A Hand-Gesture-Controlling Exergame System for Hypertension Precautions

Irin Tri Anggraini, Yanqi Xiao, Nobuo Funabiki, Cheng-Liang Shih, and Chih-Peng Fan

***Abstract*—According to the *World Health Organization (WHO)*, *high blood pressure* or *hypertension* is the current biggest risk for people around the world. It is known that blood pressure can be lowered by performing *isometric handgrip exercises* using a *foam ball*. Then, an *exergame* of playing a video game while conducting a handgrip exercise using it can be helpful for people suffering from the high blood pressure to repeat them in daily lives. In this paper, based on this motivation, we present a *hand-gesture-controlling exergame* system for *hypertension* precautions. The system runs a conventional personal computer with a browser and a camera. We define four simple hand gestures with a foam ball that can be effective in lowering the blood pressure and implement a *Python* program using *Mediapipe* library to recognize each gesture to control the video games. For evaluations, we applied the proposed system to 40 persons in Indonesia and 10 persons in Japan who may suffer from *hypertension*, and measured their blood pressures before and after the exercise. Their comparison results validated the effectiveness in lowering the blood pressure by the proposal. Besides, the *System Usability Scale (SUS)* score calculated from the questionnaire results to 10 questions confirmed the system usability and preferences by them.**

***Index Terms*—hand gesture, exergame, hypertension, handgrip exercise, foam ball, Mediapipe, Python, SUS**

I. Introduction

CURRENTLY, the *high blood pressure* or *hypertension* contributes to 13% of all the deaths worldwide [1]. The *World Health Organization (WHO)* suggests that *hypertension* is affecting people in heart or blood-related disorders primarily for people at the age between 30 and 79 [2]. It significantly increases the risk of causing a health problem such as *heart attack* and *stroke*. However, people are often unaware of *hypertension* until it becomes too late to avoid meeting health problems.

Numerous research papers have been published on precautions or managements of *hypertension*. Some of them have demonstrated that *isometric handgrip exercise* using a *foam ball* has positive effects in lowering the blood pressure [3][4][5]. Performing isometric handgrip exercises using a foam ball will lower both the systolic and diastolic blood pressure. Then, an *exergame* of playing a video game while

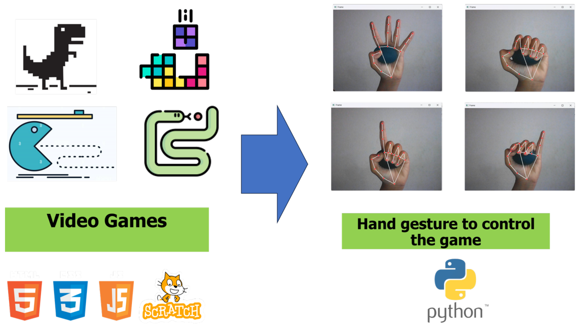

Fig. 1. System usage overview.

conducting a handgrip exercise using a *foam ball* will be helpful and effective for people suffering from high blood pressure to repeat them in their daily lives. A video game for exercise purposes is called an *exergame* [6].

Previously, we have studied a *exergame* system for dementia development suppressions [7]. We implemented a *Python* program utilizing the *Mediapipe* library [8] to recognize hand gestures for controlling video games. In our preliminary work in [9], we implemented a car racing game [10] that runs in a web browser and can be controlled using two hand gestures.

In this paper, we present a *hand-gesture-controlling exergame* system for *hypertension* precautions. This system runs on a conventional personal computer that is equipped with a camera and a web browser. To implement this system, we defined simple four *hand gestures* that are related to handgrip exercises using a foam ball. Then, we investigated proper video games that can be installed in this system. By introducing new video games and defining the hand gestures to control them, our proposed system will be more attractive for users. Moreover, it is known that these handgrip exercises with correct hand gestures are effective in lowering the blood pressure.

Figure 1 illustrates the usage overview of the system. The video game accepts four commands to *up*, *down*, *right*, and *left* for its control. As their corresponding hand gestures with a foam ball, we define the *close handgrip* gesture for *down*, the *open handgrip* gesture for *up*, index finger straight for *left* and little finger straight for *right*. Since *Mediapipe* can output the coordinates of 21 *keypoints* for one hand, we design the logic for recognizing each gesture using the relative distances between the coordinates of the significant *keypoints* of the related fingers in each gesture. A user can play the video game through the following steps: 1) run the *Python* program on a PC, 2) run the video game on the web browser, and 3) play the game by properly changing the hand gesture.

For evaluations, we applied the proposed system to 40 persons in Indonesia and 10 persons in Japan who may suffer from *hypertension*. We measured their blood pressures

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before and after playing games with hand gestures. Before the measurement, we explained to the participants how to perform the exercise using our system. Then, we analyzed the user blood pressure changed from *day 1* before starting the exercise using the system to *day 3* after completing it. The comparisons of the blood pressures confirmed the effectiveness of lowering the blood pressure by the proposed system. Besides, we asked them to answer to 10 questions on the usability as a questionnaire, and calculated the *System Usability Scale (SUS)* score [11] from the results. The obtained SUS score validated the system usability by them.

For this study, we made the research hypothesis that the proposed *handgrip exergame system* can effectively reduce the blood pressure. It is expected that a user can decrease the blood pressure by playing video games, which will encourage him/her to conduct handgrip exercises to manage *hypertension*. To prove this hypothesis, we adopted the following research methodology: 1) designing a set of four hand gestures corresponding to four different key inputs at a keyboard, 2) implementing a *Python* program using *Mediapipe* to recognize them with a web interface, 3) requesting persons that may suffer from the high blood pressure to involve this study, and 4) measuring their blood pressures before and after playing games using the system.

The rest of this paper is organized as follows: Section II discusses the research hypothesis and relevant studies in literature. Section III presents four hand gestures for handgrip exercises using a foam ball and the recognition algorithm. Section IV presents the *hand-gesture-controlling exergame* system. Section V evaluates the proposal through applications to 50 persons with the high blood pressure. Finally, Section VI concludes this paper with future works.

II. Related Works

In this section, we discuss relevant studies in the literature.

A. Hypertension

In [12], Jamie et al. showed the potential role of *isometric exercise training (IET)* as an anti-hypertensive intervention with consideration of its efficacy, acute cardiovascular stimulus, and physiological mechanistic underpinnings. Data from prospective *randomized controlled clinical trials (RCTs)* and meta-analyses indicate that IET is capable of reducing blood pressure greater than currently recommended exercise guidelines, and possibly even greater or at least similar to the standard anti-hypertensive monotherapy.

In [13], Jolene et al. showed that isometric handgrip training can effectively reduce blood pressure for middle-aged women. Their results suggested that even simple activities like sitting and standing position have positive impacts on blood pressure reductions.

In [14], Millar,et al. studied about isometric handgrip training is an effective method for lowering the resting blood pressure in individuals medicated for *hypertension*. The study found a consistent decline in systolic and diastolic blood pressure over time, with individuals experiencing higher initial blood pressure showing greater reductions.

In [15], Rinku et al. examined how training in *isometric handgrips (IHGs)* affected the resting blood pressure of healthy, normal participants. The IHG exercise training apparatus was a hand-grip spring dynamometer. A total of thirty healthy, normal volunteers at ages of 20 to 40 were recruited. The exercise training regimen comprised five 3-minute IHG exercise sessions at 30% of maximal voluntary contraction, interspersed with 5-minute rest intervals. For 10 weeks, exercise was done three times a week. The blood pressure of the subjects was taken both before and after the activity. After 10 weeks of exercises, there was a notable drop in resting blood pressure. Significant reductions were observed in both diastolic and systolic blood pressure ($p < 0.001$).

In [16], Yen et al. investigated how add-on *Yoga* with rehabilitation improved patients' *blood pressure (BP)* and hand grip strength in those who had suffered *chronic stroke* for more than 90 days. Patients in the study ranged at ages of 30 to 80 and were able to stand on their own for one minute. Both the injured hand ($p = 0.027$) and the unaffected hand ($p = 0.00025$) showed a substantial improvement in hand grip strength. Both the diastolic and systolic blood pressure in the control group, as well as the grip strength in both hands, did not alter significantly. Age and gender also had impacts on the overall rehabilitation outcomes. Women gained more in the drop of blood pressure, while men and younger individuals under 60 years old benefited from the increase of hand grip strength.

B. Hand Gesture Recognition

In [17], Tan et al. presents a *wide residual network (WRN)* for the recognition of static hand gestures. WRN enhances feature propagation and gradient flow by employing shortcut connections within residual blocks. The wide residual block enhances the residual block by augmenting the network's breadth, facilitating feature reuse, and consequently permitting a reduction in network depth and a decrease in the number of trainable parameters. The network is evaluated on three public datasets and compared with the *convolutional neural network (CNN)* variations designed for static hand gesture identification. Experimental findings indicate that WRN surpasses the current CNN variations developed for hand motion identification.

In [18], Sooai et al. studied hand gestures to interact with 3D virtual museum objects to protect the real artefacts. They used a sensor to record 10 gestures like pick-up, grab, push, and tracking hand movements. A K-nearest neighbor model is trained with the accuracy 99.3%. When tested, four gestures had over the accuracy is 92%, while three were below 64%. The most accurate gestures were chosen for the final model, making it useful for museums and education.

In [19], Liu et al. Introduced an innovative 2D CNN-based framework designed to efficiently collect spatial temporal features for hand gesture detection, minimizing computational demands and time consumption. Encoding sampled frames from a video sequence into a new image, which is subsequently transmitted to the 2D CNN, minimizes the number of parameters and decreases the computational expense of the network, facilitating temporal jittering and data augmentation through image cropping. This study has achieved competitive performance on the MSR gesture 3D dataset while ensuring a fair computing expense.

In [20], Angelina et al. designed and implemented a hand rehabilitation software incorporating hand gesture detection and recognition technology. They introduced a hand exercise physiotherapy game whose visual feedback can engage patients throughout the activity. In addition, rehabilitation could be more pleasurable, accessible, and portable. In this study, the *game 2048* is utilized for hand rehabilitation by controlling it through hand gestures.

In [21], Zabri et al. presented a hand rehabilitation system that utilizes computer vision techniques. This exercise is advantageous for enhancing hand mobility and alleviating discomfort. The hand rehabilitation system utilizes a method that involves tracking the hand and detecting the movements of individual fingers. The outcome of the activity can be used as the training data for analyzing the recuperation and healing process of the wounded hand.

In [22], Teja et al. implemented a hand gesture cricket game, which means that once the player begins playing while keeping his or her video, the player's hand movements are identified and his or her score is computed till he exits the game or video. They implemented it in two ways. The first one uses its own dataset and a custom-developed CNN. The second one uses *MediaPipe* in *Python* with *OpenCV Keras*. With 10 epochs of training, the trained CNN achieved an accuracy of 0.9767.

In [23], Farah et al. studied several ways to recognize hand gestures using three key modules: the camera and segmentation module, the detection module, and the feature extraction module. Depending on their benefits, there are a lot of different ways to get the results. A summary of previous research and the results of hand gesture methods are given in this paper. There is also a comparison of gesture recognition methods.

C. Exergame

In [24], Wu et al. conducted a study to examine the effect of *exergame* in enhancing cognitive and physical capacities in patients who are diagnosed as *dementia*. An *exergame* is proposed to substitute aerobic exercises in the treatment and early prevention of *dementia* in old persons. To improve the accuracy and applicability, future studies will be necessary using control groups who do not participate in exercises along with a large sample size.

In [25], Finco et al. presented a series of different interfaces, initial concepts, and design patterns that showcased developments of *exergames* with a focus on promoting an *active lifestyle*, in contrast to the conventional sedentary nature of video games. They surveyed evolutions of *exergames* from 1980s to the present day, focusing on the concept of exercise support through digital games.

In [26], Julianjatsono et al. created *Beat-Beat Fitness (BBF)* that has various elements to likely have effects on players' psychophysiology. To compare the benefits of *BBF* to those of other *exergames*, they used a questionnaire to assess psychophysiological effects. Based on the results, *BBF* is more actively participated than *Kinect Dance Central*. They confirmed that the inclusion of the suggested extra elements increases the psychophysiological impacts of *exergames*.

In [27], Brox et al. presented a detailed evaluation to show how *exergames* help elders to be engaged in physical activities, and examined possibilities of social connections by online *exergames* and the use of persuasive technologies. Subsequently, they contemplated the potential utilization of a social *exergame* as the means to mitigate feelings of isolation while encouraging physical exercises.

In [28], Javeed et al. proposed a method to aid cutting-edge studies in AI and signal processing while providing a VR app for gesture recognition. Their primary goal is to apply the idea of *exergames* to the creation of a system for practical gesture detections by connecting motion sensors and VR equipment. Additionally, the technology has the potential for remote rehabilitation, gaming, and training. A specialized study of human motions is recommended to attain high levels of precision.

In [29], Konstantinidis et al. investigated the effectiveness, the user adherence, and the system usability of the low-cost physical exercise and gaming or *exergame* system called *FitForAll (FFA)* platform. The design of *FFA* considers the needs of the elderly population by combining recommendations from existing research. The *FFA* architecture consists of standardized physical activity procedures in physical activity software as well as regulated physical assessments for enhanced adaptability by adjusting exercise intensities. This paves the way for future *exergame* software that may be more automatically/intelligently adaptive. 116 seniors used *FFA* five times per week throughout the eight-week controlled experiment. Formal usability testing was conducted using *SUS* and *SUMI* surveys. A group of seniors with a comparable size served as the control group.

In [30], Mulholland et al. explored the effectiveness of a physiotherapeutically developed fall prevention program using the *interactive modular tile (IMT) exergame* technology. They used a combination of objective and subjective measurements to examine the impact of *exergame* interventions on fall risks. Their findings suggested that *IMT*-based *exergames* can assist the delivery of fall prevention programs to old persons. Overall, most persons noticed decreased risks of falling and improved their dynamic balances significantly.

III. Hand Gestures for Handgrip Exercise

In this section, we define the *hand gestures* to perform a handgrip exercise using a foam ball and their recognition algorithm.

A. Handgrip Exercise Using Foam Ball

Handgrip exercises refer to physical movements and activities of a handgrip. They have been designed to improve the strength, flexibility, coordination, and dexterity of hands and fingers. For persons with *high blood pressure*, safety of exercises is essential. Their blood pressure must not become significantly high during exercises, while improving the hand strength and flexibility. As a proper exercise, the handgrip one using a small soft ball (foam ball) can be a good choice.

Figures 2 and 3 illustrate the *close* handgrip state and the *open* handgrip state with a foam ball, respectively. In the *close* handgrip state, a player bends all the fingers to keep the ball [31]. In the *open* handgrip state, he/she bends only the thumb towards the ball. In an exergame system, by repeating bending and unbending the four fingers to control a video game by moving between the two states, the player can perform the handgrip exercise using a *foam ball*. It is expected that this exercise helps improving the hand and finger strength and flexibility of the player.

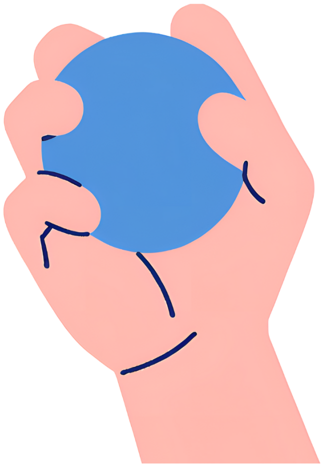

Fig. 2. *Close* handgrip state with foam ball.

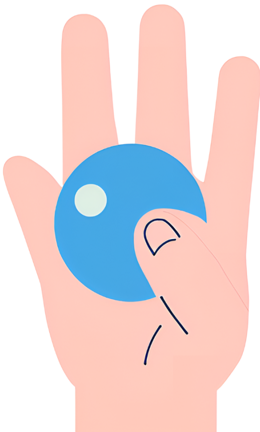

Fig. 3. *Open* handgrip state with foam ball.

B. Mediapipe *for Hand Gesture Recognition*

In this study, we define four hand gestures corresponding to the four keys required to play a video game. The gestures are recognized by applying the implemented *Python* program using the *Mediapipe* library to the hand image captured by a PC camera. This library provides the coordinates of the specific hand landmarks called *keypoints* from a hand image in real-time [8]. For each hand, 21 *keypoints* can be detected. Figure 4 shows the *keypoints* for one hand [32].

C. Hand Gesture Recognition Algorithm

A hand gesture can be defined as a combination of bended or straight fingers among the five fingers of one hand. The bended or straight state of a finger can be recognized by comparing the distance between the bottom *keypoint* of the hand and the fingertip *keypoint* with the given threshold. When this distance is larger than the threshold, it is regarded as the *bended* finger. Otherwise, it is regarded as the *straight* one. Based on this rule, we design the algorithm to recognize each of the four hand gestures, namely, *left*, *right*, *up*, and *down*.

1) Left *Hand Gesture:* Figure 5 shows the *left* hand gesture. Only the *index finger* is straight while the others are bended. In the current implementation, it represents pressing

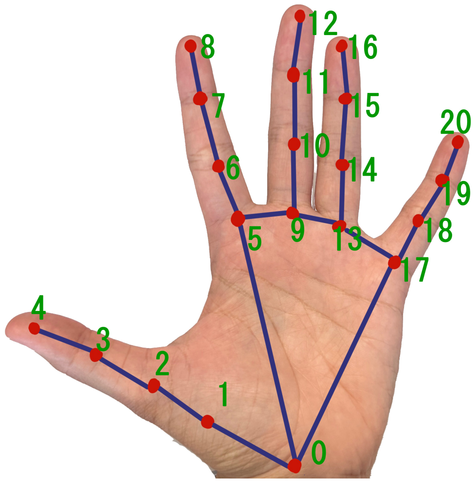

Fig. 4. 21 *keypoints* for one hand.

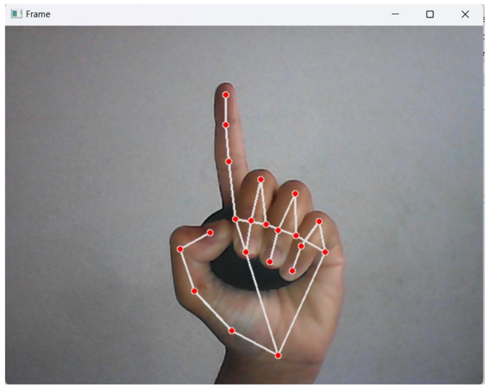

Fig. 5. *Left* hand gesture.

the *left arrow* on the keyboard. In the current implementation, it represents pressing the *left arrow* on the keyboard. The program issues the command of pressing the left key:

```
if␣count_fingers_open␣==␣1:
if␣fingers_open[1]␣==␣1:
keyboard.press(Key.left)
```

2) Right *Hand Gesture:* Figure 6 shows the *right* hand gesture. Only the *small finger* is straight while the others are bend. In the current implementation, it represents pressing the *right arrow* on the keyboard. It represents pressing the *right arrow* on the keyboard. The program issues the command of pressing the right key:

```
elif␣fingers_open[4]␣==␣1:
keyboard.press(Key.right)
```

3) Up *Hand Gesture:* Figure 7 shows the *open* hand gesture. Only the *thumb finger* is bent while the others are straight. In the current implementation, it represents pressing the *up arrow* on the keyboard. It represents pressing the *up arrow* on the keyboard. The program issues the command of pressing the up key:

```
elif␣count_fingers_open␣==␣4:
if␣fingers_open[1]␣==␣1
and␣fingers_open[2]␣==␣1
and␣fingers_open[3]␣==␣1
and␣fingers_open[4]␣==␣1:
```

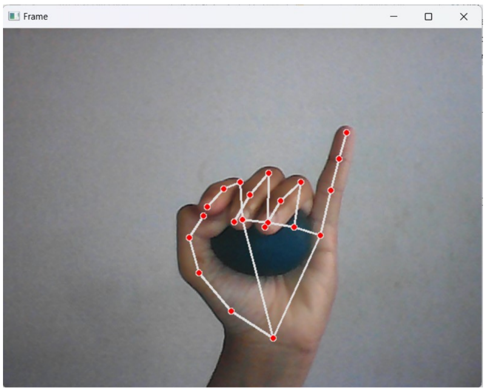

Fig. 6. *Right* hand gesture.

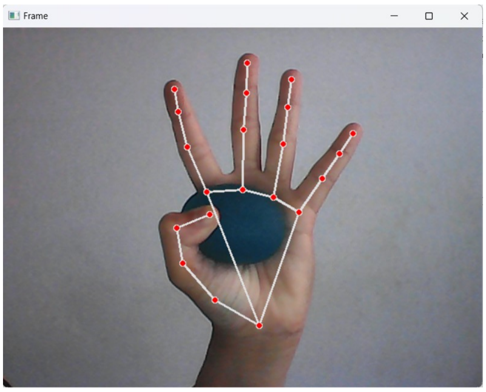

Fig. 7. *Up* hand gesture.

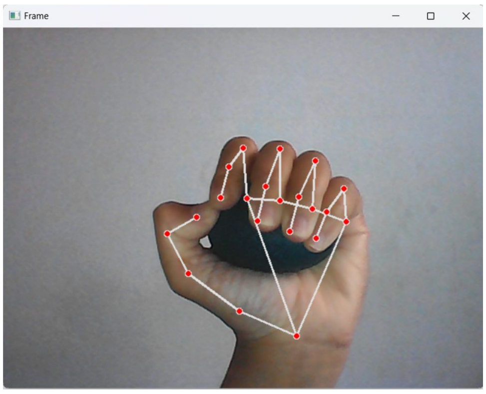

Fig. 8. *Down* hand gesture.

```
keyboard.press(Key.up)
```

4) Down Hand Gesture: Figure 8 shows the *close* hand gesture. All the fingers are bent. In the current implementation, it represents pressing the *down arrow* on the keyboard. It represents pressing the *down arrow* on the keyboard. The program issues the command of pressing the down key:

```
elif␣count_fingers_open␣==␣0:
keyboard.press(Key.down)
```

IV. Hand-Gesture-Controlling Exergame System

In this section, we present a *hand-gesture-controlling exergame* system for *hypertension* precautions.

TABLE I
Hardware platform specifications.

ITEM	SPECIFICATION
PC	OS: Windows 10 Home Single Language 64 bit memory: 8 GB CPU: Intel (R) Core (TM) i5-1935G1
camera	USB 2.0 VGA UVC Webcam
projector	ELEPHAS 5GWIFI Mini Projector
browser	Chrome Version 113.0.5672.92 (Official Build) (64-bit)
Python	v3.9.0 (64-bit)
Mediapipe	0.10.11
video game	HTML 5

Fig. 9. Car racing game.

A. Hardware and Software Platforms

Table I shows the hardware and software platforms for our implementation of the proposed system. The video game runs on a web browser such as *Chrome*. The hand gesture recognition program was made in *Python* with the *Mediapipe* library.

B. Conditions of Suitable Video Games

Here, we show the following three conditions of video games that are suitable in the *exergame* system:

- The game can be easily played even by seniors.
- The number of the keys required to control the game is at most four, since the number of implemented hand gestures is four.
- Each of the keys should be pressed randomly during the game.

C. Video Games for Two Gestures

First, we show five video games that use two different keys or gestures.

1) Car Racing Game: Figure 9 shows *Car racing* game [33]. It is popular because a player can enjoy the thrill of fast races by pressing only two keys for *stop* and *go*. In our implementation, the *open* and *close* hand gestures are used for them. A player can change the number of cars and tracks.

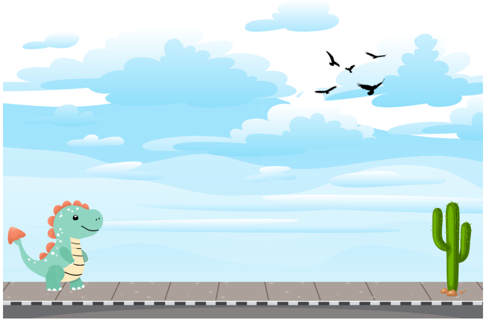

Fig. 10. Dino game.

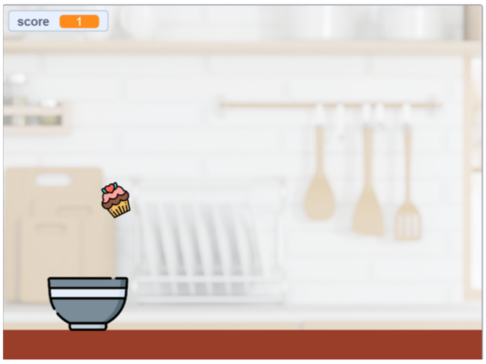

Fig. 11. Cake game.

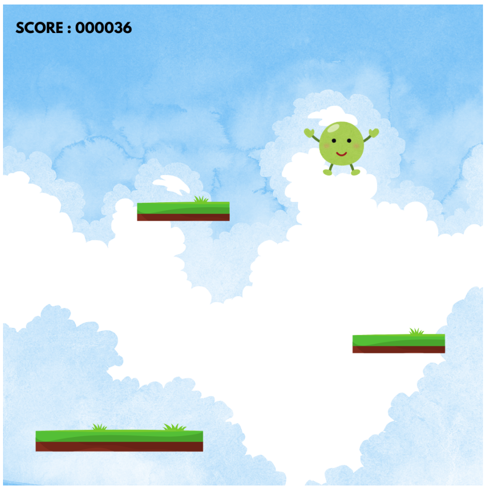

Fig. 12. Sky Jump game.

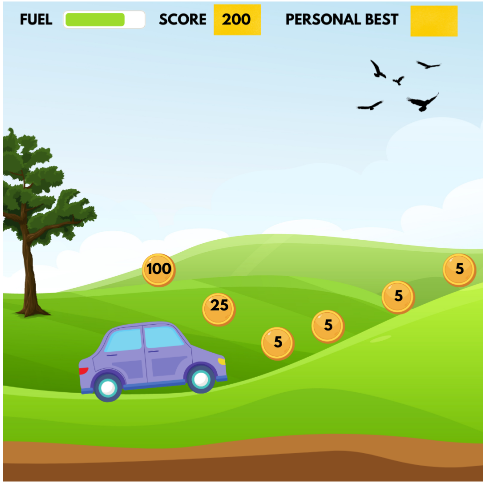

Fig. 13. Car climb racing game.

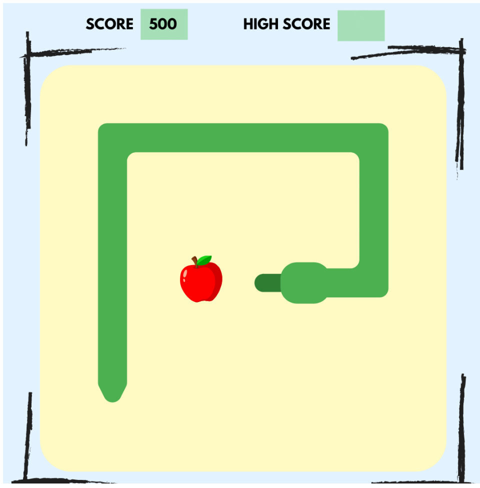

Fig. 14. Snake bite game.

2) Dino Game: Figure 10 show *Dino* game [34]. A player needs to navigate the pixelated *Tyrannosaurus* to avoid the obstacles by jumps. In our implementation, the *open* and *close* hand gestures are used for *jump* and *run*.

3) Cake Game: Figure 11 shows *Cake* game [35]. A player needs to catch falling cakes. In our implementation, the *left* and *right* hand gestures are used for *left move* and *right move*.

4) Sky Jump Game: Figure 12 shows *Sky jump* game [36]. In our implementation, the *left* and *right* hand gestures are used for *left move* and *right move*.

5) Car Climb Racing Game: Figure 13 show *Car climb racing* game [37]. In this game, a player needs to drive the car on the uneven ground without tipping over the slope, and gains the bonus point at every jump. In our implementation, the *left* and *right* hand gestures are used for *left move* and *right move*.

D. Sample Games for Four Gestures

Second, we show four video games that use four different keys or gestures.

1) Snake Bite Game: Figure 14 shows *Snake bite* game [38]. A player needs to guide the snake to eat foods as much as possible while avoiding the walls, barriers, and other moving objects that can cause the snake to collide and end the game. The four hand gestures are used to control the direction of the snake.

2) Pac-Man Game: Figure 15 shows *Pac-Man* game [39]. A player needs to navigate the object called *Pac-Man* in the maze to eat foods as much as possible while avoiding ghosts. The four hand gestures are used to change the moving direction of *Pac-Man*.

3) Tetris Game: Figure 16 shows *Tetris* game [40]. A player needs to move blocks called *Tetris* to make the line of square blocks so that it will be removed. When a block reaches the summit, the game is over. The four hand gestures are used to rotate the block in the clockwise or counter-clockwise direction, or move it in the left or right direction.

4) Maze Game: Figure 17 shows *Maze* game [41]. In this game, a player has to find an efficient route to get the

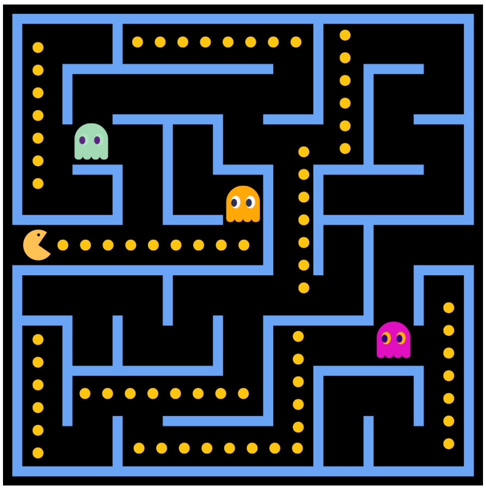

Fig. 15. Pac-Man game.

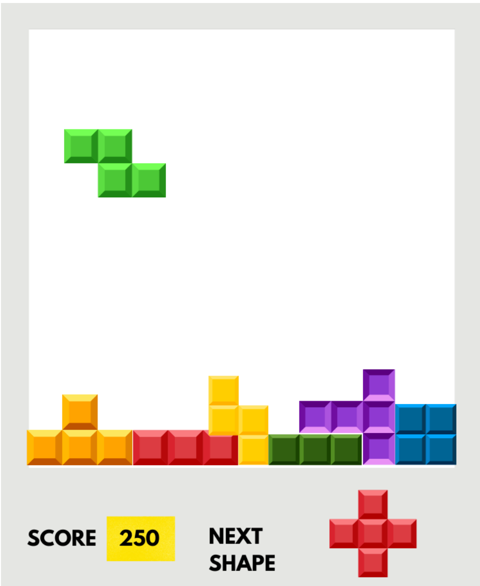

Fig. 16. Tetris game.

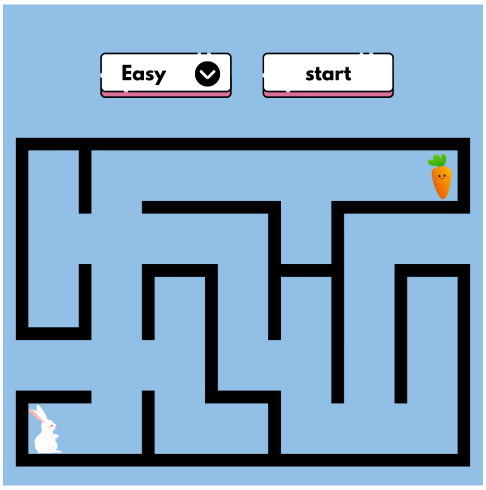

Fig. 17. Maze game.

food. The four hand gestures are used to change the moving direction.

E. System Operation Procedure

The following procedure describes the operation flow of the system:

1) Run the *Python* program for the web interface and the hand gesture recognition.
2) Run the video game on a web browser.
3) Grip the foam ball.
4) Play the video game by showing proper hand gestures while keeping the ball.

V. Evaluation

In this section, we evaluate the proposed system through applications to 40 persons in Indonesia and 10 persons in Japan who may suffer from *hypertension*. We investigate the effect on the blood pressure reduction in two different countries. Besides, we examine the usability through *System Usability Scale (SUS)* scores.

A. Application Setup

In each application, we asked each participant to freely choose a preferred game among the prepared nine games and to play it, which was repeated for 15 minutes. We measured the blood pressure before and after the exercises.

1) Blood Pressure Measurement Results: Table II shows the age and the gender, and the measured blood pressure level after the game in each day, for each of the 50 persons. According to Table III, "E" represents "Elevated Blood Pressure" with the systolic pressure ranging from 120 to $129mmHg$ or the diastolic pressure below $80mmHg$, "HS1" does "Hypertension Stage 1" with the systolic pressure between 130 and $139mmHg$ or the diastolic pressure ranging from 80 to $89mmHg$, "HS2" does "Hypertension Stage 2"with the systolic pressure of $140mmHg$ or higher, or the diastolic pressure of $90mmHg$ or higher. Any person improved the blood pressure level after the three-day exercise.

2) Blood Pressure Measurement Systolic and Diastolic Results: Figures 18 and 19 show systolic blood pressure and diastolic blood pressure measurement results before and after the three-day exercise using the proposed system, respectively. The blue line represents the results before the exercise and the red line does the results after it. Among them, *user 9* had the highest blood pressure on any day. On *day 1*, the blood pressure before the exercise was 170 for systolic and 120 for diastolic. Then, after the exercise, it was reduced to 168 and 115 respectively. Actually, for any user, the blood pressure for systolic was decreased after the exercise on any day.

3) t-test Results: We applied the *t-test* to analyze the validity of the blood pressure reduction by the proposal.

Table IV shows the application result of the *t-test* to the systolic blood pressure reduction. The *p-value* for both the one-tailed and two-tailed tests is smaller than 0.05, which indicates that there is a statistically significant difference in the systolic blood pressure between *day 1* and *day 3*. The *t-statistic* is positive and large, suggesting that the mean blood pressure on *day 1* is significantly higher than the one on *day 3*. This suggests that use of the *exergame* system has a significant effect on lowering the systolic blood pressure.

Table V shows the *t-test* result to the diastolic blood pressure reduction. The *p-value* for both the one-tailed and

TABLE II
BLOOD PRESSURE LEVEL OF 50 PERSONS.

ID	age	Gender	Day 1	Day 2	Day 3
1	58	M	HS2	HS2	HS2
2	47	F	HS1	HS1	E
3	60	F	HS2	HS1	HS1
4	63	F	HS2	HS2	HS2
5	68	M	HS1	HS1	E
6	70	M	HS2	HS1	HS1
7	45	F	HS1	HS1	HS1
8	51	M	HS2	HS1	HS1
9	65	M	HS2	HS2	HS2
10	46	F	HS1	HS1	HS1
11	61	M	HS2	HS2	HS2
12	60	M	HS2	HS2	HS2
13	69	M	HS2	HS1	HS1
14	55	F	HS1	HS1	HS1
15	62	F	HS2	HS1	HS1
16	72	M	HS2	HS2	HS2
17	56	F	HS1	HS1	E
18	63	M	HS2	HS1	HS1
19	57	F	HS2	HS1	HS1
20	61	M	HS2	HS2	HS1
21	55	M	HS2	HS2	HS2
22	62	F	HS1	HS1	HS1
23	72	F	HS2	HS2	HS1
24	45	F	HS2	HS2	HS2
25	58	M	HS1	HS1	E
26	68	M	HS2	HS1	HS1
27	70	F	HS2	HS2	HS2
28	65	M	HS2	HS2	HS2
29	58	M	HS1	HS1	E
30	68	F	HS 2	HS2	HS2
31	70	M	HS2	HS2	HS2
32	45	M	HS2	HS2	HS2
33	68	M	HS2	HS1	HS1
34	70	F	HS1	HS1	HS1
35	45	F	HS2	HS2	HS2
36	51	M	HS2	HS2	HS2
37	65	F	HS1	HS1	HS1
38	51	M	HS2	HS1	HS1
39	65	F	HS2	HS1	HS1
40	61	M	HS1	HS1	HS1
41	65	M	HS2	HS2	HS2
42	46	F	HS2	HS2	HS2
43	61	M	HS2	HS1	HS1
44	60	M	HS1	HS1	HS1
45	69	M	HS2	HS1	HS1
46	76	F	HS2	HS2	HS1
47	78	F	HS2	HS2	HS2
48	71	M	HS2	HS1	HS1
49	70	F	HS2	HS2	HS2
50	72	M	HS2	HS1	HS1

two-tailed tests is smaller than 0.05, which indicates that there is a statistically significant difference in the systolic blood pressure between them. The *t-statistic* is positive and large, suggesting that the mean blood pressure on *day 1* is significantly higher than the one on *day 3*. This suggests that

TABLE III
BLOOD PRESSURE CATEGORY.

blood pressure category	systolic $mmHg$		diastolic $mmHg$
normal (N)	<120	and	<80
elevated (E)	120-129	and	<80
hypertension stage 1 (HS1)	130-139	or	80-89
hypertension stage 2 (HS2)	140-180	or	90-120
hypertension stage 3 (HS3)	>180	or	>120

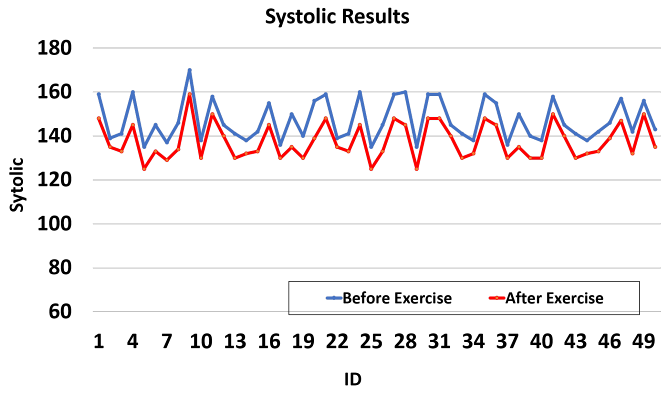

Fig. 18. Systolic blood pressure measurement results.

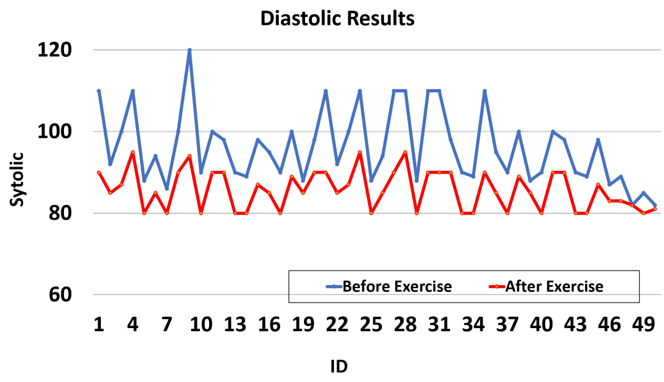

Fig. 19. Diastolic blood pressure measurement results.

exercises in the proposal have significant effects on lowering the diastolic blood pressure.

B. *Questions in Questionnaire*

After completing all the exercises in three days, we asked the 50 persons to answer the 10 questions in Table VI on the usability and preference of the exergame system with five grades (1: strongly disagree, 2: disagree, 3: neutral, 4: agree, 5: strongly agree). A higher grade answer indicates better usability for a *positive* question, while a lower one does it for a *negative* question.

C. *SUS Score Results*

For the quantitative evaluation of the questionnaire results, the questions were made to calculate the *System Usability*

TABLE IV
t-test RESULTS FOR SYSTOLIC BLOOD PRESSURE REDUCTIONS.

	Day 1 *Before Exercise*	*Day 3* *After Exercise*
Mean	147.04	137.52
Variance	86.69	67.76
Observations	50	50
Pearson Correlation	0.94	
Hypothesized Mean Difference	0	
df	49	
t Stat	21.72	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.01	

TABLE V
t-test RESULTS FOR DIASTOLIC BLOOD PRESSURE REDUCTIONS.

	Day 1 *Before Exercise*	*Day 3* *After Exercise*
Mean	96.16	85.68
Variance	81.20	23.24
Observations	50	50
Pearson Correlation	0.88	
Hypothesized Mean Difference	0	
df	49	
t Stat	14.04	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.68	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.01	

TABLE VI
QUESTIONS FOR QUESTIONNAIRE.

ID	question
1	Hand grip exercise using this system is easy to use.
2	The system cannot detect hand movements accurately.
3	The interface of this system is easy to understand.
4	The game response of hand detection has some delay.
5	Hand grip exercise with the game is more fun.
6	The hand grip gesture system is not user-friendly.
7	I feel better after handgrip exercise using this system.
8	The video game in this system is not interesting.
9	I want to continue the hand grip exercise system using another game.
10	I don't want to continue doing exercise using this system.

Scale (SUS) score [11] by the following procedure. The minimum *SUS* score is 0 and the maximum one is 100. Table VII shows the standard ranges of the *SUS* score.

1. Calculate the individual score contribution for positive question items 1, 3, 5, 7, and 9 by subtracting the answer by 1.
2. Calculate the individual score contribution for negative question items 2, 4, 6, 8, and 10 by subtracting the answer from 5.
3. Calculate the raw SUS score by adding all the individual score contributions for the 10 questions.
4. Calculate the final SUS score by multiplying the raw score with 2.5.

TABLE VII
STANDARD RANGES OF SUS SCORE.

average SUS score	grade	adjective rating
>80.3	A	excellent
68 – 80.3	B	good
68	C	okay
51 – 68	D	poor
<51	F	awful

Table VIII shows the answers to the 10 questions and the *SUS* scores of the 50 persons. The average *SUS* score is 82.3 (excellent), where the highest is 90 (excellent), and the lowest is 75 (good). The average answer grade for any *positive* question is larger than 4, and the one for a *negative* question is smaller than 2 except for ID=2 (2.1). These results indicate that the subjects positively evaluated the proposed system. Thus, the effectiveness of the proposal is confirmed.

VI. CONCLUSION

This paper presented the *hand-gesture-controlling exergame* system for *hypertension* precautions. The system runs on a conventional personal computer with a camera and a browser. Four hand gestures holding a *foam ball* were defined to control video games to offer effective handgrip exercises for lowering blood pressure. A *Python* program using the *Mediapipe* library was implemented to provide the web interface and recognize the hand gestures. For evaluations, we applied the proposed system to 50 persons in Indonesia and Japan who may suffer from *hypertension*, and measured their blood pressures before and after the exercise using the system. The results showed that handgrip exercises using the system could significantly lower the blood pressure. Besides, the questionnaire results with *SUS* scores confirmed the system usability and the preferences of the users. In future works, we will continue improving the proposed system for better usability and adding new video games with implementing the necessary hand gestures.

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TABLE VIII
QUESTIONNAIRE RESULTS.

ID	answer to questions										raw score	final score
	1	2	3	4	5	6	7	8	9	10		
1	4	3	4	2	4	2	4	2	4	1	30	75
2	5	2	5	1	4	2	5	2	4	2	34	85
3	4	1	5	2	4	2	5	1	5	2	35	87.5
4	4	2	5	1	4	1	4	2	5	2	34	85
5	5	1	5	3	5	2	5	2	5	1	36	90
6	5	2	5	2	5	1	5	2	4	2	35	87.5
7	4	1	4	2	4	2	4	2	5	2	32	80
8	4	2	4	2	4	1	4	2	5	2	32	80
9	5	1	4	2	5	2	5	2	5	2	35	87.5
10	5	3	4	2	4	2	5	2	5	1	33	82.5
11	4	3	4	2	4	2	4	2	4	1	30	75
12	4	2	5	1	4	1	4	2	5	2	34	85
13	5	1	5	3	5	2	5	2	5	1	36	90
14	4	3	4	2	4	2	4	2	5	2	30	75
15	4	2	4	2	4	2	4	2	5	1	32	80
16	5	3	5	2	5	1	5	2	4	2	34	85
17	4	1	4	3	4	2	4	1	5	1	33	82.5
18	4	2	4	2	4	1	4	2	5	2	32	80
19	5	1	3	2	5	1	5	1	4	3	34	85
20	5	3	5	1	4	2	5	2	4	2	33	82.5
21	5	1	5	3	5	2	5	2	5	1	36	90
22	4	3	4	2	4	2	4	2	5	2	30	75
23	4	1	4	3	4	2	4	1	5	1	33	82.5
24	5	2	5	2	5	1	5	2	4	2	35	87.5
25	4	2	5	1	4	1	4	2	5	2	34	85
26	5	1	3	2	5	1	5	1	4	3	34	85
27	4	3	4	2	4	2	4	2	4	1	30	75
28	5	2	5	1	4	2	5	2	4	2	34	85
29	4	2	5	1	4	1	4	2	5	2	34	85
30	4	3	4	2	4	2	4	2	4	1	30	75
31	5	2	5	1	4	2	5	2	4	2	34	85
32	4	3	4	2	4	2	4	2	4	1	30	75
33	5	2	5	1	4	2	5	2	4	2	34	85
34	4	3	4	2	4	2	4	2	4	1	30	75
35	5	2	5	1	4	2	5	2	4	2	34	85
36	4	3	4	2	4	2	4	2	4	1	30	75
37	5	2	5	1	4	2	5	2	4	2	34	85
38	5	1	5	3	5	2	5	2	5	1	36	90
39	4	2	4	2	4	1	4	2	5	2	32	80
40	4	3	4	2	4	2	4	2	4	1	30	75
41	5	2	5	1	4	2	5	2	4	2	34	85
42	5	2	5	2	5	1	5	2	4	2	35	87.5
43	4	2	5	1	4	1	4	2	5	2	34	85
44	4	3	4	2	4	2	4	2	4	1	30	75
45	4	3	4	2	4	2	4	2	4	1	30	75
46	5	2	5	1	4	2	5	2	4	2	34	85
47	4	2	5	1	4	1	4	2	5	2	34	85
48	4	3	4	2	4	2	4	2	4	1	30	75
49	5	2	5	1	4	2	5	2	4	2	34	85
50	4	1	4	2	4	2	4	2	5	2	32	80
Average	4.4	2.1	4.5	1.8	4.2	1.7	4.5	1.9	4.5	1.7	32.9	82.3

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