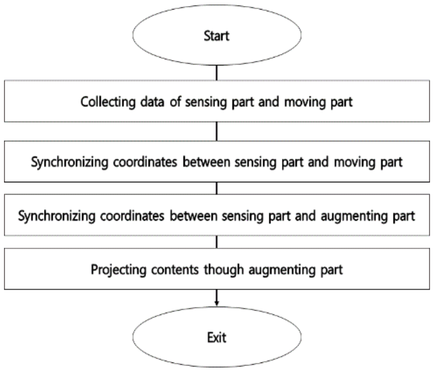


Fig.4: Flowchart of coordinate synchronization

Coordinate synchronization between virtual training content (augmenting part) and the robot (moving part) for gait training is obtained as shown in Eq. (2)

$$M_{odom} = R_{odom}T_{odom}\begin{pmatrix}\cos\theta_z & -\sin\theta_z & 0 & 0\\ \sin\theta_z & \cos\theta_z & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{pmatrix}\begin{pmatrix}x\\ y\\ z\\ 1\end{pmatrix} \quad - (2)$$

where R_{odom} and T_{odom} denote the rotational matrix and translation matrix, as shown in Eq. (3) and (4).

$$(\text{if} \quad \theta_x = 0,\ \theta_y = 0) \quad R_{odom}=R_zR_yR_x \quad =R_z = \begin{pmatrix}\cos\theta_z & -\sin\theta_z & 0 & 0\\ \sin\theta_z & \cos\theta_z & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{pmatrix} \quad - (3)$$

$$T_{odom}=\begin{pmatrix}x\\ y\\ z\\ 1\end{pmatrix} \quad - (4)$$

A rectangular-type chessboard is used to calibrate the synchronized coordinates, as shown in Figure 5.

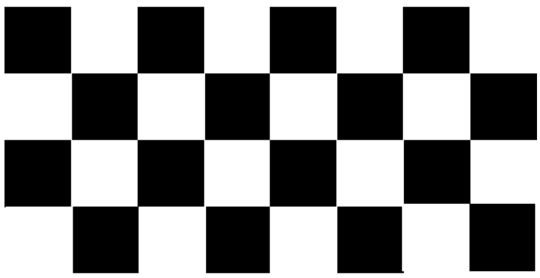


Fig.5: Chessboard used for coordinate calibration

The projected chessboard has n intersections, and x and y can be represented as the 2D coordinates of the intersection, as shown in Eq. (5).

$$\begin{bmatrix}x\\ y\end{bmatrix} = \begin{bmatrix}x_1\\ y_1\end{bmatrix}, \begin{bmatrix}x_2\\ y_2\end{bmatrix}, \dots, \begin{bmatrix}x_n\\ y_n\end{bmatrix} \quad - (5)$$

The relation between the 2D and 3D coordinates through the Kinect camera is derived as shown in Eq. (6)

$$s\begin{bmatrix}x\\ y\\ 1\end{bmatrix} = \begin{bmatrix}f_x & 0 & c_x\\ 0 & f_y & c_y\\ 0 & 0 & 1\end{bmatrix}[R|T]\begin{bmatrix}x\\ y\\ z\\ 1\end{bmatrix} \quad - (6)$$

where f_x and f_y are the camera focal distances, c_x and c_y are the camera main points, and s is the image magnification.

Using the internal parameters of the camera (f_x , f_y, c_x, c_y, s), the relation between the projected chessboard intersections and the 3D coordinates can be obtained.

Eq. (6), allows us to obtain rotation (R) and transform(T) vectors between the camera (sensing part) and the projected area (augmenting part).

Finally, the matrices used for coordinate synchronization of the augmenting part and the sensing part can be obtained as shown in Eq. (7).

$$M_{camra} = R^{-1}(0 - T) = -R^{-1}T \quad - (7)$$

3. Experiments

The proposed system should keep a distance from the patient for content augmentation, and it should recognize the patient's walk for smooth gait training.

In this section, the performance of the proposed system is examined based on two experiments: one experiment on distance keeping and the other on gait recognition.

3.1 Experiment 1: Distance-keeping between a robot and patient experiment

The first experiment was conducted to confirm the effectiveness of the proposed system in keeping a certain distance (set) between a mobile robot and a patient. To review it, the experimental environment is implemented as shown in Figure 6.

First, the distance between the robot and the patient was set to 200 cm. We then compared the manual operation with the distance-keeping function to stop exactly at the 100 cm point because the augmented content has an area of 1 sq. m. The distance was kept with an error of 5 cm at intervals of approximately 95 cm, as shown in Figure 7, using the proposed function, whereas it was kept with an error of 20 cm at intervals of approximately 120 cm by manual operation. The experiments show that the accuracy was increased by 15% (from 80% to 95%) using the proposed function.

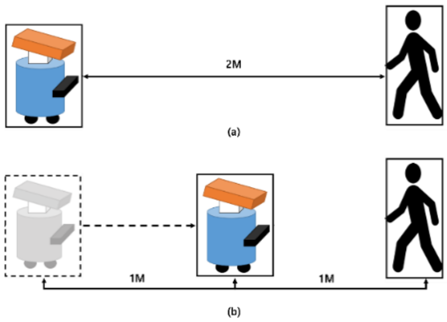


Fig.6: Distance between robot and patient function experimental environment:

(a) Set distance (2 m) moving part between patients

(b) Distance keeping (1 m) between the robot and the patient

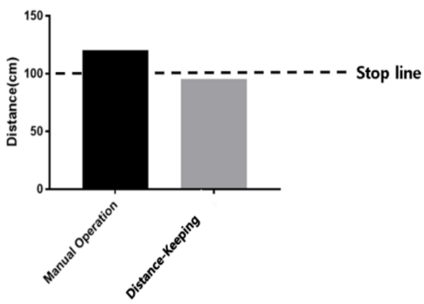


Fig.7: Experimental results of the proposed function

3.2 Experiment 2: Gait recognition experiment

The second experiment was conducted to confirm how accurately the proposed system recognizes the gait of a patient on the ground.

To review it, 10 virtual footprints projected on the ground, as shown in Figure 8, were given to the patient, and they walked along these footprints.

Then these (virtual footprints) were measured and checked to determine whether they were recorded with the patient's gait (actual footprint). The results of the experiment are presented in Table 1. The results showed that the sixth and eighth footprints were not recognized. (i.e., they have an 80% success rate).

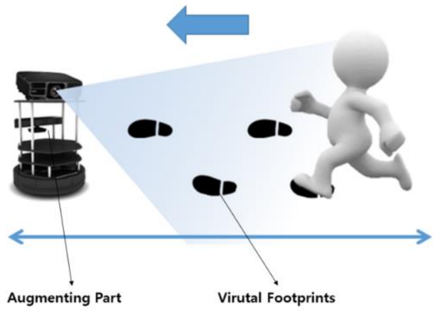


Fig.8: Patient gait recognition experiment environment

Table 1. Results of patient gait recognition experiment

Virtual footprint order	Recognition result
1	O
2	O
3	O
4	O
5	O
6	X
7	O
8	X
9	O
10	O

4. Conclusions

In this paper, we proposed a new type of gait training system that combines a mobile robot with virtual reality.

The proposed system is a mobile augmented robot system for gait training comprising a sensing part, a moving part, and an augmenting part. The sensing part measures and analyzes the patient's movement using the Kinect using the OpenNi tracker while the moving part keeps distance between the robot and the patient.

The augmenting part provides a coordinate synchronization function and virtual content to a patient. In addition, the proposed system allows users to interact with virtual training content in real time.

The performance of the proposed system was reviewed through two experiments: Experiment 1 (keeping distance between the robot and the patient) and Experiment 2 (patient gait recognition). A 15% improvement was achieved compared to conventional manual operation on Experiment 1, and an 80% recognition rate was obtained on Experiment 2.

Experiments have shown that the proposed system can keep relatively accurate distances for content augmentation in patients, and most of the patients' walking was recognizable.

Therefore, the proposed system conducted on real ground may compensate for the shortcomings of the conventional treadmill system. One of the future works possibly include improving the success rate.

References

[1] Mikolajczyk, Tadeusz, et al. "Advanced technology for gait rehabilitation: An overview." Advances in Mechanical Engineering 10 (2018): 1687814018783627: 7.

[2] Beretta, Elena, et al. "Combined robotic-aided gait training and physical therapy improve functional abilities and hip kinematics during gait in children and adolescents with acquired brain injury." Brain Injury 29 (2015): 955-962.

[3] Martini, Elena, et al. "Gait training using a robotic hip exoskeleton improves metabolic gait efficiency in the elderly." Scientific Reports 9 (2019): 7157.

[4] Giardini, Marica, et al. "Instrumental or physical-exercise rehabilitation of balance improves both balance and gait in Parkinson's disease." Neural Plasticity 2018 (2018): 5614242.

[5] Ji, Younghoon, et al. "Study on efficacy of gait training for hemiplegia patients using lower-limb wearable robot." Journal of the Korean Society for Precision Engineering 32.10 (2015): 879-883.

[6] Casuso-Holgado, María Jesús, et al. "Effectiveness of virtual reality training for balance and gait rehabilitation in people with multiple sclerosis: A systematic review and meta-analysis." Clinical Rehabilitation 32 (2018): 0269215518768084: 1220-1234.

[7] MEDICA, EDIZIONI Minerva. "Autonomous rehabilitation at stroke patients home for balance and gait: safety, usability and compliance of a virtual reality system." European journal of physical and rehabilitation medicine. (2017).

[8] https://www.hocoma.com/solutions/lokomat/.

[9] https://www.hocoma.com/solutions/c-mill/.

[10] http://walkbot.co.kr/introduction/.

[11] https://www.rehatechnology.com/en/g-eos/.

[12] Alexiadis, Dimitrios S., et al. "Evaluating a dancer's performance using Kinect-based skeleton tracking" Proceedings of the 19th ACM international conference on Multimedia. (2011).

[13] Kim, Junhee, Sae-Woung Yoo, and Kyung-Won Min "Microsoft Kinect-based indoor building information model acquisition." Journal of the Computational Structural Engineering Institute of Korea 31 (2018): 207-213.

[14] https://wiki.ros.org/openni_tracker.