



Hand Gesture Controlled Game for Hand Rehabilitation

Angelina Chow Mei Yeng, Pang Ying Han^(✉), Khoh Wee How, and Ooi Shih Yin

Faculty of Information Science and Technology, Multimedia University, Jln Ayer Keroh Lama,
75450 Ayer Keroh, Melaka, Malaysia
yhpang@mmu.edu.my

Abstract. When getting an injury or chronic pain that affects daily activities, physiotherapy is always introduced. Usually, patients will attend a few physiotherapy sessions in the presence of their physiotherapist to learn rehabilitative exercises. Then, they are advised to have home exercises frequently for faster improvement. Rehabilitation can be boring for patients as they have to perform the movements repetitively. This might cause them to feel unmotivated and skip their exercises. This paper presents the design and implementation of hand rehabilitation software with hand gesture detection and recognition technology. We introduce an interesting and interactive game in physiotherapy for hand exercises. The visual feedback provided by the game can increase patients' engagement during exercise. Besides that, the rehabilitation process could be more enjoyable, accessible and portable for them. In this work, the game 2048 is used for game-based hand rehabilitation and is controlled by the users through the detected hand gestures. In the game, similar number tiles have to be combined to obtain the highest total number possible. The hand gestures used in this gesture-controlled game-based rehabilitation are those common hand exercises recommended by medical specialists.

Keywords: Physiotherapy · Rehabilitation · Hand gesture · MediaPipe · Gesture controlled game · 2048 game

1 Introduction

Physiotherapy is a type of therapy that relies on physical treatments such as massage and exercise to treat injury, disease, or deformity. It is suitable for people at any stage of life when movement and function are threatened by ageing, injury, diseases, disorders, conditions or environmental factors [1]. Patients usually attend physiotherapy sessions where the physiotherapist will be engaged with the patient to teach and guide certain exercises for rehabilitation. Besides, the patients are advised to perform home exercises frequently for faster improvement. Figure 1 illustrates the usual physiotherapy process.

Rehabilitation can be boring with repeating the same movements many times. This might cause the patients to feel unmotivated and skip their exercises, especially at

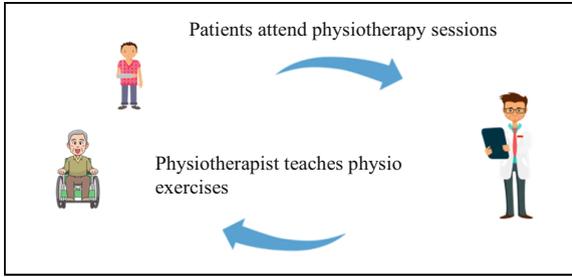


Fig. 1. Physiotherapy process

home without the supervision of a physiotherapist. There is a rising interest in developing games for rehabilitation to make this process more interesting to patients. However, most commercialized game-based rehabilitation software requires special devices which may burden the patients with financial risk. Hence, this paper presents the design and implementation of hand rehabilitation software with hand gesture detection and recognition.

In literature, Kinect One Sensor was adopted to detect a patient's hand gestures to play MIRA video games for rehabilitation [2]. MIRA is a software application that gamifies physical and cognitive physiotherapy. In addition, JINTRONIX VR rehabilitation system was introduced as another option for physiotherapy [3]. Jintronix is a rehabilitation-based virtual reality exergame system for stroke patients as an adjunct to traditional therapy. 14 stroke patients were trained with the Jintronix VR rehabilitation system. Empirical results showed that the majority of the patients enjoyed the experience. Besides that, the paper also stated that all the stroke patients showed improvements in their rehabilitation training over three sessions.

Furthermore, there is another literature that proposes a sEMG-controlled 3D game [4]. This system uses a deep learning-based architecture for real-time gesture recognition. The sEMG-controlled 3D game emphasizes on rehabilitation exercises which enable individuals with certain disabilities to use low-cost sEMG sensors to control the game experience. Besides, HandReha is a game-based system which utilizes deep learning techniques to perform real-time hand gesture recognition [5]. HandReha works by automatically recognizing a user's pre-defined hand gestures through a web camera, and using it to control an avatar in a three dimensional maze run game. 12 healthy participants took part in this study and the reported results showed that the HandReha system is intuitive and engages the user, which is vital for rehabilitation purposes. A new deep learning framework has been proposed for hand gesture recognition from the multi-session EMG signal [6]. Before feeding EMG into the CNN, the signal is transformed into time-frequency domain by STFT for more time-varying frequency attributes since EMG is a noisy time series signal. The paper reported that the recognition rate of 83% was obtained.

Unlike the abovementioned game-based rehabilitation software applications which require a Microsoft Kinect sensor, our proposed game-based rehabilitation software just requires a normal laptop with a working webcam that is usually owned in every household in today's world.

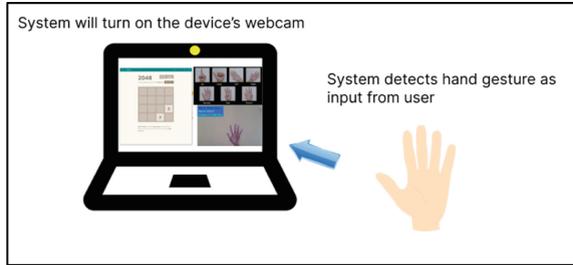


Fig. 2. System get input from user

2 Method

In our proposed game-based hand rehabilitation system, as mentioned above, a laptop with a working webcam is required to run the software application. The user is required to place his hand in front of the camera for hand gesture detection and system activation. Figure 2 illustrates the proposed system getting hand gesture input from a user.

In this system, a Python module known as MediaPipe Hands is implemented [7] for hand gesture detection and tracking. This framework consists of three basic models: (1) a palm detector model, it is also known as BlazePalm, (2) a hand landmark model and (3) a gesture recognizer. Figure 3 illustrates the overview of the hand detection process. When the webcam (camera) detects the presence of a hand, BlazePalm will process the captured image, crop the image and pass the cropped palm image to the hand landmark model for further process. Next, the hand landmark model will generate 21 3D hand keypoints on the user's hand for a 3D landmark. Details about MediaPipe Hands algorithm can be referred to [7].

In the proposed game-based hand rehabilitation system, the hand gesture is used to control the game by tracing the motion of the fingers. The state of each finger, i.e. straight or bending finger, is computed. The finger state set is mapped to a pre-defined hand gesture set, i.e. hand therapy exercises. The flow chart of the hand gesture recognition is shown in Fig. 4. Lastly, the system will compare the computed hand keypoints with the pre-defined game-controlled action corresponding to the specific hand gesture, refer to Table 1.

3 Gesture Controlled Game System

The “2048” game was adopted as the game to be used in this project. The game is available for free on Microsoft Store or the 2048 website [8]. The increased involvement in cognitive activities in older age may be related to slower cognitive decline and lower danger of mild cognitive impairment [9]. Hence, some hand gestures were selected from common hand therapy exercises and movements which involve exercising the arm, wrist, hand and finger areas. Table 2 shows some of the selected hand gestures in the game-based rehabilitation system and the common hand exercises.

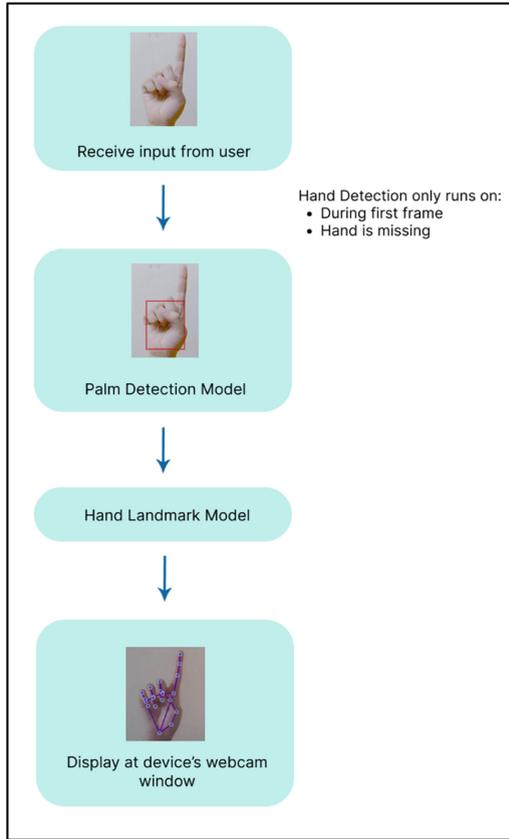


Fig. 3. Overview of hand detection process

4 Experiments

This work was implemented in the environment:

- Laptop or computer with a working webcam
- Windows 10 × 64 bit
- Visual Studio Code v1.65.2
- “2048-Pro” or “2048” Website
- Python (64-bit) v3.7.6
- OpenCV v4.5.5
- Numpy v1.21.5
- MediaPipe v0.8.9.1
- Pyinstaller v4.9
- Pymsgbox v1.0.9
- Imutils v0.5.4

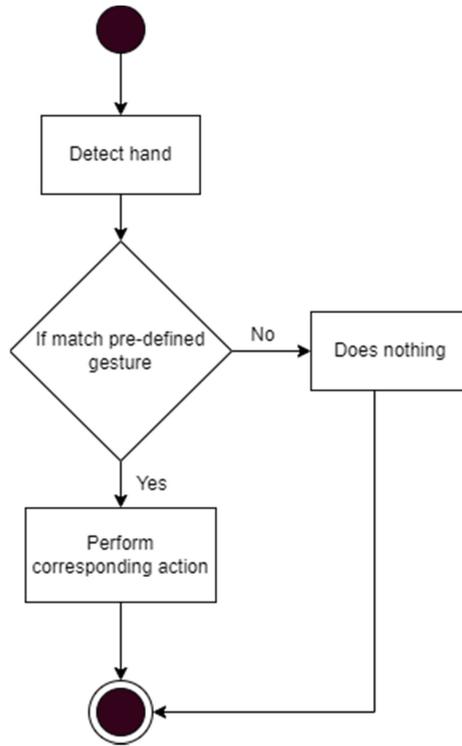


Fig. 4. The flow chart of hand gesture recognition

There are seven hand gestures to use in the system, as shown in Fig. 5. Each hand gesture is connected to a specific action, as listed in Table 1. When the open palm hand gesture is detected, the flags for all the hand gestures will be reset to the default value (Fig. 5a). Hence, it is necessary for the user to perform this gesture after attempting the other hand gestures. Figure 5b to e shows the hand gestures which controls the direction of the number tiles in the “2048” game. In Fig. 5b, the index finger pointing up gesture tells the system for the “Up” arrow key. This will then move all the number tiles in the “2048” game in upwards direction. The thumb pointing out sideways gesture (Fig. 5c) prompts the system for the “Down” arrow key.

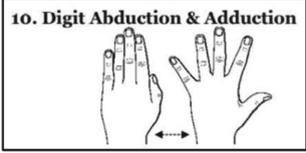
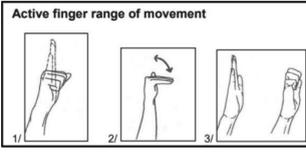
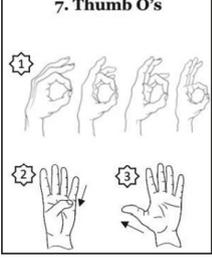
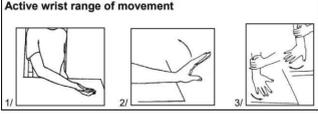
When all fingers are pointing in the left or right direction, it is for the “Left” or “Right” arrow keys accordingly (Fig. 5d and e). When the user closes only the little finger inwards, the system will restart the “2048” game (Fig. 5f). The thumb closing inwards gesture (Fig. 5g) prompts the system to simultaneously emit a beeping sound and displays a message box. The beeping noise is to alert the surrounding people for SOS help and will only stop after the “OK” button on the message box is pressed. All hand gestures are designed for the user’s palm to face the camera.

In addition, the image of the hand gestures and description of their corresponding actions are always displayed on the screen. Hence, patients can always refer to the information to see which gestures to use in the game.

Table 1. Corresponding actions for hand gestures

Hand gesture	Corresponding actions for the game-based hand rehabilitation system
 Up	Move all the number tiles in an upward direction
 Down	Move all the number tiles in a downward direction
 Left	Move all the number tiles to the left side
 Right	Move all the number tiles to the right side
 Restart	Restarts the game
 Standby	Reset the flags of other hand gestures
 Help	Trigger the system to emit a beeping sound and display a message box. The sound will not stop until the “OK” button is clicked

Table 2. System hand gesture and hand exercise. Some photos are from [10]

Hand gesture in game system	Popular hand exercises
 <p>Standby</p>	 <p>10. Digit Abduction & Adduction</p>
 <p>Down</p>	 <p>Active finger range of movement</p>
 <p>Help</p>	 <p>7. Thumb O's</p>
 <p>Left</p>  <p>Right</p>	 <p>Active wrist range of movement</p>

4.1 System's Performance Evaluation

To evaluate the performance of this system, nine users of different ages, with age range 21–50 years old, were invited to test the system. All of the users were briefed beforehand on what is the purpose of this project, how to play the “2048” game and how to use hand gestures to play the game. Furthermore, the users were also demonstrated how to start the system and exit it. Experiments were conducted at different locations to examine the robustness of the developed system under different environmental conditions such as lighting conditions, indoors vs outdoors, the distance between webcam and hand, background etc., as shown in Fig. 6. It is worth to be noted that all these three locations

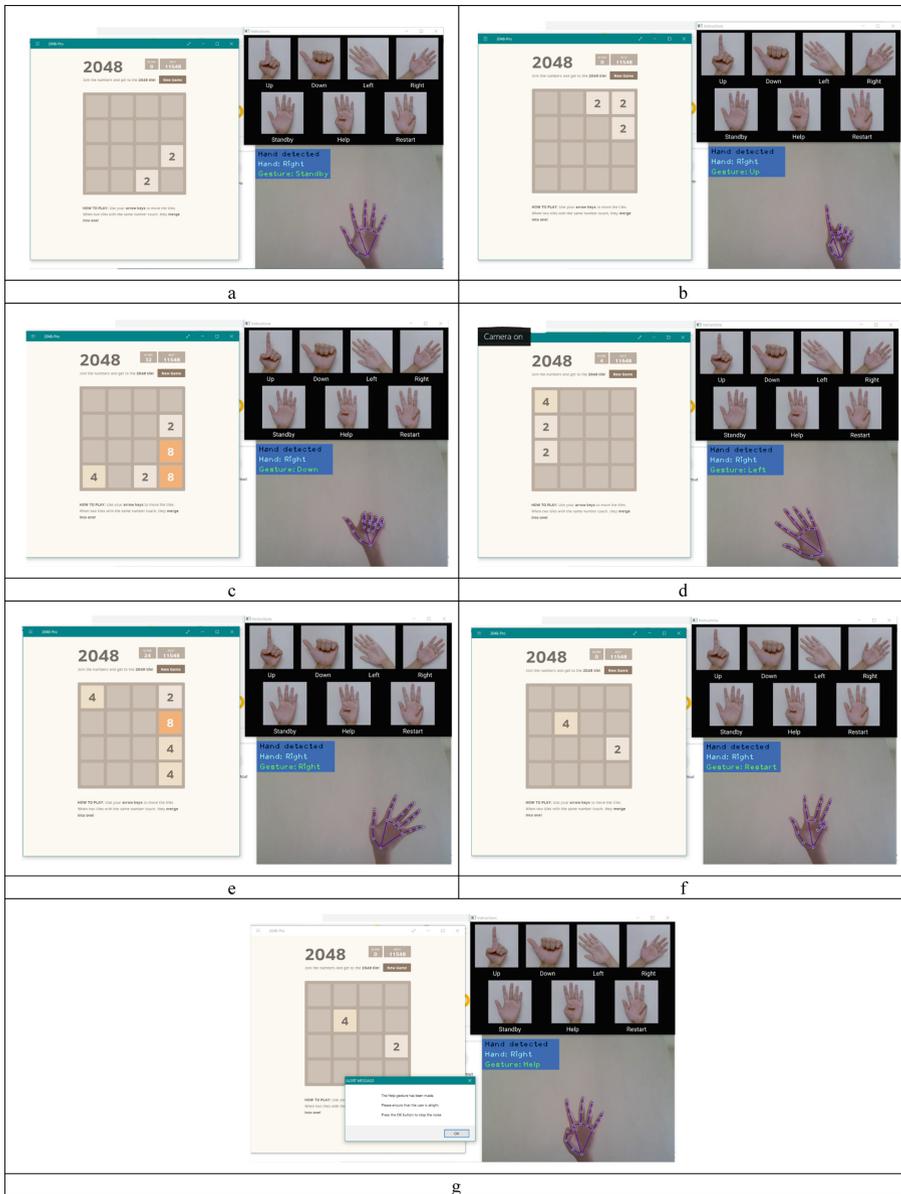


Fig. 5. User interface of the developed hand gesture controlled game for hand rehabilitation

were chosen with no regard for a plain background. This is to evaluate the robustness of the system in detecting a hand even with a noisy background.

From the experiments, we noticed that the system is able to detect accurately the users' hand with the webcam-hand distance of 0.52 to 0.73 m, regardless of indoor or outdoor location. This is the normal distance of a computer monitor from the user

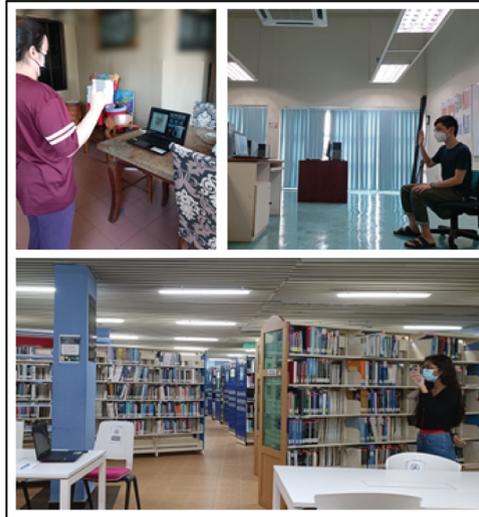


Fig. 6. Different locations for system testing

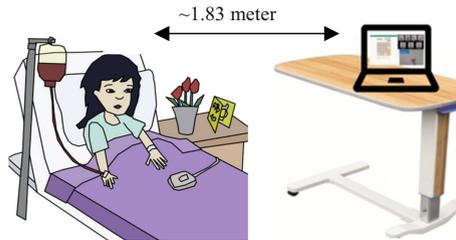


Fig. 7. Distance between user and system on overbed table

[11]. Furthermore, the findings also show that when the testing environment is outdoor with varying illumination conditions, the hand detection may be slightly affected if the webcam-hand distance is ~ 1.83 m. Even so, hand detection is still successful in indoor locations even with the webcam-hand distance of ~ 1.83 m. Hence, we can deduce that the system is still reliable and robust for bedridden patients to use this system by placing the laptop (with the gesture-controlled game system) on an overbed table, see Fig. 7. However, if the webcam-hand distance exceeds 2.5 m, occasionally the hand detection is not successful even in indoor environments. The reason may be due to the smaller appearance of the user's hand on the webcam due to the longer distance.

5 Conclusion

This study has presented a hand gesture-controlled game system for hand rehabilitation. The system is using a popular game, which is "2048". In the system, a hand is firstly detected and captured via MediaPipe Hands algorithm. Next, the hand gesture is

processed and matched with pre-defined hand gestures. If there is a match, the system will execute the corresponding action. The experiment result showed that an appropriate distance between webcam (computer monitor) and hand (user) is significant in this game-based hand rehabilitation system. The normal distance of the computer monitor from the user, i.e. in the range of 0.52 to 0.73 m, always makes the hand detection and tracking successful, regardless of indoor or outdoor environments. The system can still work well in the indoor environment with longer distance, i.e. ~1.83 m, for bedridden patients. For future works, algorithms with more stable tracking capability may be explored for better hand detections and tracing.

Acknowledgments. This research is supported by Fundamental Research Grant Scheme (FRGS), FRGS/1/2021/ICT02/MMU/03/3. The authors acknowledged the Ministry of Higher Education Malaysia (MOHE).

Authors' Contributions. AC conceived of the study, analysed the data and prepared the draft manuscript. YH aided in interpreting the data, supervising and writing-review. WH provided expertise on hand gesture recognition. SY aided in the design of the study.

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