Design Studies and Intelligence Engineering
L.C. Jain et al. (Eds.)

doi:10.3233/FAIA231441

An Interactive Application for Hand Muscle Fatigue Relief Based on Gesture Recognition

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Abstract. Prolonged use of a keyboard or mouse can lead to continuous bending and twisting of the wrist, which can lead to muscle fatigue and pain. Finger exercises can reduce the hand muscle fatigue effectively. However, the repetitive exercises will bring boring and tedious experience. In this paper, we developed a hand rehabilitation exercise system based on gesture recognition technology and gamification design, which provides a more enjoyable, personalized and effective rehabilitation experience. The hand fatigue relief system was designed with the fusion of game elements and gesture interaction, which can enhance users' engagement and their rehabilitation motivation.

Keywords. Muscle fatigue, Finger exercises, Gamification design, Gesture recognition technology

1. Introduction

The rapid information technology development has completely changed individuals' lifestyles and work methods, elevating computers as the important tool in people's workplace, and elevating mobile phones as seemingly ubiquitous "third affiliates" [1]. About half of employees are often surrounded by electronic devices, and they may encounter health problems related to wrist and finger joints. This concern is particularly evident among technical personnel engaged in computer-centered tasks, which are often characterized by prolonged sitting and immobility. A few people actively choose to rest, while over 30% of people choose activities such as computer games or mobile phone use during their break [2]. However, prolonged keyboard input, mouse clicks, and screen interaction often lead to various hand diseases, including arthritis, tendinitis, and synovitis. The main manifestations are discomfort in the wrist, decreased wrist flexibility, numbness, and finger stiffness. It is undeniable that these issues have affected personal quality of life and professional efficiency [3]. In order to reduce hand fatigue, some games and applications have been developed specifically for this purpose. However, existing solutions often lack fun, and users do not practice on their own, resulting in no significant improvement, making it difficult to continue attracting users' attention and interest, and achieving the goal of reducing fatigue and preventing hand diseases. How to combine advanced gesture recognition technology to design a more

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comprehensive, interesting, and practical hand fatigue relief game has become an important direction of current research.

Based on the above content, this study attempts to study the construction of an enhanced interactive game framework for alleviating hand fatigue. This objective is achieved through the methods of established Openpose-based gesture recognition, machine learning methodologies, and gamification design model. This study aims to enhance the effectiveness of alleviating hand fatigue by promoting dynamic and sustained user engagement through engaging gaming experiences and astute mitigation strategies. The proposed system delves into the technical field by utilizing gesture recognition technology for real-time posture monitoring and adjustment. In addition, it also explores the integration of gamified design in the field of rehabilitation application. The overall research roadmap of this article is shown in Fig. 1.

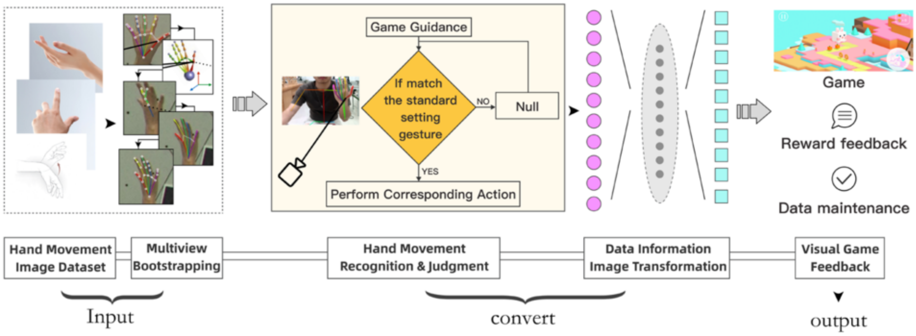

Figure 1. The research roadmap of hand muscle fatigue relief application study.

2. Related Works

2.1. Gesture recognition in human-computer interaction

Gestures can convey information and express users' intuitive intentions. At present, gesture recognition technology is being widely applied and developed as a new human-computer interaction mode. By analyzing user gestures and actions, more intelligent and smooth interface operations can be achieved, thereby alleviating hand muscle tension and reducing the occurrence of hand fatigue. In addition, gesture recognition has shown great potential in replacing traditional control methods, promoting human-machine collaboration, translating sign language, satisfying physical and virtual reality experiences, and helping to improve and guide standardized actions [4].

Visual based gesture recognition is a widely applied technology in human computer interaction that uses cameras to capture scenes containing gestures, and then deploys computer algorithms to recognize, extract, and classify gesture features present in images. In a broad sense, developing a comprehensive mechanism for gesture interaction in a visual based gesture recognition system includes three basic stages: data collection, data processing, and gesture representation [5]. For visual based gesture recognition sensing devices, the popular universal RGB cameras on the market fully meet these requirements. Given the inherent robustness and speed of camera-based gesture recognition methods, this technology has been widely applied in various fields, such as virtual reality (VR), augmented reality (AR), and education. For instance, Zixin Zhou developed an auxiliary system for Gu Zheng fingering practice that leverages gesture recognition to provide user feedback assistance, and the comparative experiments have revealed a significant enhancement of novice self-directed practice abilities [6].

2.2. Hand rehabilitation movements

Hand rehabilitation training plays a crucial role in alleviating hand fatigue and promoting muscle recovery. Through carefully customized rehabilitation exercises, targeted exercises can be carried out to solve different problems in hand muscle tissue, thereby stimulating muscle activity and enhancing blood circulation. Healthcare professionals typically provide advice on exercise for patients during treatment [7]. It is studied that hand manipulation exercises can promote local motor enhancement, effectively enhancing muscle strength, flexibility, and coordination, while reducing discomfort related to prolonged use of electronic devices. In an existing study, Shuo Jiang demonstrated that repetitive exercise is the best strategy for restoring muscle activation, enhancing muscle strength, and avoiding hand fatigue [8].

When choosing hand rehabilitation exercises, it is necessary to attach great importance to the fatigue relief of specific areas, especially for areas such as finger joints or wrist muscles. This selection process must take into account the actions that ordinary people can easily master for learning and imitation purposes, as well as the differences in user needs and abilities. Therefore, exercise selection should be based on the user's perspective, ensuring its practical effectiveness in promoting rehabilitation progress and improving user satisfaction.

2.3. Rehabilitation guidance based on gesture recognition

Gesture recognition technology provides a new approach for rehabilitation guidance; by real-time monitoring of user gestures, the system can accurately recognize the accuracy of user actions, providing more targeted guidance [9]. Researchers generally believe that specific hand rehabilitation systems using computer vision technology exhibit higher correlation and interactivity, helping to enhance hand flexibility and reduce discomfort. For instance, empirical findings by Farnaz Farahanipad revealed that nearly all participants rated games with gesture recognition as moderately to highly effective and engaging [10]. This technology can significantly help users understand the correct rehabilitation actions. In addition, gesture recognition technology can record users' rehabilitation progress and process, providing valuable data for rehabilitation experts to design more effective personalized rehabilitation plans [11].

2.4. Gamification design principles

Repetitive exercise therapy strives to cultivate effective motor learning and neural plasticity by creating games that are consistent with corresponding training actions, thereby making the rehabilitation process more systematic, professional, informative, and enjoyable [12]. However, scholars emphasize that the effect of repeated practice is not always positive, as continuous repetition often leads to monotony and decreased motivation [13]. Therefore, the integration of gamified design principles is crucial. This requires attracting users' different senses through goals, rules, feedback, and voluntary participation activities in the game. Integrating gamified elements into repetitive behavior can become a key driving force for improving user engagement and emotional satisfaction, making the experience enjoyable and promoting sustained behavioral persistence. Gamification design uses game elements to motivate positive behavior and enhance motivation and participation in specific tasks [14]. In addition, gamified design facilitates real-time feedback and result display, providing users with a sense of achievement and fatigue, thereby improving satisfaction and willingness to continue using.

Yu-Kai Chou created the Octagonal Behavioral Analysis Framework after proposing a theory of gamification analysis, also known as the Octalysis Framework for analyzing and designing gamified experiences, see Fig. 2. He found that human behavior is driven by the driving factors behind it, while successful games are supported by multiple driving factors [15].

In the conceptualization of games, users have a clear need to alleviate their hands in this area, so providing challenging tasks in the game to give users a certain sense of mission will make the game more attractive to them. And design relevant reward mechanisms, such as points and medal collection. Encouraged by a sense of achievement driven mechanism, users feel a sense of achievement and are willing to continue participating, enhancing participation and continuity.

Figure 2. Octalysis framework

3. Methodology

3.1. Openpose working mechanism

By leveraging the hand's symmetry and the flexibility attributes of the fingers, coupled with existing finger exercise movements aimed at alleviating hand fatigue, finger exercises and real-time interactive games for the hand are synergistically integrated through techniques like gesture recognition and machine learning. Consequently, this system necessitates the gathering of data, its subsequent analysis, and the presentation of visual feedback within the gaming context to enhance guidance efficacy.

The data acquisition layer comprises an annotation approach involving the selection of 21 key hand points alongside corresponding gesture categories. This approach is adopted to accommodate complex gestures and enhance recognition accuracy. These 21 hand points encompass pivotal hand and joint areas, their annotation encapsulating the entirety of hand motion patterns. A representation of the annotation process is provided in Figure 4. For data annotation, the 21 key hand points in conjunction with gesture labels are utilized to annotate gesture images. Each key point incorporates both observable and latent attributes [16]. The gesture labels encompass gesture classification, the gender of the data collector, the side of the hand (left or right), the orientation of the gesture (front or back), the environment of acquisition, camera orientation, gesture rotation angle, and other pertinent aspects.

The gesture model, derived from visual imagery extracted from gesture labels and employing parametric modeling methodologies, is an abstract construct. This model is essentially categorized into two modalities: a 2D gesture model predicated on visual features and a 3D gesture model founded on skeletal attributes [17]. By employing the pertinent data pertaining to gesture acquisition and labeling, judgments regarding the correctness of the current gesture are made in accordance with stipulated criteria. Ultimately, the evaluated gesture is directly presented on the interactive interface to ensure the precision and comprehensiveness of the fatigue alleviation request.

3.2. Workflow of Openpose

Initially, a limited set of annotated image datasets containing human hand keypoints is employed to train a Convolutional Pose Machines (CPM) network, which is similar to methods used for human pose keypoints. This training process yields an initial estimation of hand keypoints. A total of thirty-one high-definition (HD) cameras were deployed to capture diverse viewpoints of the human hand, as depicted in Fig. 3.

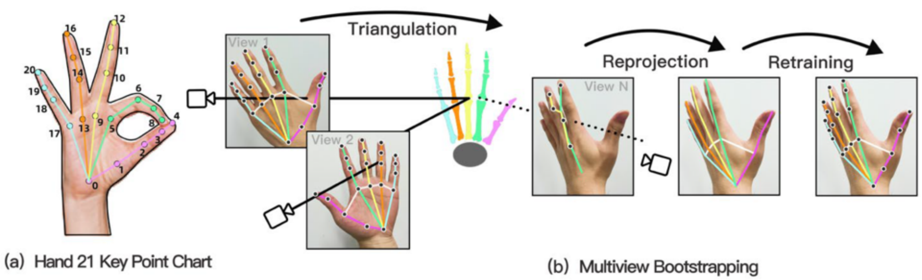

Figure 3. The Hand recognition technology is (a) Hand 21 key point chart and (b) Multiview Bootstrapping

The captured images are input into the hand keypoint detector to yield preliminary keypoint detections. Once the keypoints from varying viewpoints of the same hand are available, a process of keypoint triangulation is undertaken to deduce the three-dimensional (3D) positions of these keypoints.

The 3D positions of the keypoints are projected back from their 3D space onto each 2D image corresponding to different viewpoints. Subsequently, the network is subjected to further training using these 2D images and their associated keypoints, enabling the prediction of hand keypoint locations. This approach proves particularly effective for scenarios where keypoint predictions are challenging. Notably, a more accurate hand keypoint detector can be attained through a limited number of training iterations.

The efficacy of gesture recognition techniques was identified when employing conventional RGB cameras. By utilizing multi view bootstrapping, a rich training dataset can be constructed to improve the quantity and quality of annotations. Building a large number of annotated datasets is often an important bottleneck in various machine learning and computer vision tasks. To address this issue, multi perspective geometry is used as an external source of supervision to enhance weakly supervised learning [18].

3.3. System architecture and module design

3.3.1. Standard setting and database construction for rehabilitation

Establishing standards is a key mechanism to ensure consistency and data consistency in rehabilitation training. In our system, the selection of rehabilitation training and the conceptualization of gamified design constitute two crucial design elements that require meticulous and rigorous standardization. Firstly, the standardization of rehabilitation actions is a key factor in ensuring the effectiveness and safety of rehabilitation training. Secondly, the gamification design concept includes incorporating game elements and principles into rehabilitation exercises to enhance user engagement and motivation.

In the process of selecting rehabilitation actions, drawing on existing literature and consulting rehabilitation experts and doctors can help improve the accuracy and rationality of the selected actions. A standardised approach to data preparation in rehabilitation requires important considerations such as the integration of physiological and rehabilitative principles such as muscle strength and joint co-ordination suggested by rehabilitation specialists, followed by the complexity of the postures and movements, which need to be simple and easy to understand for the user to ensure a high rate of completion and accuracy of the rehabilitation exercise, thus reducing the risk of discomfort and injury due to incorrect movements.

During the posture selection phase, we collected various postures from a carefully researched medical validated posture library related to manual therapy [19].

3.3.2. System architecture

Initially, during the initial interaction between users and the system, a series of interactions will be arranged to ensure continuous operational sustainability. These interactions include elements such as the system's startup page, game selection options, personal information configuration, and progress indicator display. Subsequently, the system takes on the task of capturing the posture and movements of the user's hand, which is then converted into understandable data for processing by the system. This specific functional layer can include various hardware components, including gesture sensors, cameras, and gesture recognition algorithms. The subsequent level involves the integration of gamified design principles, including the game's contextual framework, progress level, task allocation, and mechanisms to reward user participation. This layer closely integrates gamification elements with the goals of muscle relief plans, ensuring the coherence and purposefulness of gamification principles (Shown in Fig.4).

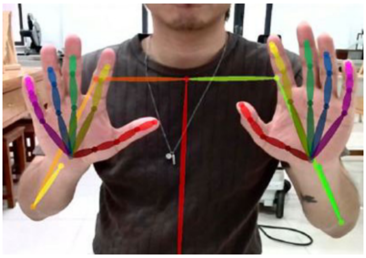

Figure 4. Gesture Recognition Capture Map

When users run the system, integrated technical support provides real-time feedback on rehabilitation actions and guides users in correctly executing rehabilitation actions. The game has designed a reward mechanism to motivate users to complete tasks and achieve rehabilitation goals, providing them with an interesting interactive experience while guiding them towards liberation. Finally, in order to maintain the long-term stability of the system, it is necessary to regularly update and maintain the data standard library and incorporates the latest medical research and rehabilitation theories to maintain the standardization of rehabilitation exercises. The function for gesture-controlled games to relieve hand fatigue is shown below.

	Function : Hand Gesture Controlled Game for Hand fatigue relief
1)	***Get user gesture :*** *//handGesture = getHandGesture() // Use OpenPose to recognize the user's hand posture and movement*
2)	***Complete the game with gestures :*** *//rehabPlan = designRehabPlan(handGesture) // The user chooses a relief plan based on the condition of the hand* *//gameElements = integrateGameElements(rehabPlan) // Integrate the rehabilitation plan with the gamified elements* *//Hand fatigue relief games playGame(gameElements) // Users play hand fatigue relief games and perform rehabilitation actions and tasks* *//Real-time feedback and personalized adjustment feedback = provideRealtimeFeedback(handGesture, rehabPlan) // Provides real-time feedback according to the user's rehabilitation progress* *//if(gameIsCompleted(rehabPlan)){user.isplaying = false // If (gameiscompleted (rehabplan)){user.isplaying = false // If the user has completed the game, then decide whether to continue the game}}* *//Data analysis and personalized Adjustment analyzeDataAndAdjustPlan(user, handGesture, feedback) // Collect and analyze user rehabilitation data and adjust rehabilitation plans and game tasks*
3)	***Game over:****//DisplayResultsAndFeedback (user) / / display saveGameData rehabilitation results and feedback of user information (user) / / save the user's data recovery and game record return user}*

4. Application

4.1. Application operation process and modular design

This hand rehabilitation exercise system uses gesture recognition technology and gamified design to help users reduce hand muscle fatigue. By integrating game elements and gesture interaction, it provides an enjoyable, personalized, and efficient rehabilitation experience that motivates users to exercise.

1) User interface and interaction module: Provide a user-friendly interface, including start page, game level selection, personal information settings, etc. The interaction module is responsible for responding to user gestures and achieving interaction with the game.

2) Gesture recognition module: Use gesture recognition technology to monitor user gestures and convert them into game actions. This module needs to be highly accurate and real-time to ensure that user gestures can be accurately captured and converted into

in-game actions.

3) Gamification design module: This is the core module of the game, responsible for designing interesting game scenes, levels, tasks, and reward mechanisms. The gamified design module should develop game tasks related to rehabilitation goals based on rehabilitation plans and user situations.

4) Real time feedback and achievement module: Provides real-time feedback on rehabilitation actions, guiding users to correctly execute rehabilitation actions. At the same time, a reward mechanism has been designed to encourage users to complete tasks and achieve rehabilitation goals, in order to increase their sense of achievement and sustained engagement.

5) Data analysis and personalized adjustment module: Collect and analyze rehabilitation data of users to understand their progress and performance. Based on the analysis results, the system can adjust the difficulty and content of the rehabilitation plan to maintain the effectiveness of rehabilitation.

6) Data storage management module: stores user personal information, rehabilitation data, progress records, and other information. At the same time, ensure data security and privacy protection.

7) User feedback and support module: Provides user feedback and support channels to help users solve problems and receive rehabilitation advice.

4.2. Main interface and function introduction

The main user interfaces of the application “TUJI’s Adventure” are shown in Figure 5. The gesture-based hand fatigue relief game has the following key functions:

- Personalized fatigue relief strategy: Using collected data, the system provides personalized suggestions and strategies to alleviate hand fatigue. It suggests appropriate exercise, relaxation techniques, and pauses based on the user's fatigue level to promote a balanced and safe gaming experience.
- Gesture based rehabilitation exercises: The game design integrates a series of gesture-based rehabilitation exercises aimed at alleviating hand fatigue, improving hand flexibility and strength. Users can use therapeutic gestures and actions to counteract the effects of prolonged gaming.
- Interactive and captivating games: Game design provides an interactive and captivating gaming experience, inspiring users to participate in activities that alleviate fatigue. Users can follow the prompts to engage in pleasant hand movements, which can help users to relax their hands.

5. Conclusion and future work

The aim of this work is to develop a hand rehabilitation system that utilizes gesture recognition technology and gamification design principles to solve hand fatigue problems. Gesture recognition and gamification techniques were applied in the system establishment. This process helps to identify key attributes for connecting gesture recognition and fatigue relief, thus developing a game model centered on gesture interaction. Subsequently, based on the research results, an application was designed to provide a more enjoyable and effective rehabilitation experience. This work is of benefit in improving hand muscle fatigue, maintaining overall physical health.

In the next stage, we plan to combine multimodal interactions to enhance the naturalness of rehabilitation interactions. In addition, we are exploring ways to extend gamified rehabilitation systems to mobile platforms, so that users can easily take rehabilitation training at any time and place. Our efforts include integrating social interaction and competition into a gamified framework, transforming the mitigation process into an engaging multiplayer interactive experience.

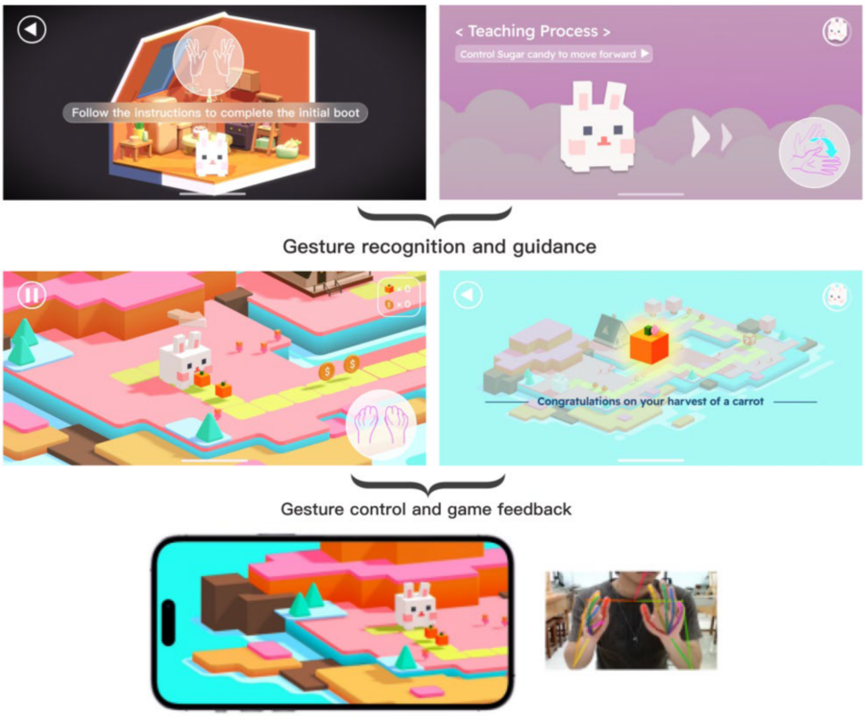

Figure 5. User interface of the application "TUJI's Adventure" and the user interaction mechanism.

Acknowledgments

This study is partly supported by Fundamental Research Funds for the Provincial Universities of Zhejiang (GB202003008).

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