FATIGUE PREDICTIVE MODEL FOR MID-AIR GESTURE INTERACTION

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FATIGUE PREDICTIVE MODEL FOR MID-AIR GESTURE INTERACTION

ABSTRACT

Gesture interaction in HCI has been one of the most important evaluation. For mid-air gesture interaction, the user moves their hand in different directions to imitate signals that the machine can understand. These hand gestures were borrowed from different sign languages. Studies performed on sign language interpreters show that most of the sign language interpreters face different kinds of fatigue or mild to serious kind of physical disorder which is an alarming phenomenon for the computer science industry. The objective of the present research is to identify the existing hand gesture signals in HCI application areas and find the fatigue criteria for these hand gesture signals. Based on the fatigue criteria a Fatigue Predictive Model has been proposed, based on a preliminary study done using the Cogulator tool. Then a prototype which can analyze fatigue in mid-air gesture interaction was designed, developed, and evaluated. A quantitative study of the prototype was conducted with 60 participants. From 29 mid-air hand gesture signals participants felt discomfort and muscle tension in 7 hand gesture interactions. These 7 gestures are separated into two categories based on their gesture design pattern. These gestures were unique in design, involved extensive muscle usage and had to repeat the gestures to avoid false tracking. This study proposes a predictive model to find out the gestures which have higher possibilities to cause fatigue among users based on the data found from fatigue criteria which will help HCI industry or manufacturers to choose the gestures according to the convenience to the users who will be conducting the gestures.

Keywords: Hand gesture, Fatigue, Mid-air gesture, Human Computer Interaction, Fatigue Model

MODEL PREDIKTIF KELETIHAN UNTUK INTERAKSI ISYARAT ATAS ANGIN

ABSTRAK

Interaksi isyarat dalam HCI telah menjadi salah satu penilaian yang paling penting. Untuk interaksi isyarat udara, pengguna menggerakkan tangan mereka ke arah yang berbeza untuk meniru isyarat yang dapat difahami oleh mesin. Gerakan tangan ini dipinjam dari bahasa isyarat yang berbeza. Kajian yang dilakukan terhadap penafsir bahasa isyarat menunjukkan bahawa sebilangan besar penafsir bahasa isyarat menghadapi pelbagai jenis keletihan atau gangguan fizikal ringan hingga serius yang merupakan fenomena yang membimbangkan bagi industri sains komputer. Objektif penyelidikan ini adalah untuk mengenal pasti isyarat isyarat tangan yang ada di kawasan aplikasi HCI dan mencari kriteria keletihan untuk isyarat isyarat tangan ini. Berdasarkan kriteria keletihan, Model Prediksi Keletihan telah diusulkan, berdasarkan kajian awal yang dilakukan menggunakan alat Cogulator. Kemudian prototaip yang dapat menganalisis keletihan dalam interaksi isyarat udara dirancang, dikembangkan dan dinilai. Kajian kuantitatif prototaip dilakukan dengan 60 peserta. Dari 29 isyarat isyarat tangan udara peserta merasa tidak selesa dan ketegangan otot dalam 7 interaksi isyarat tangan. 7 gerak isyarat ini dipisahkan menjadi dua kategori berdasarkan corak reka bentuk gerak isyarat mereka. Gerakan ini unik dalam reka bentuk, melibatkan penggunaan otot yang luas dan harus mengulangi gerak isyarat untuk mengelakkan penjejakan yang salah. Kajian ini mencadangkan model ramalan untuk mengetahui gerak isyarat yang mempunyai kemungkinan lebih tinggi untuk menyebabkan keletihan di kalangan pengguna berdasarkan data yang didapati dari kriteria keletihan yang akan membantu industri atau pengeluar HCI untuk memilih gerak isyarat mengikut keselesaan kepada pengguna yang akan melakukan gerak isyarat.

Kata kunci: Isyarat tangan, Keletihan, Gerakan udara, Interaksi Komputer Manusia, Model Keletihan

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Author

Md Ibnul Adib

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CHAPTER 1: INTRODUCTION

1.1 Background

Human Computer Interaction (HCI) is an essential part of human race in the current modernized era. The rise of the third industrial revolution, which concentrated on digital technology, dramatically altered the world we live in. Human Computer Interaction (HCI) has expanded swiftly and progressively over the last three decades, starting in the late 1970s and early 1980s (Grudin, 2005). Gesture-based interaction methods are increasing in popularity due to the expansion of low-cost platforms such as Microsoft Kinect, Leap Motion, Myo Armband and many other sensors that enable computer interaction through gestures (Cabreira & Hwang, 2015).

Gesture and gesture recognition terms are profoundly encountered in human computer interaction. Gestures are the summation of body motion or physical actions acted by the user in order to pass meaningful information to a computer (machine) and on the other hand gesture recognition is the process of making it known to the system (Anwar et al., 2019).

Throughout the continuous development and evolution of gesture driver devices it has been evident that there remain mainly two kinds of gestures that have been extensively utilized in the industry – Interactive Surface Gesture & Mid-air gesture (Cabreira & Hwang, 2015). In this study, the discomfort and disadvantages of mid-air hand gesture will be focused on which creates fatigue among users while interacting with computer devices to perform tasks.

1.2 Problem Statement

As modern technology in Human Computer Interaction has embraced hand gesture recognition also known as mid-air gestures, it is getting more and more widespread for both users and manufacturers to appear with advanced gesture recognition devices in daily life. There is an absence of standard training and precise outlines to guide the design and evaluation of interfaces based on mid-air gestures (Cabreira & Hwang, 2015). Also, on the other hand, continuously performing hand gestures in front of the gesture recognition system may cause discomfort in the wrist, shoulder and arm (Sánchez-Nielsen et al., 2004). Repeating gestures and imitating complex curves for a longer timeframe may lead to various types of diseases like: Carpal Tunnel Syndrome, Shoulder Pain, Arm pain, and this affects can lead the user to a serious medical condition. Long hours of using hand gesture signals, positioning of the hand, and complex signs are the main reason for developing physical discomfort and may lead to fatigue (Pereira et al., 2015). There is no specific guideline for creating hand gesture signals in the Human-Computer Interaction field. Proper ergonomics for hand gesture signals were not followed during the introduction of the gestures in different types of hand gesture recognition systems. There is no standard method by which hand gesture signals can be chosen for end-users. The Cogulator tool is a cognitive calculator which can estimate task time, working memory load and mental workload but it does not calculate the physical workload of hand gesture signals. The purpose of this study is to determine the physical workload for commonly used hand gesture signals that are currently in use for gesture recognition systems.

1.3 Objectives

Gesture recognition is introduced in smart devices to improve the user experience and satisfaction. The main purpose of the present study is to identify the existing gestures used for human-computer interaction in gesture recognition system and predict fatigue among users.

- To identify existing hand gesture signals used in Human-Computer Interaction among applications of the Gesture Recognition System.
- To predict fatigue criteria for hand gesture signals in Gesture Recognition System.
- To design, implement and evaluate a prototype to analyze fatigue in a gesture recognition system.

1.4 Research Questions

- To identify existing hand gesture signals used in Human-Computer Interaction among application areas of Gesture Recognition.
    - What are the application areas of the Hand Gesture Recognition system?
    - What are the existing hand gestures in the Gesture Recognition System?

- To predict fatigue for hand gesture signals in Gesture Recognition System.
    - What kinds of literature are related to fatigue?
    - What are the criteria for predicting fatigue through Task Analysis in Human Computer Interaction?

- To design, implement and evaluate a prototype to analyze fatigue in a gesture recognition system.

- How to design, implement and evaluate a prototype to analyze fatigue in a gesture recognition system?

1.5 Scope of Research

All existing mid-air hand gesture signals are listed in the research which is currently used in different application areas of human computer interaction. A detailed discussion of fatigue criteria is summarized, and GOMS model analysis has been conducted as a task analysis using the Cogulator tool which is a cognitive calculator for GOMS modeling.

1.6 Methodology

First, an extensive literature review will be prepared regarding hand gesture signals and fatigue to address the objectives. All the hand gesture signals used in the application area of hand gesture recognition can be narrowed down based on literatures. As of preliminary study, the sample size for this research is 60 participants. The participants are divided into two groups based on their age. The first group is formed based on the respondents' ages between 12-18 years and the second group has been formed with participants who are 18 years old and above. Before conducting the survey, the participants are provided with a consent form and description of the selected hand gesture signals. The consent form will consist of information on the purpose, risks, benefits, confidentiality, data security of the study and the agreement to participate. The participants imitated selected hand gesture signals. Survey form is available at Appendix B(I). The Cogulator tool will be used to create and analyze GOMS-Modeling based on the imitated hand gesture signals by the participants. The Cogulator tool is a cognitive calculator for GOMS modeling.

A tool will be designed and developed after the preliminary study which can take user input and analyze the gesture signals, hand positions and types of interaction (operators in GOMS analysis). Finally, the tool is to evaluate the given data and provide the prediction of fatigue in the gesture recognition system.

The following flowchart in Figure 1.1 displays the steps to achieve the objectives anticipated for this research while adopting all the research questions stated in an earlier subsection.

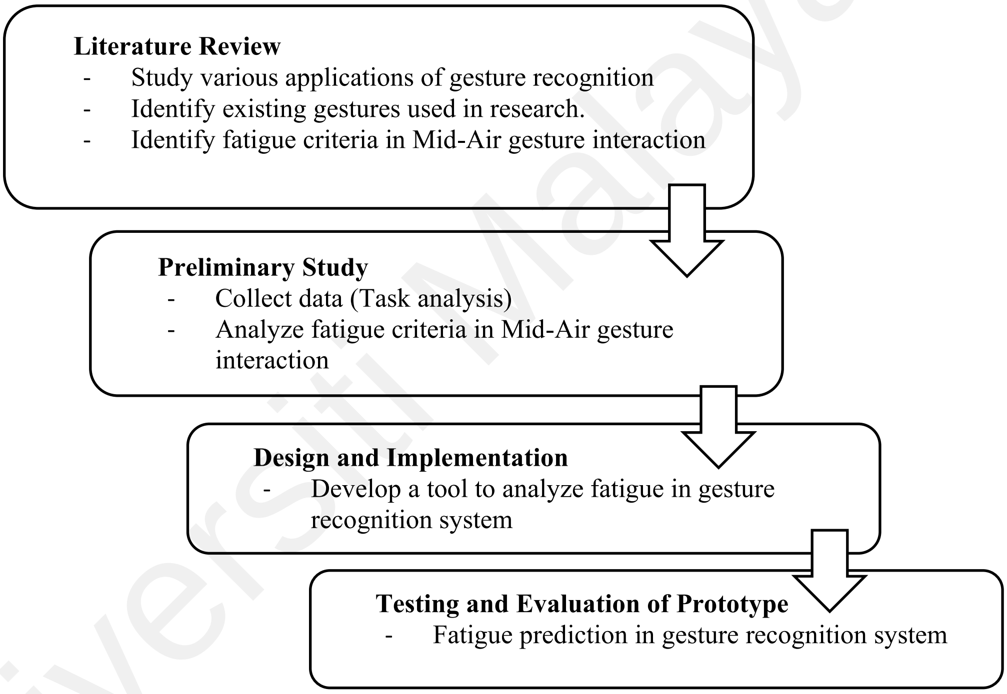


Figure 1. 1: Flow chart of research methodology

1.7 Target Group

The target group for the present research is users of the gesture recognition system, those who perform mid-air gestures as a form of communication with the machine (computer).

1.8 Significance of the Research

This study has several important significances based on the aforementioned research objectives. Firstly, this study determines the existing hand gestures in gesture recognition systems that are widely used in gesture-controlled user interface applications. Secondly, it further provides a detailed analysis on the time duration that takes for selected gestures to perform and the positioning of the hand to imitate the hand gestures. Thirdly, the study provides an understanding of the hand gesture position, curves and mapping that user are using frequently. Lastly, based on the results of the survey, data analysis and its explanations will help to determine fatigue among users while using a gesture recognition system.

1.9 Overall structure of the Dissertation

Chapter one contains an introduction on the research background, problem statement, research objectives, research questions, the significance of the research and the thesis structure. Chapter two elaborates an extensive literature review of the related work of the research including existing hand gestures, technologies used for hand gesture recognition and mostly used application areas of hand gestures system. The research methodology has been elaborated on chapter three. The Preliminary study is described in chapter four to address the research questions of the thesis. And the intended assistive tool has been modelled, developed, and implemented in chapter five. The process of testing and evaluating the tool can be found in chapter six. Finally, all the research findings and outcomes are concluded in chapter seven.

CHAPTER 2: LITERATURE REVIEW

2.1 Related Work

In recent years Gesture recognition has become a very influential term in the field of Human-computer interaction (HCI). There are a few systems developed for Gesture recognition for tracing and recognizing various hand gesture signals. Each one of the gesture recognition systems has its pros and cons.

In the '90s sign language recognition research was started. Hand gesture signal-related research can be divided into two segments. One is known as electromagnetic gloves and sensors detection, which can determine the shape, orientation, and movement of the hand. The other is based on computer vision based. This technique involves image processing techniques (Islam et al., 2017).

The first one among electromagnetic gloves and sensors is "Wired Technology", in which users need to wear a special suit or gloves which relates to wire in order to connect or interact with the computer system. Wire Technology has two drawbacks within as in this system the user is connected with the device via wire, a user is unable to move freely and cannot maintain distance from the device. These wired gloves are known as: instrumented gloves, electronics gloves, or data gloves. These gloves are an example of wired technology. These wired gloves are equipped with sensors that provides information related to hand location, finger position orientation etc. (Panwar, 2012).These data gloves deliver good results, but they are extremely expensive to utilize in wide range of common applications. After data gloves the recognition system was replaced by "Optical Markers". These optical markers project Infra-Red light and imitate this light on the screen to provide information about the position of the hand or tips of fingers wherever the markers are wearing on hand, the consistent portion will display on the user interface of the gesture recognition system. This system also provides good result but require very complex configuration (Haria et al., 2017). After Optical Markers, some advanced techniques have been introduced known as image-based techniques which requires the processing of image features like texture, color etc. When working with these features of the image for hand gesture recognition the result may vary and could be different as skin tones and texture changes very rapidly from person to person (Jinda-Apiraksa, 2010). For utilizing various hand gesture to promote real-time application Vision-Based hand gesture recognition system works on shape-based features for hand gesture recognition.

The usage of hand gestures is known as a significant input method for HCI, but it has not yet successfully reached the top of the methods for interaction as of today. In recent days, HCI applications are mostly limited to keyboard and mouse functionalities to command digital information due to their highest accuracy level and privilege of providing input through just clicking buttons. Nevertheless, the traditional process of using a keyboard and mouse does not provide the leverage to communicating with machines in a similar way to communication with any kind of object with a hand, provides (Shanthakumar et al., 2020).

Most of the hand gesture signals that are currently used in human-computer interaction are like American Sign Language (ASL). Few of the hand gestures are different in HCI gestures than in American Sign Language (ASL). The recognition of American Sign Language (ASL) alphabets and numbers with the hand gesture signals used in human-computer interaction shows an accuracy of 94.32% (Islam et al., 2017).

For a VR-based resource, the crucial and one of the most important 3D interactions would be navigation or moving. Nevertheless, head-mounted displays may produce a constraint if lower choices of input are given. The popular usage of joystick for VR-based solutions, may frequently manipulate the visual if it is moved in a short span of time and in an irregular manner, which eventually causes motion sickness since this might cause an anomaly between visual and vestibular stimuli. There are a few processes that have been adopted over time to lessen the fatigue. The Portal method and walking in place are two of them but to ensure much lower possibilities of fatigue, the user will have to be allowed to sit in a specific location in the VR environment and use techniques such as finger walking, touch supported movement or gaming pads. Nevertheless, even these techniques might cause motion sickness if any kind of joysticks is being utilized (Zhang et al., 2017). Other than reducing the scope of motion sickness, getting rid of joysticks can provide the leverage for the user to not require checking for control icons over the controller and possibly cause less fatigue (Lin et al., 2019). Moreover, fatigue can be dictated by both mental and physical involvement and strength, even though there are not many studies regarding HCI models in recent days which are able to provide a legit prediction of fatigue (Jang et al., 2017).

2.2 Application areas of Hand Gesture Recognition

Recognition systems or hand gestures can be implemented through various implementations in multiple sectors, for example, interpretation of signed languages, automated monitoring systems, controlling bots, improving medical appliances and facilities, maintaining an environment for virtual domains, etc. (Anwar et al., 2019). Some hand gesture application areas are listed below:

2.2.1 Sign Language Recognition:

The basic use of sign language was initiated to understand and justify any given issue while communicating. Given the urgency and use of this system, it caught the attention of many specialists (Anwar et al., 2019). Sign language is mainly used by mute person, human-computer interaction field pick up the opportunity to use the hand gestures practiced by them. Sign language hand gestures can also help the blind people. By imitating the sign language hand gestures blind people can also communicate with electronic appliances. Many methods which use various kinds of signed languages have been taken into consideration to acknowledge gestures. Such as, established American Sign Language (ASL) has been trying out histograms for the boundary, multi-layered protection for cross-checking dynamic programming and neural network (Wysoski et al., 2002), established Japanese Sign Language is uses Continual Neural Network for 42 characters and 10 words (Kotsidou, 2018), established Arabic Sign Language (ArSl) uses two different types of Neural Network which are Partial and Completely Continual Neural Network (Maraqa & Abu-Zaiter, 2008). Among all the hand gesture signals from different languages American sign language is the most widely used in daily commodities. Sign language recognition helps the mute and blind people to operate the systems that is able to understand the meaning of gestures and helps them to communicate with machine. Sign language recognition is one of the widely used hand gesture recognition system.

2.2.2 Robot Control:

One of the most hyped implementations in this sector is known as controlling bots through hand gestures. This sector has recommended a process that can use the enumeration system to calculate the fingers of a hand to control a bot through gestures presented by the hand. The tasks are provided to the bots to execute any specifically given chore. Here, every single sign has a particular meaning and expresses a specific functionality (Algorithm et al., 2006). Such as, to move forward for the bot, the instruction is “one”, similarly, to let the bot stop, the instruction has to show “five” etc. A prominent benefit of such a system is that it presents a natural way to send geometrical information to the robot such as: left, right, etc (Raheja et al., 2010). Based on the technology many manufactures are coming up with different kinds of bots that can understand the hand gestures signal and complete actions based on the task. In different sectors manufactures are trying to build bots that can help people in their old age, these bots can be a substitute of human solder in war field. Few manufactures are even producing bot pets that can guide travelers in remote areas. As days will pass by engineers tend to look more into the robot control sector so that it helps the human race to reduce their physical labor. Both industrial and service applications have triggered the attention of light weight robot manipulators and the integration of mobile robots (Mazhar et al., 2018).

2.2.3 Graphic Editor Control:

The graphical control process needs the gesture system to be monitored and installed as a procedure of previous processing (Anwar et al., 2019). This process utilizes 12 different gestures to build and alter the graphical process. Triangular, circular, arctic, horizontal, vertical and rectangular lines are the shapes that are required to build the process and copying, deletion, moving, swapping, undoing and closing instructions are given to alter the graphical process (Min et al., 1997). Hand gesture signal can help the graphics editors in their daily work, graphics work has many sophisticated tasks to perform. Sometimes these tasks are very difficult to perform through help of the mouse and the keyboard where hand gestures can help to ease the task by pointing to the very detail actions. Implementing hand gesture control will also help the graphics designers to get rid of heavy weight equipment’s like drawing pad. These equipment’s are also very expensive. If in near future hand gesture signals can take over the graphical use this sector will benefit. The significant use of gestures in daily life for different types of tools for the graphical editor has great emphasis (Suguna & S, 2017).

2.2.4 Virtual Environments (VEs):

Maintaining the environment for virtual domains is one of the most renowned implementations of gesture recognition systems specifically through media systems used for communicating (LaViola, 1999). This sector has explored three-dimensional pointing recognition for gestures in terms of natural human-computer interaction in a real-time from telescoping views. The system is precise and self-dependent even through the alteration of user traits and environments (Guan & Zheng, 2008). To date, there are three types of devices that are designed to capture motion data: glove-based devices, full-body motion capture systems, and gesture recognition systems (Shiratuddin & Wong, 2011). Even Though hand gesture signals are suitable for virtual environments due to structural issues, recognizing the hand gesture is more challenging than using a keyboard and mouse. False tracking and user difficulties are the key challenges for virtual environments (Raees et al., 2019). From a study on the impacts of hand and foot gestures on immersive maps in augmented reality, it was recognized that, people who are using hand gestures in this sector prefer single-handed gestures rather than both hands for gliding, producing a new pin and selecting an existing location pin for zooming in and out and modifying the height of the map, people prefer both handed gestures (Austin et al., 2020). Augmented reality is already in place in different types of gaming console and indoor games. Gaming console like PlayStation and Xbox has already implemented hand gesture control in gaming. User can use their hand during a game to maintain the character and perform different tasks. Hand gesture is also seen in VR games like fighting, racing, and many more. In near future Virtual Reality will take over in travel industry also. Hand gesture recognition can play a vital role in this application area of hand gesture recognition system. Hand gesture signal is also used in many flights' simulation during pilot training.

2.2.5 Numbers Recognition:

Identifying numbers using hand gestures is a revolutionary implementation in this sector. This gesture recognition system has presented a self-activating system that can differentiate and understand any substantial gesture through the movement of the hand for the numbers given in the Arabic language from zero to 9 in a real-time process through HMM (Elmezain et al., 2009). Recognizing numbers was a revolutionary discovery in gesture recognition system. This process can be used in any sector where a camera is used. By image extraction the system can recognize any kid of number and as per the set action the machine can act on the selected task. This number recognition helped a lot of industry, mostly heavy industry was helped with this discovery. Number recognition is currently used in seaports, airport, factory where big containers or machines needs to move in shorter time. For human being it takes longer time to move these heavy equipment's. But with the help of bot control and number recognition, machine can understand the task and take proper action. The Convexity hull algorithm is a very appropriate and convenient method for finger point detection and number recognition (Nikam & Ambekar, 2017).

2.2.6 Automotive Control:

Nowadays, hand gestures are also being used to regulate automotive devices. This recognition system has shown that hand gestures can be used to regulate dashboard panel functionalities. For example, switching on and off of the display panel, altering volume, turning on and off of volume and changing the program by opening and closing of hand signals (Freeman & Weissman, 1995). In recent years, gesture recognition has been considered a realistic alternative to vehicle controls in the automotive industry. BMW a well- known car brand abbreviation for *Bayerische Motoren Werke* (in the German language) offers gesture controls technology with certain functions such as volume control, answering and dismissing calls, and others (Loehmann et al., 2013).

2.2.7 Three-Dimensional Modeling:

To create three-dimensional modeling, a selection of hand gestures needs to be produced, processed, and viewed by a three-dimensional model of the hand. Few of the processes create two-dimensional and three-dimensional objects through hand cutouts (LaViola, 1999). The use of three-dimensional hand modeling for this cause could be a potential sector of study. Progress in computer vision allows mid-air hand motion to be tracked by affordable optical sensors, such as the Leap Motion controller, uSens Fingo, and Creative Senz3D (Cui & Sourin, 2018).

Table 2. 1 Application areas and their functions in the industry

No.	Application Area	Function	Year & Author
1.	Sign Language Recognition	Operate or communicate with a machine	(Maraqa & Abu-Zaiter, 2008)
2.	Robot Control	Heavy industry work	(Mazhar et al., 2018)
3.	Graphic Editor Control	Use of critical graphical tools	(Suguna & S, 2017)
4.	Virtual Environments (VEs)	VR controls, Augmented Reality	(Austin et al., 2020)
5.	Number recognition	Recognize different types of sign languages	(Nikam & Ambekar, 2017)
6.	Automotive Control	Operate display, Steering control	(Loehmann et al., 2013)
7.	Three-Dimensional Modeling	3D drawing, Product Modeling	(Cui & Sourin, 2018)

In Table 2.1 the application area where hand gestures are used is shown in the application area column and where they are used is present in the function column.

2.2.8 Summary

Day by day experiment on hand gesture signals in HCI in increasing because of the advanced technology. Many new sectors are trying to implement mid-air hand gestures in the industry. Few electronic companies have already started to show demo of their appliances which can be operated by hand gesture signals. Recently wide range of hand gesture signal is in use for smart TV operation (S. H. Lee et al., 2013). By approaching RGB feature extraction and Depth feature extraction smart TV industry has implemented the hand gesture control system (Hakim et al., 2019). Industry is also trying to implement hand gesture signals in daily life electrical appliances. A group of engineers have already built a system that can be used to control fan speed, light on off. The technology is known as AirTouch, which augments mobile gestures into mid-air gesture interaction to operate home appliances (S. C. Lee et al., 2011). Hand gesture signals has been also implemented in UAV flight control. Deep learning based hand gesture recognition system is implemented to eliminate the tough piloting of the UAV flight (Hu & Wang, 2020). A well-known UAV flight manufacturer company "DJI" introduced a hand gesture recognition system drone named as "DJI Spark", the company has already made a prototype and still under further improvement, they are expecting it to be in the production very soon (*Spark - DJI*, n.d.).

Implementation of hand gesture recognition is growing rapidly in various application areas of Human computer engineering. Virtual environment is now implemented in indoor games, vehicle control, UAV flight control and hand gesture signals are very important for virtual environments. As the implementation of VRs will increase in the industry, use of hand gesture will also increase. Deep learning and augmented reality will give more opportunity for the industry to implement hand gesture signals and expand the field of hand gesture recognition system.

2.3 Hand Gesture Signals in Human-computer Interaction

Currently many hand gesture signals are used in the gesture recognition system. Each gesture signal has different curves and postures. Different hand gesture signals are used for different purposes to accomplish different tasks in applications that runs on gesture recognition. Below all the existing hand gesture signals are described with respect to their application purpose. Each existing hand gesture signal is described in the chart with gesture signal drawing. A list of all 29 hand gesture signals is attached in Appendix A.

2.3.1. Alphabet and Number Recognition

In the gesture recognition system number recognition is very commonly used. As machines are yet to learn a more natural way to communicate with humans this is now an easy way to communicate with machines by providing numeric numbers which are assigned to specific tasks to perform. Below widely used hand gestures are shown in the drawing and describe how they are performed.

Table 2. 2: Hand gesture signal drawings for number recognition

No.	Gesture Signal Drawing	Gesture Signal Description	Year & Author
1.	 0	**Close Fist:** User points a close fist in front of the gesture recognition system.	(Ren et al., 2013)
2.	 1	**One finger up:** User points 1 finger up and rest close to fist in front of the gesture recognition system.	(Ren et al., 2013)
3.	 2	**Two fingers up:** User points 2 finger up and rest close to fist in front of the gesture recognition system.	(Ren et al., 2013)
4.	 3	**Three fingers up:** User points 3 finger up and rest close to fist in front of the gesture recognition system.	(Ren et al., 2013)
5.	 4	**Four fingers up:** User points 4 finger up and rest close to fist in front of the gesture recognition system.	(Ren et al., 2013)
6.	 5	**Five fingers up or Stop:** User points 5 finger up or the full palm in front of the gesture recognition system.	(Ren et al., 2013)
7.	 6	**Two finger splits:** Thumb and little finger splits open in front of the gesture recognition system.	(Ren et al., 2013)

Table 2.2, continued

No.	Gesture Signal Drawing	Gesture Signal Description	Year & Author
8.	 7	**Rock sign:** Thumb, Index and little finger up and rest fingers folder near palm in front of gesture recognition system.	(Ren et al., 2013)
9.	 8	**Gun Sign:** Thumb and Index finger split out and rest of the fingers folder near palm in front of gesture recognition system.	(Ren et al., 2013)
10.	 9	**Thumbs up or YES:** Only thumb is up, and rest of the fingers are folded towards palm in front of gesture recognition system.	(Ren et al., 2013)
11.	 +	**Open Palm pointing up:** All fingers stay together and fingers pointing up and palm showing in front of the gesture recognition system.	(Ren et al., 2013)
12.	 −	**Open palm pointing down:** All fingers stay together and fingers pointing down in front of the gesture recognition system.	(Ren et al., 2013)
13.	 ×	**Open palm, fingers pointing right:** All fingers stay together and fingers pointing right in front of the gesture recognition system.	(Ren et al., 2013)

Table 2. 2, continued

No.	**Gesture Signal Drawing**	**Gesture Signal Description**	Year & Author
14.	 ÷	**Open palm down, fingers pointing left:** All fingers stay together and fingers pointing left in front of the gesture recognition system.	(Ren et al., 2013)

In Table 2.2 hand gesture signals for number recognition is provided with their gesture design description.

2.3.2. Robot control

Usage of hand gesture recognition is increasing day by day in the heavy lift industry. Machines are now operated by robots who receives the assigned task by analyzing the specific hand gesture signals.

Table 2. 3: Hand gesture signal drawings for robot control

No.	**Gesture Signal Drawing**	**Gesture Signal Description**	Year & Author
1.	 1	**One finger up:** User points 1 finger up and rest close to fist in front of the gesture recognition system.	(Zhao et al., 2011)
2.	 2	**Two fingers up:** User points 2 finger up and rest close to fist in front of the gesture recognition system.	(Hasanuzzaman et al., 2004)
3.	 3	**Three fingers up:** User points 3 finger up and rest close to fist in front of the gesture recognition system.	(Hasanuzzaman et al., 2004)

Table 2. 3, continued

No.	**Gesture Signal Drawing**	**Gesture Signal Description**	Year & Author
4.	 5	**Five fingers up or Stop:** User points 5 finger up or the full palm in front of the gesture recognition system.	(Zabulis et al., 2009)
5.	 9	**Thumbs up or YES:** Only thumb is up, and rest of the fingers are folded towards palm in front of gesture recognition system.	(Zabulis et al., 2009)
6.	 ×	**Open palm, fingers pointing right:** All fingers stay together and fingers pointing right in front of the gesture recognition system.	(Hasanuzzaman et al., 2004)
7.	 ÷	**Open palm down, fingers pointing left:** All fingers stay together and fingers pointing left in front of the gesture recognition system.	(Hasanuzzaman et al., 2004)
8.	 DOWN	**NO or Stop:** Close fist with open thumb pointing down and rest fingers folded towards palm.	(Zabulis et al., 2009)

In Table 2.3 hand gesture signals for the robot control are provided with their gesture design description.

2.3.3. Graphical Editor

Many graphical editor tools are now adapting hand gesture signals when they are working in a big canvas or platform. It is much easier to imitate the hand gesture signals informant of the gesture recognition panel to perform a specific task.

Table 2. 4: Hand gesture signal drawings for the graphical editor.

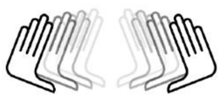
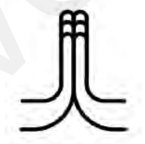
No.	**Gesture Signal Drawing**	**Gesture Signal Description**	Year & Author
1.		**Zoom In:** Moving away two palms from each other.	(Mistry et al., 2009)
2.		**Zoom Out:** Moving in two palms towards each other.	(Mistry et al., 2009)
3.		**Frame:** Holding both palm and making a box shape that creates a square shape between thumbs.	(Mistry et al., 2009)
4.		**Namaste:** Holding both hands together with palm joining each other.	(Mistry et al., 2009)
5.		**Pen Up:** Thumb and index finger pointing outside and rest of the fingers folder. This is same as the Gun shape.	(Mistry et al., 2009)

Table 2.4, continued

No.	Gesture Signal Drawing	Gesture Signal Description	Year & Author
6.		**Pen Down:** Only index finger is pointed out and can move at any direction. Rest of the fingers are folder inside palm.	(Mistry et al., 2009)
7.	 DOWN	**NO or Stop:** Close fist with open thumb pointing down and rest fingers folded towards palm.	(Yikai et al., 2007)
8.	 RIGHT	**Right hand thumb out:** A close fist with knuckles down and thumb pointing out.	(Yikai et al., 2007)
9.	 LEFT	**Right hand thumb out:** A close fist with knuckles upwards and thumb pointing out.	(Yikai et al., 2007)
10.	 0	**Close Fist:** User points a close fist in front of the gesture recognition system to close any tab.	(Zhao et al., 2011)
11.	 5	**Five fingers up or Stop:** User points 5 finger up or the full palm in front of the gesture recognition system to move any tab.	(Yikai *et al.*, 2007
12.	 9	**Thumbs up or OK:** Only thumb is up, and rest of the fingers are folded towards palm in front of gesture recognition system.	(Yikai *et al.*, 2007

In Table 2.4 hand gesture signals for the graphical editor are provided with their gesture design description.

2.3.4. Virtual Environments (VEs)

Many virtual environments are now allowing hand gesture signals to take over some tasks such as sending email, chat, document sharing applications.

Table 2. 5: Hand gesture signal drawings for virtual environments (VEs).

No.	Gesture Signal Drawing	Gesture Signal Description	Year & Author
1.		**Close Fist:** User points a close fist in front of the gesture recognition system.	(Zhao et al., 2011)**,** (Qing et al., 2007)
2.		**Open Palm pointing up:** All fingers stay together and fingers pointing up and palm showing in front of the gesture recognition system.	(Qing et al., 2007)
3.		**Two fingers up:** Index and middle finger pointing out rest fingers folder inside palm. Fingers can move any side.	(Qing et al., 2007)
4.		**Little finger up:** Only little finger pointing outside, and rest are folded inside palm.	(Qing et al., 2007)

In Table 2.5 hand gesture signals for virtual environments is provided with their gesture design description.

2.3.5. Automotive Interfaces

Hand gesture signals are gradually taking over the automotive industry. Top-known manufacturers are now implementing hand gesture signals for driving so that drivers can have less distraction while driving while performing other tasks apart from driving.

Table 2. 6: Hand gesture signal drawings for automotive interfaces.

No.	**Gesture Signal Drawing**	**Gesture Signal Description**	Year & Author
1.		**Clockwise O swipe:** Making O shape swipe to change display panel.	(Ohn-Bar & Trivedi, 2014)
2.		**Rotate Clockwise:** Rotate thumb and index figure in a clockwise motion.	(Ohn-Bar & Trivedi, 2014)
3.		**Two fingers scroll up:** Index and middle finger move as scroll up.	(Ohn-Bar & Trivedi, 2014)
4.		**Two fingers pinch:** Thumb and index fingertip closing gap in-between.	(Ohn-Bar & Trivedi, 2014)

In Table 2.6 hand gesture signals for automotive interfaces are provided with their gesture design description.

2.4 Fatigue in Wrist, Arm & Shoulder

Fatigue is generally defined as a feeling of lack of energy and motivation that can be physical, mental or both. Our body stores glucose, muscles use this glucose to produce energy and maintain the contraction of the muscle. Fatigue occurs when this energy is used up (Hincapié-Ramos et al., 2014). This lack of energy can be caused by lack of sleep and mainly muscle weakness or tiredness. In today's world, fatigue feelings among computer users are observed at a high rate. This fatigue is mainly targeted at wrist, arm, hand, and shoulder pain. As the user needs to move hand frequently to use the mouse and keyboard to establish communication with the computer (machine). Placing the hand in the discomfort zone might affect the muscle to be in a position that is not its natural position thus the muscle pain arises in arm and shoulder. At a discomfort zone, blood flow may be reduced to the muscle thus less oxygen reaches to the muscle and the muscle contracts which can lead to fatigue (Hincapié-Ramos et al., 2014).

Today, advanced technology uses gesture recognition to establish interaction with the computer. Hand gestures are the widely used form of gesture recognition in the Human-Computer Interaction field. The idea of hand gesture signals in Human-Computer Interaction came from sign language. Information technology has taken a lot of hand gestures from different sign languages based on acceptance of comfort and easy posture. As these hand gesture signals were inherited from various sign languages the same level of discomfort may occur among the users of the hand gesture recognition system that the sign language interpreters are going through.

2.4.1 Diseases formed from Fatigue

Advanced technologies have produced low-cost human motion tracking methods, and these methods are used in mid-air gesture interaction in virtual environments, medical operations, and gaming. To avoid fatigue, physical ergonomics is an important design factor for mid-air interaction (Jang et al., 2017). A long-term fatigue disorder can lead to serious physical illness.

2.4.1.1 Gorilla Arm Effect

The Gorilla Arm Effect is a feeling of a heavy arm, Due to prolonged use, users' arms begin to feel fatigued or discomfort (Jang et al., 2017). It does not only occur for prolonged use of mid-air gesture interaction, but performing mid-air gesture interaction for even a moderate period of time can also cause fatigue (Hansberger et al., 2017). The Gorilla arm is caused because of the arm muscle contraction level. If the users' hand is stretched and out from the torso and does not have any support in due time, the user will start to feel heaviness in the arm.

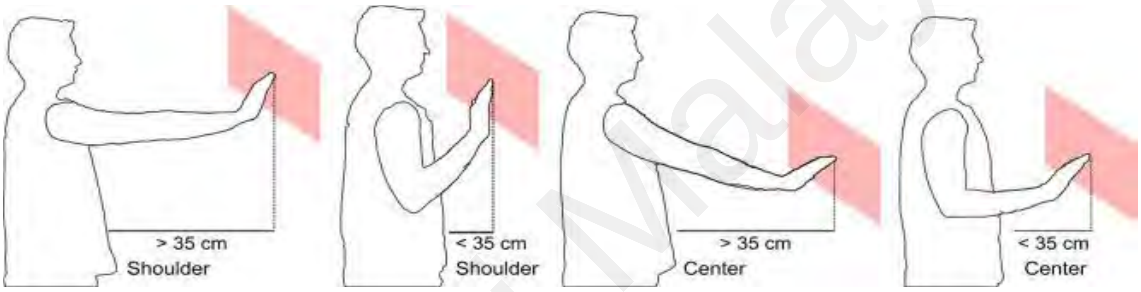


Figure 2. 1: Gorilla Arm Effect hand positioning

In figure 2.1 (left to right), the first image shows that the users' hand is stretched at full which is more than 35 cm. This creates tension around the muscles around the shoulder. If the hand is held towards the center of the body and the distance from the body to the fingertips is less than 35cm then there is less chance of muscle fatigue. Eventually, it turns into the "Gorilla-arm effect" (Hincapié-Ramos et al., 2014).

2.4.1.2 Bursitis

Bursitis is common around the shoulder and elbow. It occurs because of the inflammation or irritation of the bursa sac in the shoulder and elbows joints. This inflammation can occur because of repetitive movement of the bone joint. The most common cause of bursitis is repeated physical activity (Bhuiyan & Picking, 2009).

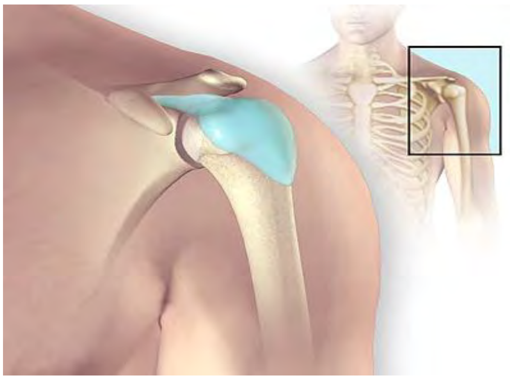


Figure 2. 2: Image of inflamed Bursa sac due to fatigue.

2.4.1.3 Tendonitis

Tendonitis can be caused by a sudden injury, but it stems from the repetition of a particular movement over time. Tendonitis is seen among people whose jobs require repetitive motions. This puts stress on the tendons. Repetitive motions and awkward positioning of the hand increase the reason for tendonitis (Mayo Clinic Staff, 2020).

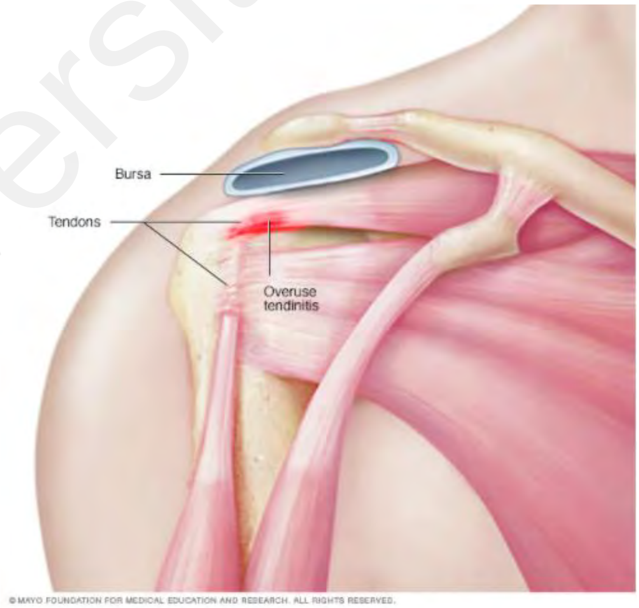


Figure 2. 3: Image of overuse tendonitis.

2.4.1.4 Tenosynovitis

Tenosynovitis is also caused by repeated motions. Especially while working placing the hand over the head can be a major cause of inflammation in the tendons. Serious cases can form cysts that can tear or break the tendons. Long time work where the hand placement is over the head and repeated motions are the main reason for tenosynovitis (Frysh, 2021).

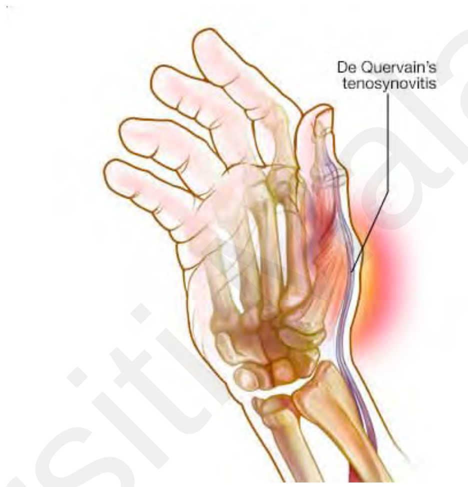


Figure 2. 4: Image of Inflamed tenosynovitis

2.4.1.5 Tennis Elbow

Tennis elbow occurs when there is pain around the elbow due to repeated action of muscles in the forearm, near the elbow joint. Tennis elbow is also associated with lifting a hand for longer time, raising hand in extreme extension or straighten the wrist. This can strain the muscle and put too much stretch on the tendons, this tugging can cause microscopic tears in the tissue resulting in tennis elbow (DerSarkissian, 2020).

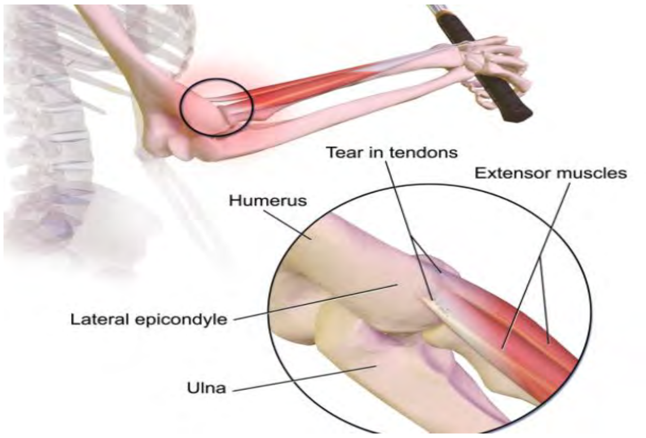


Figure 2. 5:Tennis elbow - extensor muscles

2.4.1.6 Trigger Finger

In trigger finger, the tone of the finger gets stuck in a bent position. It can produce an abnormal sensation in the body. The finger tendon and pully have a separate design for each finger. If due to extensive muscle movement the design is changed it can trigger the finger to get stuck due to muscle and nerve fatigue (ASSH Hand Surgeon, 2020).

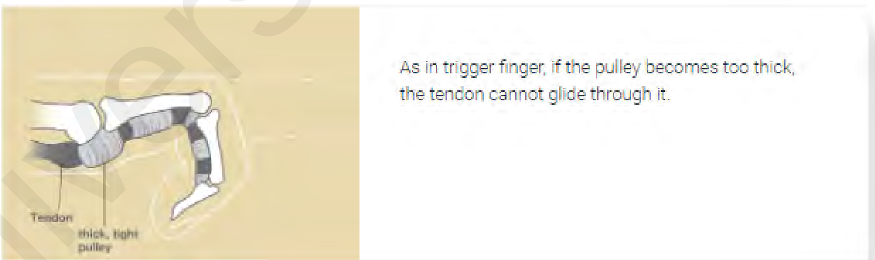


Figure 2. 6:Trigger finger stuck at bend position

2.4.1.7 Carpal Tunnel Syndrome

Professional language interpreters are at a higher risk of developing carpal tunnel syndrome. In a survey of 314 language interpreters, 38% of the respondents were diagnosed with carpel-tunnel syndrome (Fischer & Woodcock, 2012). Normal pressure in the carpal tunnel is 2 to 10 mmHG. Extreme positioning of the wrist can increase pressure in the nerve entrapment and injury (Duncan & Kakinoki, 2017).

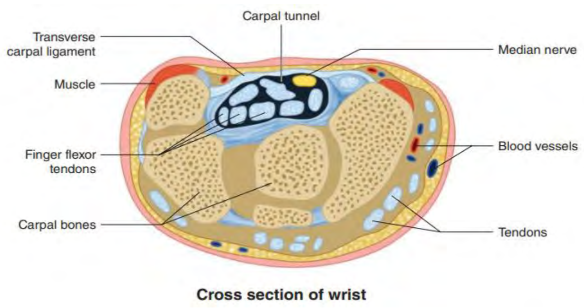


Figure 2. 7: Carpal Tunnel and median nerve cross-section

2.5 Fatigue Criteria

A previous study shows that the evaluation of gesturing for interaction with computers was not considered based on the ergonomics of gestures and the physical fatigue and discomfort associated with prolonged gesturing (Pereira et al., 2015). Proper gesturing posture is very important because the uncomfortable placement of the hand and arm can lead to physical pain (Sánchez-Nielsen et al., 2004). Repeatedly forming hand gestures may be associated with hand pain, depending on the duration of gesturing , the gesture movement patterns and the gesture postures based on epidemiologic and physiologic studies of the hand and studies of sign language interpreters (Pereira et al., 2015). The extensive and unique formation of hand gestures is used by Sign Language Interpreters and gesturing for several hours may cause hand or arm pain (Johnson & Feuerstein, 2005). The risk associated with hand or wrist disorders such as carpal tunnel syndrome is a concern for those who use sign language communication. Carpal tunnel syndrome victims experience pain and other indications vacillating from the numbness of the hand or finger

(Smith et al., 2000). These findings are alarming when considering the possibility of users using the computer by performing gestures for many long hours every day (Pereira et al., 2015). Gesturing for HCI could pose a similar risk to hand and arm pain and fatigue if done for many hours per week. It is conceivable that gesturing for HCI will replace some or all keyboard and mouse input and could be done for 20-50 hours per week which is more than sign language interpreters weekly work hours (Rempel et al., 2014).

The ideal location of the hands for gesturing in front of the camera of a gesture recognition system is near the lower chest area. The preferred position is the midline of the body and must be far away from the torso. Basically, hands should not stay higher than shoulder level and should not be wider. Unless there is support for resting the elbow, the hands should not be further away approximately 45 degrees from the body. Similar recommendations apply to the seated and standing positions in front of the gesture recognition system. Hand gesture signals, the extravagances of gesticulation such as a tight fist or a hand with figures widespread requires high levels of muscle movement. These hand gesture signals will be more fatiguing compared to a relaxed hand gesture signal with the fingers moderately curved that need a smaller amount of muscle movement (Rempel et al., 2014).

Based on the positioning of the hand the 29 gestures can be categorized into 2 sections:

- Lower chest gesture
- Upper chest gesture

Table 2. 7: Location based hand gesture category

Gesture No	Upper Chest Gesture	Lower Chest Gesture
GestureNo1	✓	
GestureNo2	✓	
GestureNo3	✓	
GestureNo4	✓	
GestureNo5	✓	
GestureNo6	✓	
GestureNo7	✓	
GestureNo8	✓	
GestureNo9	✓	
GestureNo10	✓	
GestureNo11	✓	
GestureNo12		✓
GestureNo13		✓
GestureNo14		✓
GestureNo15		✓
GestureNo16	✓	
GestureNo17		✓
GestureNo18		✓
GestureNo19		✓
GestureNo20	✓	
GestureNo21	✓	
GestureNo22	✓	
GestureNo23	✓	
GestureNo24	✓	
GestureNo25	✓	
GestureNo26	✓	
GestureNo27	✓	
GestureNo28	✓	
GestureNo29		✓

Table 2.7 shows the category of the mid-air gestures based on the positioning of the hand with the body.

2.6 Limitation of Existing tool to predict fatigue

No studies were found on predicting or calculating fatigue in hand gesture recognition systems through the Cogulator tool. From the features of the Cogulator tool it can be told that this tool can only calculate the timeline of a task and can produce memory and mental workload, it is unable to provide any calculation for a physical workload that can determine fatigue criteria in hand gesture signals. The Cogulator tool does not take any information from a user based on the comfort or discomfort of hand gesture signals. It only provides a standard time to perform a hand gesture signal and breaks it down into perceptual, cognitive, and motor movements.

2.7 Summary

This chapter depicts the mid-air gesture interaction application areas along with the existing mid-air hand gestures are categorized under application areas. In section 2.4 common diseases are described that are observed in sign language interpreters (Fischer & Woodcock, 2012). Also, section 2.5 describes the reasons behind the discomfort and fatigue related to hand gesture signals. There are a few common factors in hand gesture signals which are responsible for arousing the reason for wrist, arm, and shoulder fatigue.

Well-designed mid-air gesture is very important to eliminate the risk of fatigue. As the previous study shows that ergonomic were not considered during the usage of the mid-air hand gesture signals, these are the fatigue criteria directly involved in causing fatigue due to mid-air gesture interaction:

- Prolong usage of gesture
- Tight or widespread use of hand muscle
- Repetition of gesture
- Uncomfortable hand position

- Extensive and unique gesture design

CHAPTER 3: RESEARCH METHODOLOGY

This research study has been consucted in four steps. The methodology is designed to achieve the objectives intended for the current research while addressing all the research questions mentioned in section 1.5 in Chapter One.

The following flowchart in Figure 3.1 shows each step to reach the mentioned research objectives projected for the present research while addressing all the research questions mentions above.

The steps are self-explanatory. Under literature review all the commonly used hand gesture recognition in the application area is described. In the preliminary study, data is collected through task analysis. Based upon the data a prototype will be designed that can predict the fatigue in the gesture recognition system.

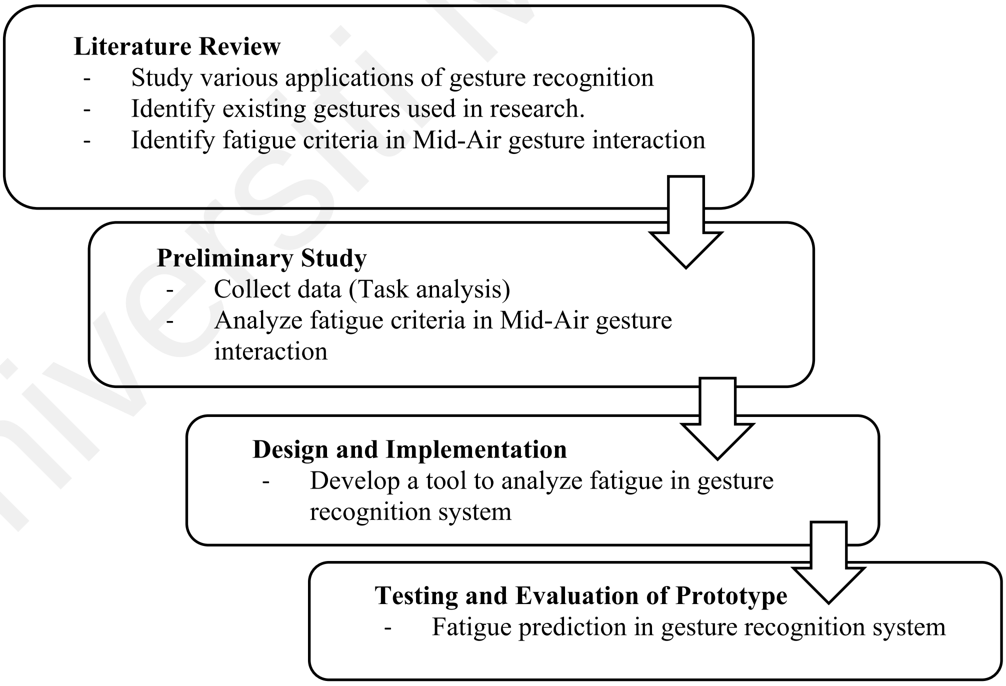


Figure 3. 1: Flow chart of Research Methodology

3.1 Preliminary Study

A primarily quantitative research method has been adopted that involves 60 participants with each imitating 29 hand gesture signals who participated in task analysis. Task analysis is the process of knowledge about regular users by observing them in action to understand in detail how they perform their tasks and achieve their proposed goals. The participants are divided into two groups based on their age. The first group is formed based on the age between 12-17 years old and the second group will be anyone above 18 years old and above. During the survey the participants were provided with a survey form that includes the description of the selected hand gesture signals. The survey form consists of the information on the purpose, risks, benefits, confidentiality, data security of the study and the agreement to participate.

3.1.1 Task Analysis

The preliminary study is done by following the Task Analysis activity. Task analysis helps identify the tasks that an application must support and can also help to refine or re-define the navigation of the application by determining the appropriate content possibility.

The purpose of task analysis was thoroughly described in the book ***"User and Task Analysis for Interface Design" by JoAnn Hockos and Janics Redish*** (T. Hackos & Redish, 1998). Task analysis helps the participants to understand users' goals and the achievable target. Through task analysis the users follow a set of rules to achieve the goals of the task, the user provides experiences that brings to the task and how the users are influenced by the physical environment.

There are few types of task analysis techniques used in several cases. But most used are:

- **Cognitive Task Analysis:** This task analysis is focused on the understanding task that requires decision-making, problem-solving, memory, attention and judgment.

- **Hierarchical Task Analysis**: This task analysis is focused on decomposing a high-level task subtask.

3.1.2 GOMS Models for Task Analysis

A GOMS model is a description off the procedural knowledge that a user must have in order to carry out tasks or a device or system. The acronym GOMS stands for Goals, Operators, Methods, and Selection rules. Briefly, a GOMS model consists of descriptions of models needed to accomplish specified goals.

Evaluating a task into Goals, Operators, Methods, and Selection rules (GOMS) is a conventional method for illustrating a user's procedural knowledge. When combined with other theoretical mechanisms, the resulting GOMS model provides a way to quantitatively predict human learning and performance for an interface design, in addition to serving as a useful qualitative description of how the user will use a computer system to perform a task (Diaper & A.Stanton, 2008).

3.1.3 Cogulator Tool

The Cogulator tool is a cognitive calculator for GOMS modeling. It is a simple human performance modeling tool for estimating task times, working memory load and mental workload. Cogulator tool allows adding new operators or allows changing default operator without changing the details to the code base whereas alike tools known as GLEAN and CogTool needs to change in the code base to add or amend any operator information.

In this research the identified 29 hand gestures signals were mapped in the Cogulator tool. Cogulator tool automatically provides a Gantt chart with Perceptual (hear, see), Cognitive (look, think), and motor (Say, Hand) time movement. And it provides a general time to perform hand signal gestures.

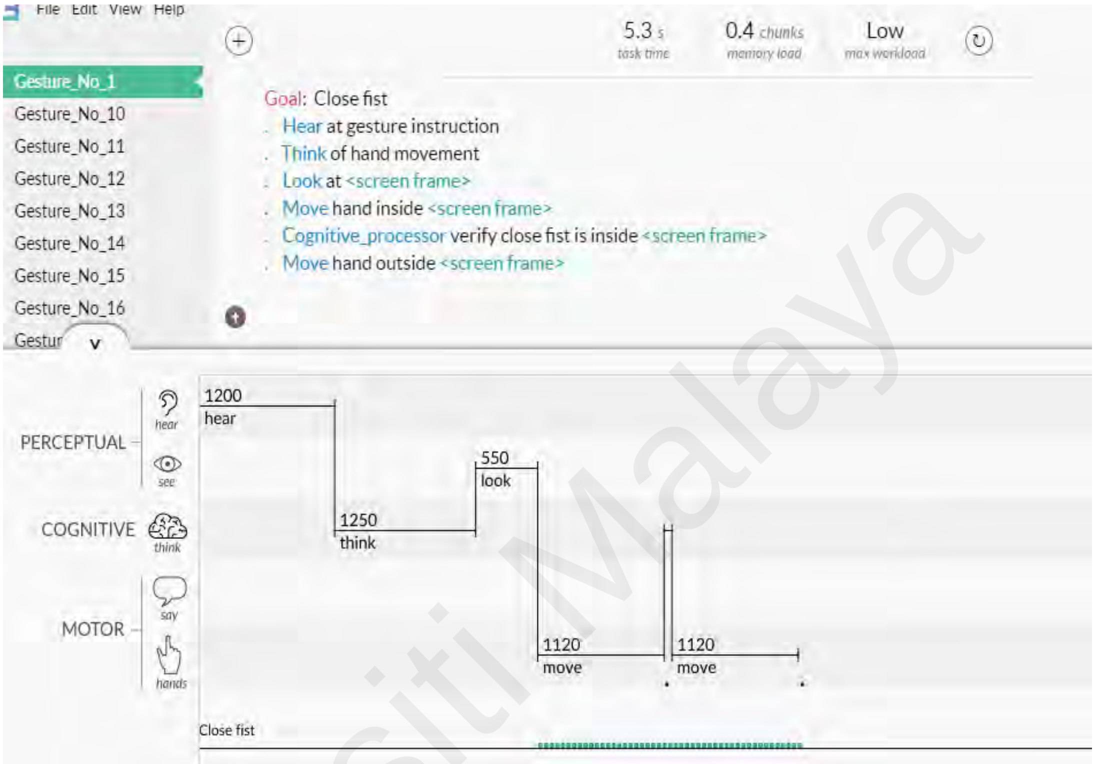


Figure 3. 2: Cogulator tool terminal

Figure 3.2 shows the Cogulator terminal where the hand gesture signal steps can be mapped, and the system automatically calculates the human perceptual, cognitive, and motor timing in milliseconds. Below the Cogulator tool a Gantt chart is automatically populated which calculates the task time in seconds.

There are four different models for GOMS: The Keystroke-Level Model, CMN-GOMS, NGOMSL, and CPM-GOMS. The Keystroke-Level Model (KLM) is the simplest and first technique in GOMS that was created by Stuart Card (Newell et al., 1980). But nowadays a new type of model is also introduce known as Touch Level Model

(TLM) , which is introduced by Andred D (Rice & Lartigue, 2014). In this research operators of the Keystroke-Level Model (KLM) and Touch Level Model (TLM) will be used to determining the task analysis.

3.1.4 Test Score

The test score of the participants was recorded, and a statistical one-sample t-test was done to find if there was any significant difference between the groups. (Glen, 2016). The one-sample t-test p-value was calculated by using IBM SPSS Statistics, version 25.

3.2 Identify Hand gesture signals

An extensive literature review has been done regarding hand gesture signals and fatigue to address the objectives mentioned in section 1.4 in Chapter 1. All the hand gesture signals used in the application area of hand gesture recognition has been narrowed down to 29 gestures. All the commonly used hand gesture signals are described in section 2.2 in Chapter 2. A list of hand gesture signals with continuous numbering is attached in the appendix for ease of understanding in chapter 4.

3.3 Prototype

3.3.1 Target users

The target group for the present research is users of the gesture recognition system, those who perform mid-air gestures as a form of communication with the machine (computer). The users are divided into two groups based on their age. The first group is formed based on the age between 12-17 years old and the second group will be anyone above 18 years old and above.

3.3.2 Fatigue prediction

Using the Cogulator tool and based on the fatigue criteria described in section 2.5 Fatigue Criteria, 5 questionnaires are derived and are shown in the prototype. The questionnaires are as below:

Q1: You have faced uncomfortable placing of hand while performing this hand gesture (Sánchez-Nielsen et al., 2004).

Q2: You had to repeat the hand gesture while performing this hand gesture in front of the camera (Pereira et al., 2015).

Q3: This hand gesture was extensive and unique to perform (Johnson & Feuerstein, 2005).

Q4: You perform hand gestures signals more than 4 hours per day for occupational purposes (Rempel et al., 2014).

Q5: You perform tight fist and figures widespread hand gesture signals for occupational purposes (Pereira et al., 2015).

These questionnaires were created based on the information gathered from the related studies based on professional language interpreters those who have faced different kind of fatigue or mild to serious kind of physical disorder or form lifelong disabilities in their hand, wrist, shoulder, or arm. Questions are available with answer option in Appendix B (II).

The user must answer the questions. In the questionnaire the options were given from the scale of strongly disagree to strongly agree based on a 5-point Likert Scale where strongly disagree was given the number of 1 on a scale of 5; strongly disagree as 1, disagree as 2, neutral as 3, agree as 4 and strongly agree was 5. If the accumulated number is above 15 then the user has a risk of developing fatigue. As the total number of the 5-Point Likert chart is 30, if the result is more than 50% (15 points) then the scale indicates towards the response "Agree" & "Strongly Agree", which means the responder has positive answers towards the right side of the scale (Weijters et al., 2021). Also, the system will show the actual time taken to imitate the hand gesture signal and show the standard gesturing time received from the Cogulator tool Gannt chart. Any time taken more than the standard time is a sign that the user will develop fatigue in near future because of daily usage of the hand gesture signal.

3.4 Tool Development

The tool will require a database to store information, a programming language for development, backend support the structure of the application, frontend technology have a user interface, Open CV library is used for real-time computer vision. There are three modules for the prototype. They are described as follows:

3.4.1 User Interface

The interface will be simple for this prototype. There are three main components of the user interface. These things will be addressed in the UI development. 1. Gesture Selection 2. Gesture detection and 3. Result.

3.5 Implementation

The following steps will be followed to implement. Figure 3.3 shows the major steps of implementation.

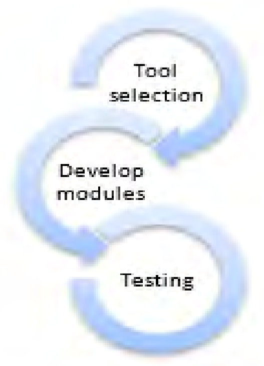


Figure 3. 3: Steps of Implementation

3.5.1 Tool Selection

Fast, compact, proper documentation, and most recent are the parameters that will be thought of while picking technologies or tool for the prototype.

3.5.2 Module Development

All the required modules of the tool will be built using Python programming language and OpenCV-Python library. Programming resolution will be followed throughout the turn of events.

3.5.3 Testing

In the testing part, the prototype is tested to verify its functionality. This has been elaborated in detail in the testing and evaluation chapter.

3.6 Testing and Evaluation of the Prototype

Three basic testing models will be used to test the prototype. For to test each part of the program and show that the individual parts are correct, a unit test will be conducted and to test overall functionality, System performance testing and interconnections of each of the module integration tests will be performed.

University lecturers and IT professionals will be asked to use the tool and evaluate the usability of the tool in three aspects. These are general aspect, structure and navigation, and system evaluation. The Evaluation process is further explained in the Testing and Evaluation chapter.

3.7 Summary

This chapter depicts the overall method of the research. It shows that all four steps are done one after another. First, an extensive literature review is prepared regarding hand gesture signals and fatigue to address the objectives. All the hand gesture signals used in the application area of hand gesture recognition can be narrowed down based on literatures. As of preliminary study, the sample size for this research is set to 60 participants. The participants will imitate selected hand gesture signals. Cogulator tool will be used to create and analyze GOMS task analysis, based on the imitated hand gesture signals by the participants.

A tool will be designed and developed after the preliminary study which can take user input and analyze the gesture signals, hand positions, and types of interaction (operators in GOMS analysis). Finally, the tool will evaluate the given data and provide the prediction of fatigue in the gesture recognition system. All the research objectives shall be achieved by addressing respective research questions.

CHAPTER 4: PRELIMINARY STUDY

This is a quantitative preliminary study that provides the practical data of the research. Alongside, this will help to gather more data that will help to determine the design and implementation of the prototype. This chapter attempts to expose preliminary study and the accurate steps a user will perform for each hand gesture signals through Cogulator calculator. This study aims to investigate through task analysis which are the hand gesture signals that the user will face any kind of muscle tension while imitating the selected hand gestures signals. The study will also provide the average task completion time for each hand gesture signal. Cogulator tool will also provide the number of steps or operators used for this hand gesture signals to perform after mapping the selected hand gesture signals into Cogulator terminal. GOMS task analysis will be carried out through Cogulator tool to gather data against each hand gesture signal mentioned in section 2.2 in Chapter 2.

Preliminary study is focused on imitating the selected 29 hand gesture signals from literature review. The participants were asked to imitate the 29 hand gesture signals by following the steps acquired from the Cogulator tool for each gesture. The time taken to complete the hand gesture signals will be calculated for each hand gesture signal.

4.1 Materials

4.1.1 Participants

A total of 60 participants participated this survey. The participants were chosen based on their computer literacy, knowledge based on Human computer interaction and experience on hand gesture signals. Participants with human computer interaction and hand gesture signal is important for this survey, participants without any prior knowledge of human computer interaction and hand gesture signal might not provide the accurate data for this study.

Among the 60 participants 31 participants were female and 29 participants were male.

Figure 4. 1: Demographic (Gender of participants)

Figure 4.1 Shows that 51.7 % participants were female, and 48.3 % participants were male.

From the responded participants 30 participants were between the age 12-17 years old and rest 30 participants were 18 years and above.

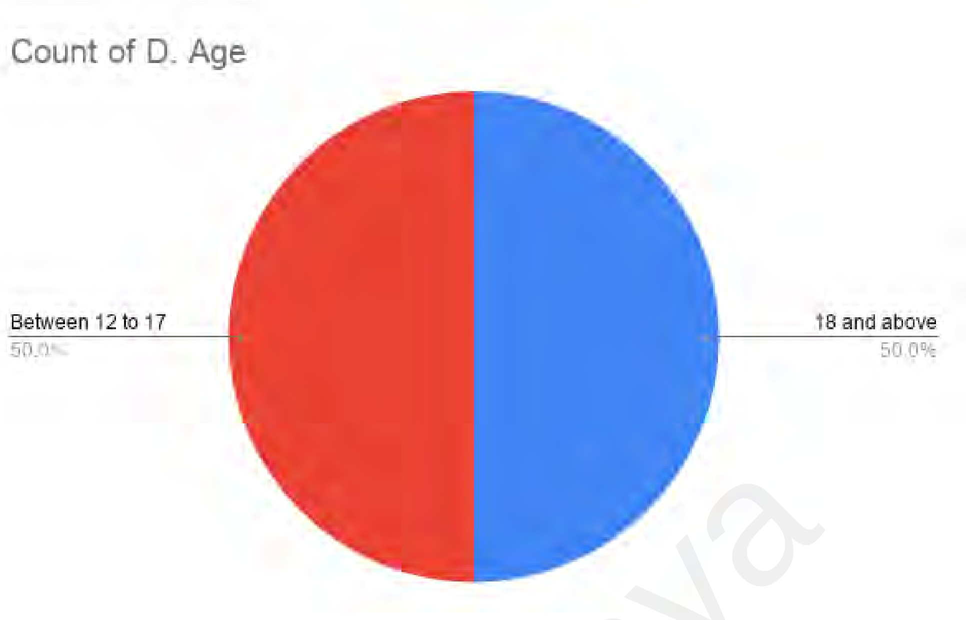
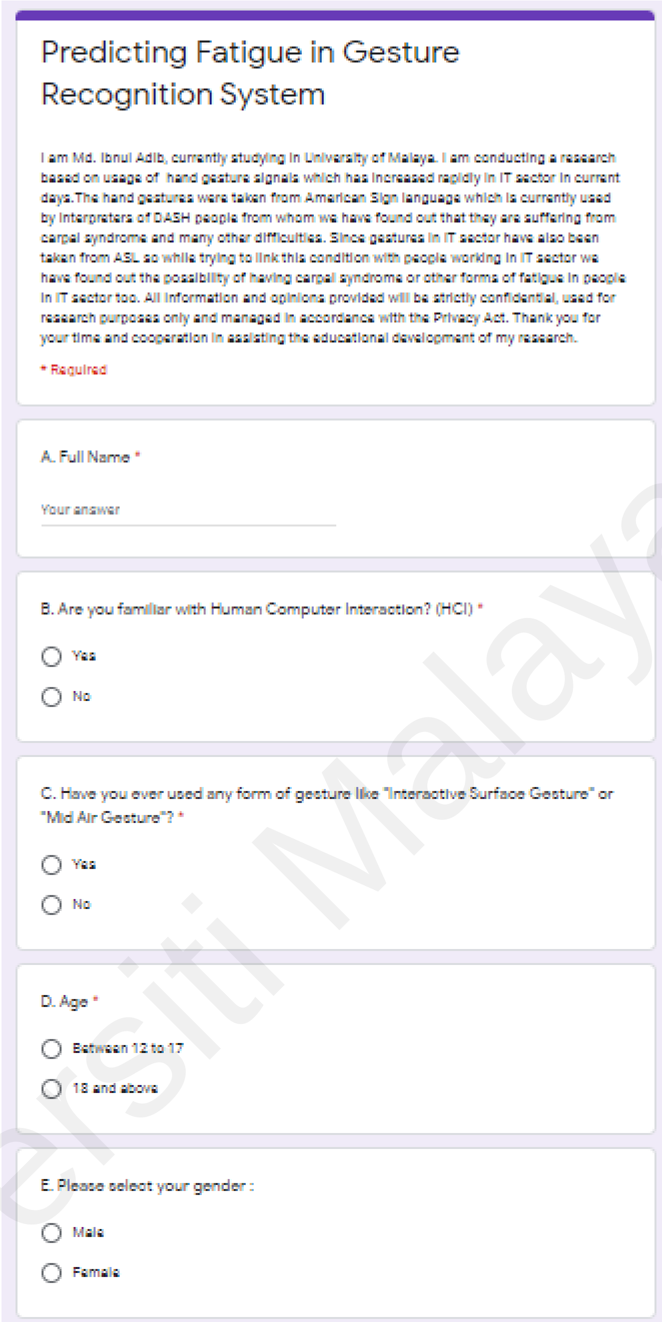


Figure 4. 2: Demographic (Age of participants)

Figure 4.2 shows that 50 % participants were between age 12-17 and 50 % participants were 18 years and above.

4.1.2 Survey Form

Participants were provided with a Google survey form before the survey. This survey form consists of 3 sections. Section 1 requires the information about the participants. Participant's name, age, gender and if they have adequate knowledge on Human computer interaction and if they have ever performed any kind of hand gesture signals. If both questions were in affirmative only then the participant is allowed to proceed to the Section 2. Section 2 consist of the 29-hand gesture signal drawing along with descriptions of the hand gesture signals. Section 2 of the survey form is added in the Appendix B (I) section and the 3rd section of the survey form is a thank you note for the respondents. Also, if the responded choses No for any of the question "B" and "C" from section 1, then the form leads them to section 3 of the survey form since that response would be irrelevant for this study.



Predicting Fatigue in Gesture Recognition System

I am Md. Ibnul Adib, currently studying in University of Malaya. I am conducting a research based on usage of hand gesture signals which has increased rapidly in IT sector in current days.The hand gestures were taken from American Sign language which is currently used by interpreters of DASH people from whom we have found out that they are suffering from carpal syndrome and many other difficulties. Since gestures in IT sector have also been taken from ASL so while trying to link this condition with people working in IT sector we have found out the possibility of having carpal syndrome or other forms of fatigue in people in IT sector too. All information and opinions provided will be strictly confidential, used for research purposes only and managed in accordance with the Privacy Act. Thank you for your time and cooperation in assisting the educational development of my research.

* Required

A. Full Name *

Your answer

B. Are you familiar with Human Computer Interaction? (HCI) *

- Yes
- No

C. Have you ever used any form of gesture like "Interactive Surface Gesture" or "Mid Air Gesture"? *

- Yes
- No

D. Age *

- Between 12 to 17
- 18 and above

E. Please select your gender :

- Male
- Female

Figure 4. 3: Section 1 of Survey Form

4.1.3 Cogulator Tool

All 29 hand gesture signals were mapped in the Cogulator tool to get the operators number and standard time to perform each hand gesture signal. Operator number indicated numbers of steps one participant had to follow to perform to imitate the hand gesture signal. All the 29 gestures Cogulator graph are available at Appendix D. Participants marked 'Yes' for majority hand gestures are shown below:

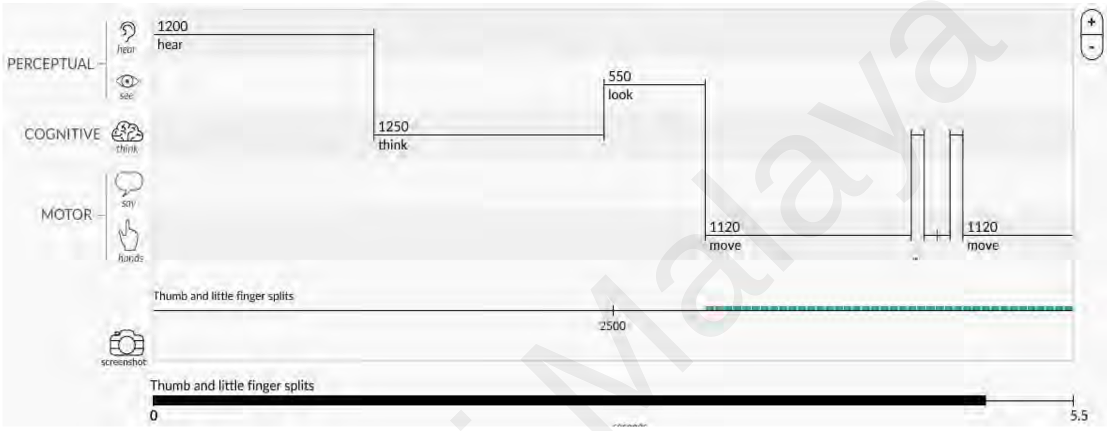


Figure 4. 4: Gesture no 7 Cogulator Gantt chart

Figure 4.4 shows the Gantt chart of the gesture no 7 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 7 in the Cogulator tool the standard time to perform this hand gesture signal is 5.5 seconds.

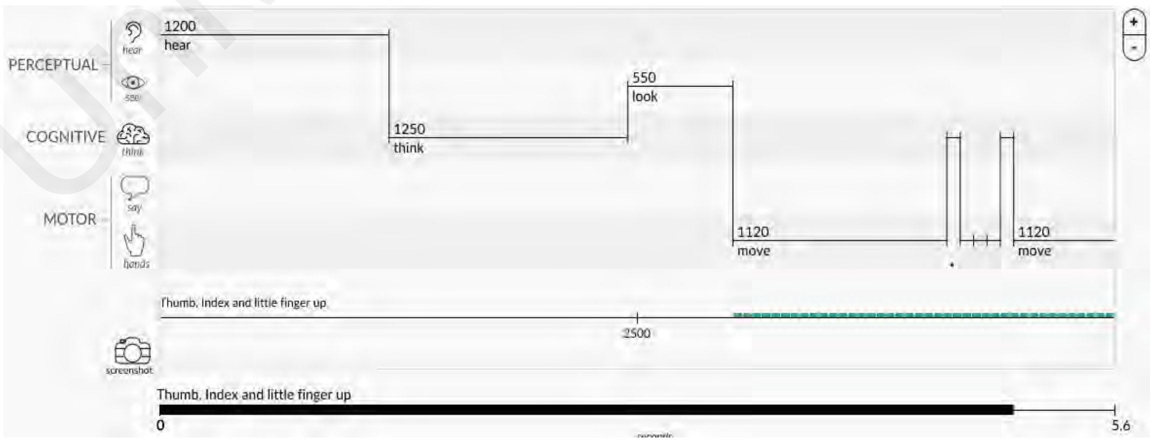


Figure 4. 5: Gesture no 8 Cogulator Gantt chart

Figure 4.5 shows the Gantt chart of the gesture no 8 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 8 in the Cogulator tool the standard time to perform this hand gesture signal is 5.6 seconds.

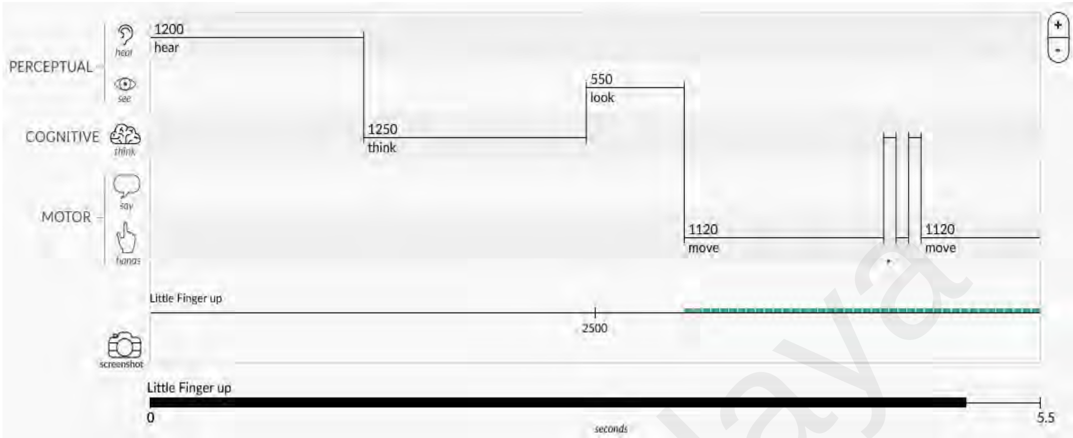


Figure 4. 6: Gesture no 16 Cogulator Gantt chart

Figure 4.6 shows the Gantt chart of the gesture no 16 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 16 in the Cogulator tool the standard time to perform this hand gesture signal is 5.5 seconds.

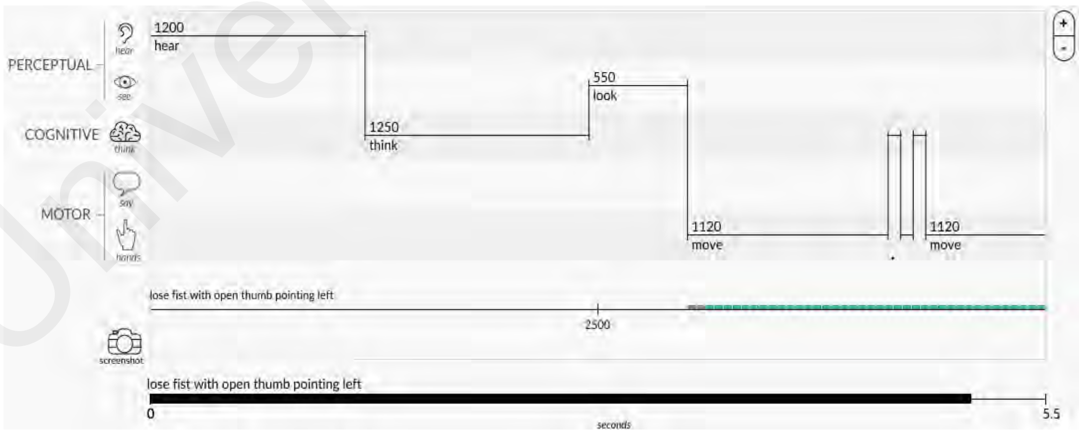


Figure 4. 7: Gesture no 17 Cogulator Gantt chart

Figure 4.7 shows the Gantt chart of the gesture no 17 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 17 in the Cogulator tool the standard time to perform this hand gesture signal is 5.5 seconds.

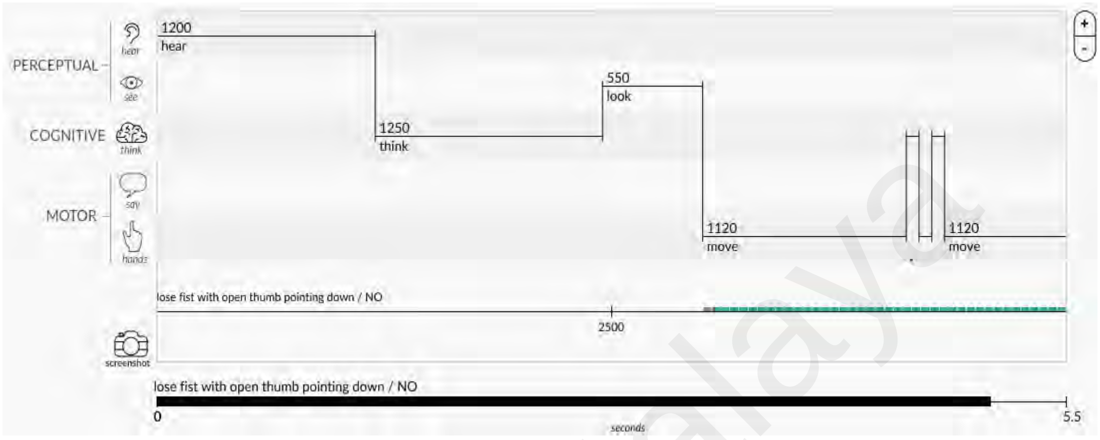


Figure 4. 8: Gesture no 19 Cogulator Gantt chart

Figure 4.8 shows the Gantt chart of the gesture no 19 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 19 in the Cogulator tool the standard time to perform this hand gesture signal is 5.5

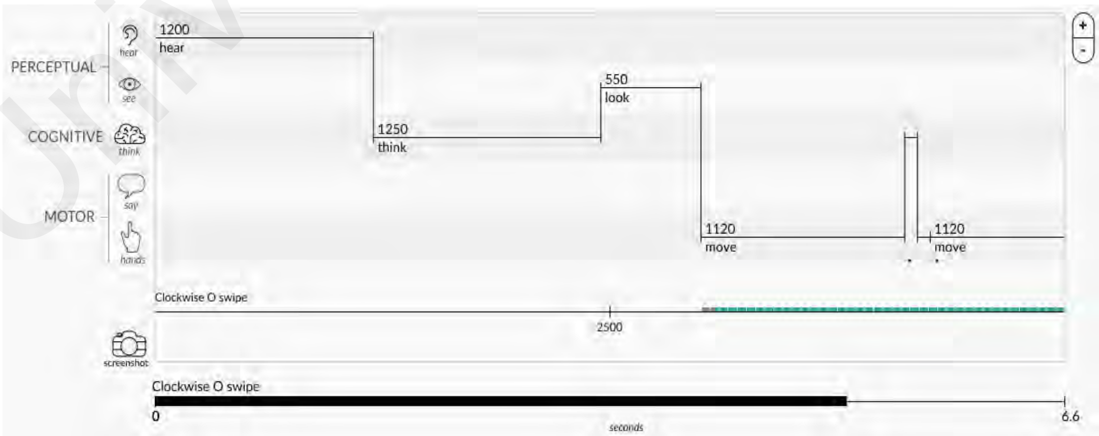


Figure 4. 9: Gesture no 26 Cogulator Gantt chart

Figure 4.9 shows the Gantt chart of the gesture no 26 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 26 in the Cogulator tool the standard time to perform this hand gesture signal is 6.6 seconds.

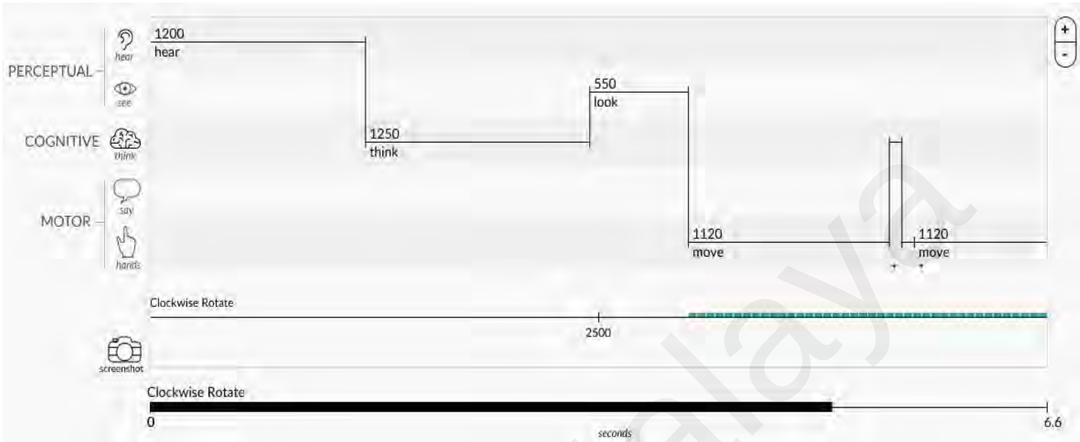


Figure 4. 10: Gesture no 27 Cogulator Gantt chart

Figure 4.10 shows the Gantt chart of the gesture no 27 mapped in the Cogulator tool. The chart shows the perceptual, cognitive, and motor operators. After mapping the Gesture no 27 in the Cogulator tool the standard time to perform this hand gesture signal is 6.6 seconds.

4.1.4 Instruction

At first the participants were briefed on the hand gesture signals from literature review. The researcher also demonstrated the gestures to the participants and explained how they have to perform it during the task activity according to the Gantt chart provided by the Cogulator tool. The participants were also asked to practice few hand gestures freely to gather some confidence among them. After the participant agrees that they are confident enough and understood the full procedure they were given the Google form link to show their consent for participating this research survey.

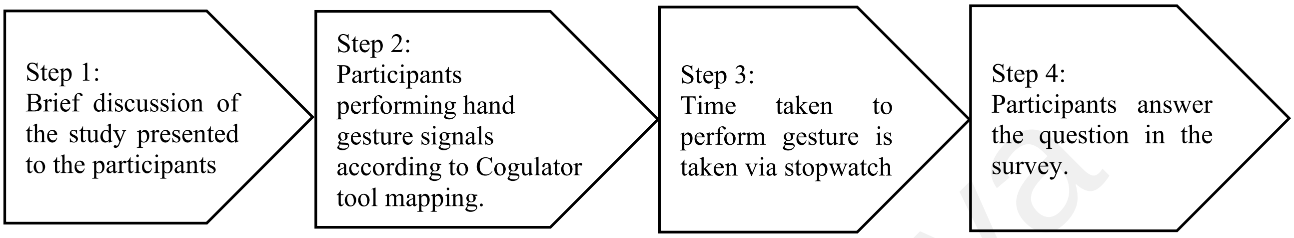
After completing the first section of the form the participant will start imitating the hand gesture signals in order as mentioned in the survey form. Participants were asked if they need any camera screen open in front of them so that they can do the hand gesture signals inside a close frame This is optional as few of the participants were already a user of hand gesture signals, so they were more knowledgeable to perform the task without even looking at the camera screen. As the participants will start the task the research will start the stopwatch and only stop the timer when one of the hand gesture signals is completed. After each gesture is performed the participant had to answer the question on the survey form related to the performed hand gesture signal.

4.2 Survey Procedure

This survey was conducted in three steps. First, the participant was given a brief description of the study and explained about the fatigue in gesture recognition system. The participants were shown the 29 hand gesture signals and how to perform them by describing the Gantt chart from Cogulator tool. When the participants were confident enough and they understood the gestures that they have to perform they the second stage starts. In the second step the participants are provided with a structured Google Survey form. The form has three sections. The first section asks about the participants name, age, gender and the information if they are aware of human computer interaction and if they have ever used any interactive surface gesture or mid-air gesture. Only if both the options are in affirmative then the form will take the participant to the section two of the form.

In the second section the participant will see a list of 29 hand gesture signals with a short description of the hand gesture signal drawings. During this session the participants will imitate each hand gesture signals and the researcher takes down the time of the task performed through a stopwatch. After the participants finish their task, they are asked to answer the question on the form related to the performed hand gesture signal. They will continue performing each gesture accordingly. After the participant completes all the questions then they can click submit to finish the survey.

Steps of Survey:



4.3 Result

A single sample t-test was conducted to determine if a statistically significant difference existed between performance time from Cogulator tool and the data we received from the population for all the hand gesture signals. Results from survey and one sample t-test is shown below where majority of the user make “Yes” for muscle tension. The gestures are gesture number 7, 8, 16, 17, 19, 26, 27. Rest of the results are available at Appendix E.

4.3.1 Gesture No 7

6

Gesture No 7 is two finger splits, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 9 and standard time to perform this hand gesture signal is 5.5 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

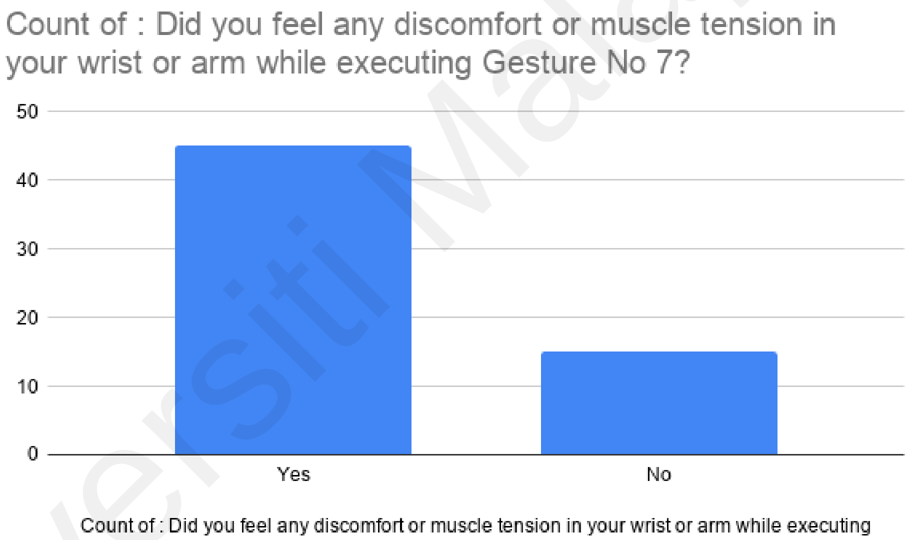


Figure 4. 11: Count of gesture no 7 from survey

Figure 4.11 shows the bar chart in which out of 60 participants 45 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 15 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo7	60	5.9333	.57657	.07443

Figure 4. 12: One-Sample statistics for Gesture no 7

One-Sample Test

	Test Value = 5.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo7	5.822	59	.000	.43333	.2844	.5823

Figure 4. 13: One-Sample test for Gesture no 7

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 5.93, SD = .57) compared to general performance time, t (59) = 5.822, $p < 0.05$.

4.3.2 Gesture No 8

Gesture No 8 is rock sign, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 10 and standard time to perform this hand gesture signal is 5.6 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

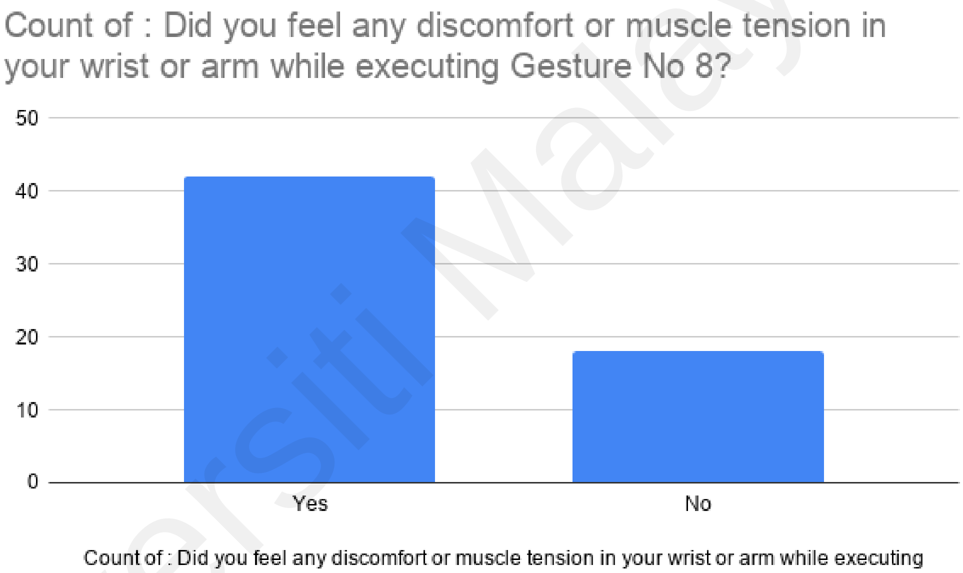


Figure 4. 14: Count of gesture no 8 from survey

Figure 4.14 shows the bar chart in which out of 60 participants 42 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 18 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo8	60	5.8150	.41080	.05303

Figure 4. 15: One-Sample Statistics for Gesture no 8

One-Sample Test

	Test Value = 5.6					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo8	4.054	59	.000	.21500	.1089	.3211

Figure 4. 16: One-Sample test for Gesture no 8

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 5.81, SD = .41) compared to general performance time, t (59) = 4.054, $p < 0.05$.

4.3.3 Gesture No 16

Gesture No 16 is only little finger up, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 8 and standard time to perform this hand gesture signal is 5.5 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

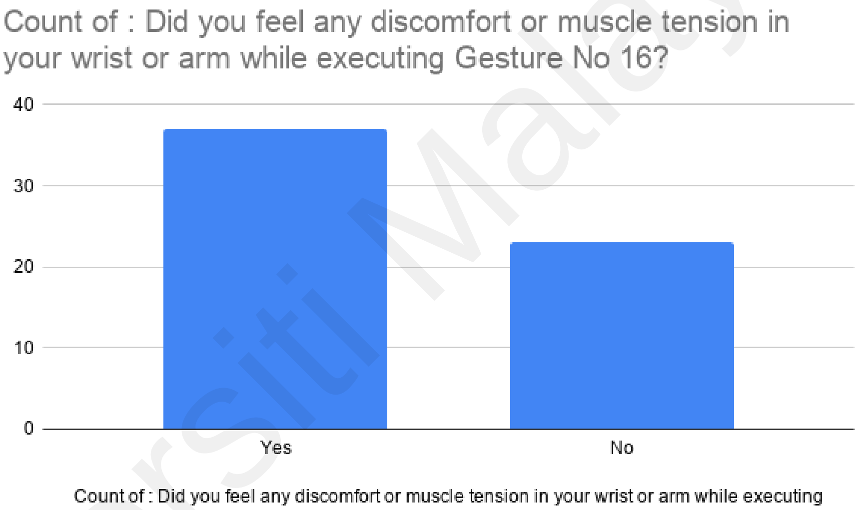


Figure 4. 17: Count of gesture no 16 from survey

Figure 4.17 shows the bar chart in which out of 60 participants 37 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 23 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo16	60	5.8450	.44471	.05741

Figure 4. 18: One-Sample statistics for gesture no 16

One-Sample Test

	Test Value = 5.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo16	6.009	59	.000	.34500	.2301	.4599

Figure 4. 19: One-Sample test for Gesture no 16

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 5.84, SD = .44) compared to general performance time, $t(59) = 6.009$, $p < 0.05$.

4.3.4 Gesture No 17

Gesture No 17 is close fist with open thumb pointing left, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 8 and standard time to perform this hand gesture signal is 5.5 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

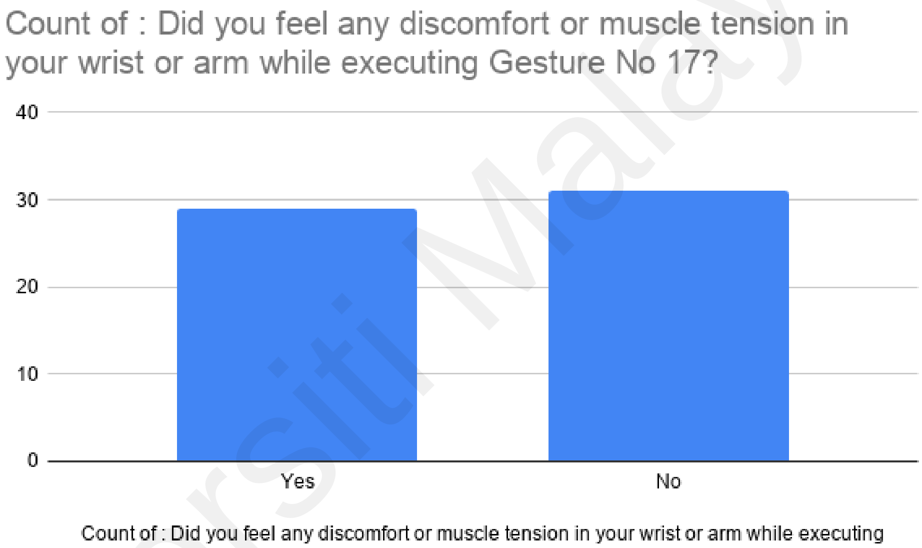


Figure 4. 20: Count of gesture no 17 from survey

Figure 4.20 shows the bar chart in which out of 60 participants 29 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 31 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo17	60	5.8100	.45870	.05922

Figure 4. 21: One-Sample statistics for Gesture no 17

One-Sample Test

	Test Value = 5.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo17	5.235	59	.000	.31000	.1915	.4285

Figure 4. 22: One-Sample test for Gesture no 17

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 5.81, SD = .45) compared to general performance time, t (59) = 5.235, $p < 0.05$.

4.3.5 Gesture No 19

Gesture No 19 is close fist with open thumb pointing down / NO, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 8 and standard time to perform this hand gesture signal is 5.5 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

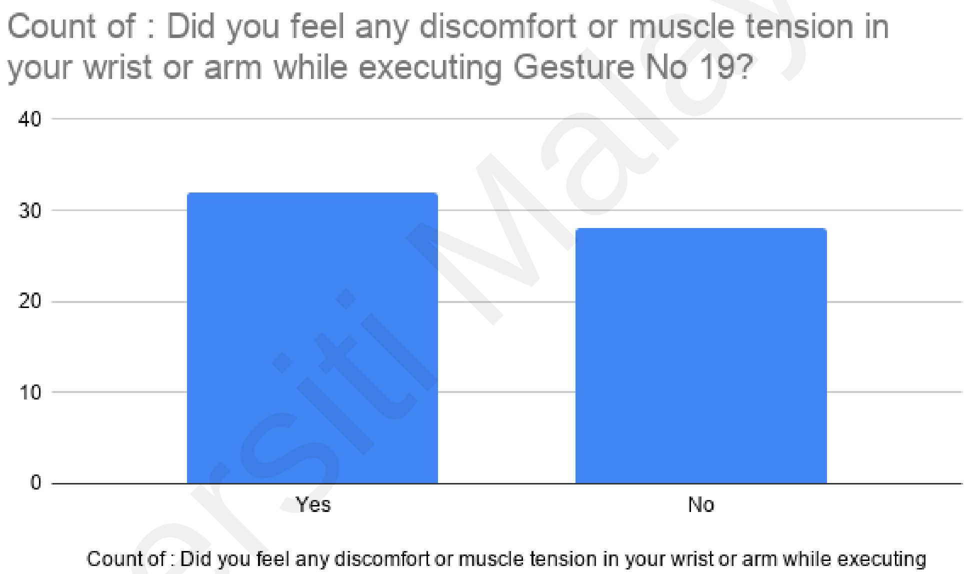


Figure 4. 23: Count of gesture no 19 from survey

Figure 4.23 shows the bar chart in which out of 60 participants 32 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 28 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo19	60	5.9950	.46847	.06048

Figure 4. 24: One-Sample statistics for Gesture no 19

One-Sample Test

	Test Value = 5.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo19	8.185	59	.000	.49500	.3740	.6160

Figure 4. 25: One-Sample test for gesture no 19

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 5.99, SD = .46) compared to general performance time, t (59) = 8.185, p < 0.05.

4.3.6 Gesture No 26

Gesture No 26 is clockwise "O" swipe, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 9 and standard time to perform this hand gesture signal is 6.6 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

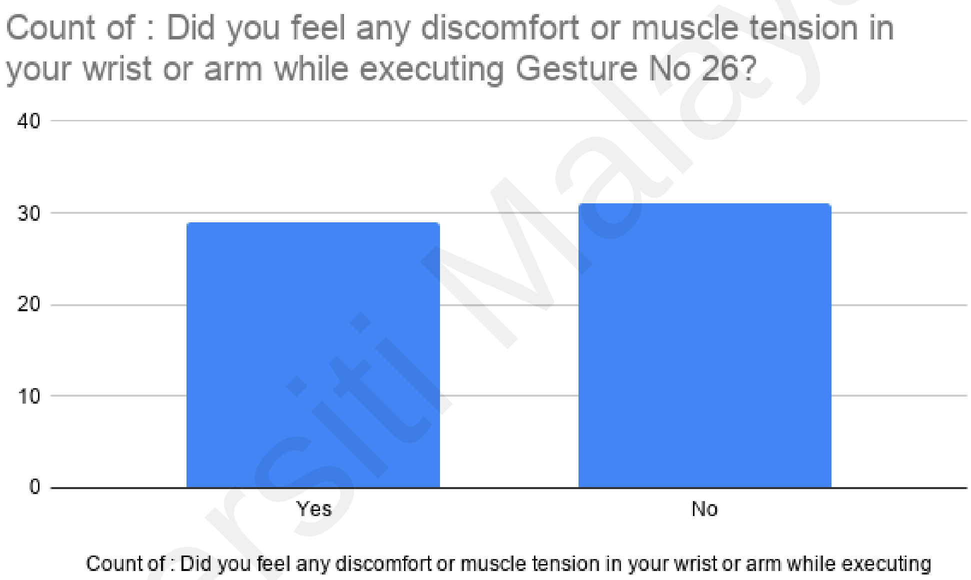


Figure 4. 26: Count of gesture no 26 from survey

Figure 4.26 shows the bar chart in which out of 60 participants 29 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 31 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo26	60	7.2817	.47603	.06146

Figure 4. 27: One-Sample statistics for Gesture no 26

One-Sample Test

	Test Value = 6.6					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo26	11.092	59	.000	.68167	.5587	.8046

Figure 4. 28: One-Sample test for gesture no 26

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 7.28, SD = .47) compared to general performance time, $t(59) = 11.092$, $p < 0.05$.

4.3.7 Gesture No 27

Gesture No 27 is rotate clockwise, for this hand gesture signal a total of 60 participants attended the survey. The standard operators for this hand gesture signal are 9 and standard time to perform this hand gesture signal is 6.6 seconds. This information can be seen in the Gantt chart provided by the Cogulator tool.

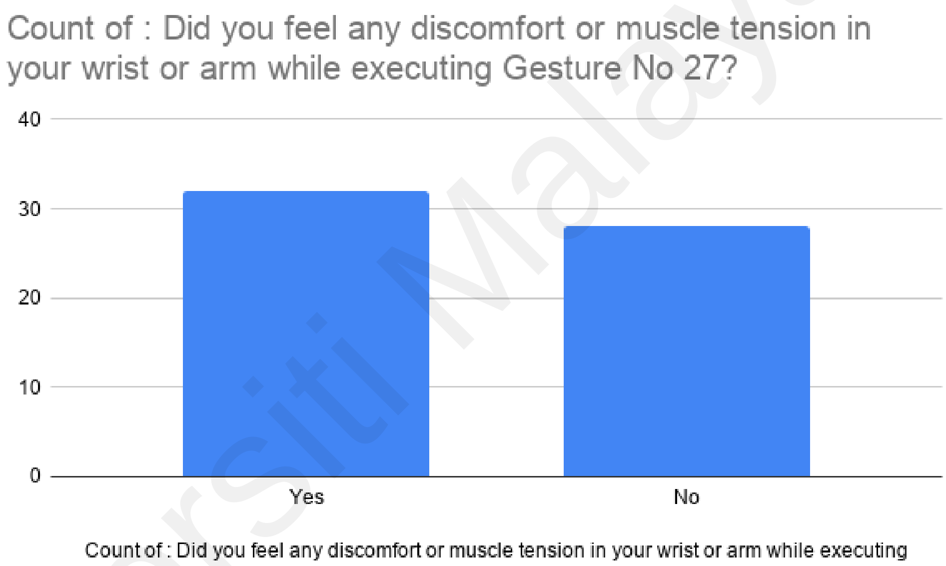


Figure 4. 29: Count of gesture no 27 from survey

Figure 4.29 shows the bar chart in which out of 60 participants 32 participants felt muscle tightness or muscle tension while imitating the close fist hand gesture signal and rest 28 participants didn't feel any problem while performing the task.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
GestureNo27	60	7.2733	.47331	.06110

Figure 4. 30: One-Sample statistics for Gesture no 27

One-Sample Test

	Test Value = 6.6					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
GestureNo27	11.019	59	.000	.67333	.5511	.7956

Figure 4. 31: One-Sample test for Gesture no 27

Respondents participating in this survey reported statistically significant performance time for gesture no 1 for test (M = 7.27, SD = .47) compared to general performance time, t (59) = 11.019, $p < 0.05$.

4.4 Discussion

Twenty-nine hand gesture signals were practiced in the survey that are already in use in different application area of hand gesture recognition system. The activity of imitating hand gesture signal was conducted involving participants who are familiar with human computer interaction and has already used any form of interactive hand gesture signal or mid-air gesture. A total of 60 participants attended the survey among which 31 were female and 29 males. Also, among these 60 participants 30 participants were between 12-17 years old and other 30 participants were 18 years old and above. Each participant provided 29 set of data which sums up of a total of 1740 data altogether for the selected hand gesture signals.

It has been observed through the analysis that to some extend in all of the gestures few participants felt muscle discomfort or muscle tension while performing the hand gesture signals. Specially participants were facing discomfort in those hand gesture signals where there were more operators to perform the hand gesture signals rather than the low number of operators. Specially the participants faced discomfort in those hand gesture signals where the hand gesture signals are combination of curves and difficult posture than the normal movement of the hand and arm.

Table 4. 1: Comparison between gesture results

Gesture No	Category	Operator No	Time (Seconds)	M	SD	p Value	Muscle Tension	
							Yes	No
1	UP	6	5.3	5.76	0.53	<0.05	7	53
2	UP	8	5.5	5.67	0.25	<0.05	3	57
3	UP	8	5.5	5.78	0.49	<0.05	5	55
4	UP	8	5.5	5.95	0.61	<0.05	10	50
5	UP	8	5.5	5.98	0.77	<0.05	15	45
6	UP	8	5.5	6.2	0.69	<0.05	4	56
7	UP	9	5.5	5.93	0.57	<0.05	45	15
8	UP	10	5.6	5.81	0.41	<0.05	42	18
9	UP	9	5.5	5.8	0.54	<0.05	5	55
10	UP	8	5.5	5.63	0.42	.018	3	57
11	UP	7	5.4	5.65	0.52	<0.05	2	58
12	LC	8	6.5	7.01	0.39	<0.05	3	57
13	LC	8	6.5	7.09	0.42	<0.05	2	58
14	LC	8	6.5	6.98	0.43	<0.05	3	57
15	LC	8	5.5	6	0.68	<0.05	12	48
16	UP	8	5.5	5.84	0.44	<0.05	37	23
17	LC	8	5.5	5.81	0.45	<0.05	29	31
18	LC	8	5.5	6.11	0.65	<0.05	8	52
19	LC	8	5.5	5.99	0.46	<0.05	32	28
20	UP	8	6.5	7.03	0.43	<0.05	5	55
21	UP	8	6.5	7.01	0.5	<0.05	4	56
22	UP	8	6.5	7.12	0.43	<0.05	10	50
23	UP	8	6.5	7.05	0.48	<0.05	5	55
24	UP	9	5.5	6.17	0.42	<0.05	11	49
25	UP	9	6.6	7.17	0.41	<0.05	6	54
26	UP	9	6.6	7.28	0.47	<0.05	29	31
27	UP	9	6.6	7.27	0.47	<0.05	32	28
28	UP	9	6.6	7.48	0.38	<0.05	8	52
29	LC	9	6.6	7.14	0.5	<0.05	5	55

In Table 4.1 comparison between gesture results is shown, the comparison is done based on task analysis results, Cogulator tool graph result and one sample t-test. In this table Upper chest gesture has been defined as "UP" and Lower chest gesture has been defined as "LC".

Additionally, from the analysis it is observed that the hand gesture signals that follows the rule of turning and twisting the hand or folding fingers may cause muscle tension may last in muscle pain. However, discomfort in hand gesture signal data did not vary based on age and gender, it is shown in the Table 4.2. The results were different based on the different types of wrists and hand movement.

Table 4. 2: Comparison between different age group

Gesture No	Age: 18+ (Mean)	Age: Below 18(Mean)
GestureNo1	5.8	5.8
GestureNo2	5.7	5.7
GestureNo3	5.8	5.7
GestureNo4	6.0	5.9
GestureNo5	6.2	5.7
GestureNo6	6.2	6.3
GestureNo7	5.9	6.0
GestureNo8	5.8	5.7
GestureNo9	5.9	5.7
GestureNo10	5.6	5.7
GestureNo11	5.8	5.6
GestureNo12	7.0	7.0
GestureNo13	7.1	7.1
GestureNo14	7.0	7.0
GestureNo15	6.2	5.8
GestureNo16	7.8	5.8
GestureNo17	5.7	5.9
GestureNo18	6.3	5.9
GestureNo19	6.0	6.0
GestureNo20	7.1	7.0
GestureNo21	6.9	7.1
GestureNo22	9.1	7.2

Table 4.2, continued		
Gesture No	**Age: 18+ (Mean)**	**Age: Below 18(Mean)**
GestureNo23	7.1	7.0
GestureNo24	6.1	6.2
GestureNo25	7.2	7.2
GestureNo26	7.2	7.3
GestureNo27	7.3	7.3
GestureNo28	7.5	7.4
GestureNo29	7.1	7.2

4.5 Fatigue Predictive Model

A fatigue predictive model can be build based on the information from section 2.4 in Chapter 2, section 2.5 in Chapter 2, and survey results. 5 fatigue criteria have been identified previously from section 2.4 as below:

- Prolong usage of gesture
- Tight or widespread use of hand muscle
- Repetition of gesture
- Uncomfortable hand position
- Extensive and unique gesture design

Previous studies shows that professional sign language interpreters tend to form many kinds of wrist, arm, and shoulder diseases and disorders. Because of performing hand gesture signal their muscle and nerve starts to get fatigue and slowly it turns to various kind of diseases. Language interpreters perform these hand gesture signals for longer time, and they had to repeat the signals in their day to day live. Eventually they start to feel fatigue in their muscles that are in extensive use. From the survey many participants marked “Yes” where they faced muscle tension or discomfort while imitating the hand gestures.

Many participants had to repeat the hand gesture signals because of false tracking in the gesture recognition system. Repeating hand gesture signals where there is use of carpal tunnel, elbow, shoulder rotator cuff has a major reason to arouse fatigue in arm and shoulder. Uncomfortable placing of hand can cause low blood flow in the muscle. If the muscle does not receive correct amount of blood, then the muscle loses energy and it tend to start feel fatigue. Extensive and unique hand gestures like hand above chest level, tight fist, widespread fingers can lead to wrist and for-arm fatigue.

According to Cogulator tool a task is measured with 3 steps: Perceptual, Cognitive and Motor. Perceptual consists of hearing or seeing the task, Cognitive consists of thinking and Motor consist of motion. To predict fatigue, following the steps of Cogulator tool first the user will have to see if it is a unique gesture. Then the user will use the thinking ability to define if the user will have any discomfort while performing the gesture and finally the user will perform the motion of applying the gesture and find out if it has any extensive muscle use. When a user observes a new or different pattern of gesture that makes the finger, arm and shoulder to imitate a design pattern which is different than hand's natural positioning falls under Perceptual action. If the design pattern is new to the user or observing it for the first time the user will find this as a unique gesture patter, when the user will think to perform the gesture, it falls under Cognitive action. By applying thinking process the user will determine if the gesture's design pattern is uncomfortable because of finger, arm and shoulder placing. And finally, when the user will apply the gesture signal it falls under Motor action. Through motor action user will determine if the gesture consists of tight fist, stiff muscle or widespread fingers that uses the muscles of finger, arm and shoulder extensively.

It is known from the survey that participants faced discomfort, muscle stretch while performing gesture no. 7, 8, 16, 17, 19, 26 and 27 where gesture number 7, 8, 16, 26, and 27 is upper chest gesture and gesture number 17, 19 is lower chest gesture. Out of 7 gesture 5 are upper chest and 2 are from lower chest gesture category, which indicates that upper chest gestures have more possibility of fatigue (Rempel et al., 2014). Based on the similarity the gestures can be categorized in two groups on positioning of hand.

Table 4. 3 : Gesture category based on hand positioning.

No.	Upper Chest Gestures	Lower Chest Gestures
1.	Gesture No 7	Gesture No 17
2.	Gesture No 8	Gesture No 19
3.	Gesture No 16	-
4.	Gesture No 26	-
5.	Gesture No 27	-

From the seven above mentioned gestures another similarity is observed among the gesture's performing pattern. During performing the gesture no 7, 8 and 16 users have to use the little finger and on gesture no. 17, 19, 26 and 27 users have to twist or rotate the wrist or shoulder.

In gesture no 7, when thumb and little finger is split open and rest three fingers are folded against the palm, which makes the palm muscle to be stiff. As a result, the arm muscle also gets stiff. In gesture no 8, thumb, index finger and little finger is open, and rest two fingers are folded against palm which also creates similar muscle tension as gesture no 7 in the palm and arm muscle. In gesture no 16, all the fingers are folded against the palm but little finger. From the findings whenever the middle finger and ring finger is folder against palm and little finger is open it creates muscle tension in palm, and arm muscles. In this gesture patterns the palm and arm muscle get stiff. Stiffness of arm and palm muscle and similar usage of little finger is observed in these three hand gestures which can conclude these three gestures to fall under similar category.

In gesture no 17 and gesture no 19 thumb is open wide, and rest of the fingers are folded against the palm. In gesture no 17 users have to rotate the wrist to point the thumb to its opposite side than to its natural placing which produce pressure in arm muscle. Also, in gesture no 19 users have to point the thumb down by rotating the wrist anti clockwise along with the use of shoulder rotator. In gesture no 26, the user performs an "O" shape which uses the shoulder rotator and in gesture no 27, the user again has to rotate the wrist clockwise to imitate the gesture. Rotation of wrist or shoulder can be found as a similar pattern in these four gestures which can conclude these four gestures to fall under similar category.

Depending on the similarity of findings of the gesture design pattern these gestures can be categorized into two categories.

Table 4. 4 : Gesture category based on design pattern.

No.	Use of Little Finger	Rotation of Wrist/Shoulder
1	Gesture no 7	Gesture no 17
2	Gesture no 8	Gesture no 19
3	Gesture no 16	Gesture no 26
4	-	Gesture no 27

These are the most unique designed hand gestures among all the hand gesture signals. Participants agreed that these hand gestures were difficult to perform, and they required to repeat the hand gestures to avoid false tracking. If a user performs a unique designed mid-air gesture which does not follow ergonomics, includes extensive muscle movement, uncomfortable placing in terms of the body and that mid-air gesture is performed for interaction for longer hours occurrence of fatigue can be predicted among users for those types of mid-air hand gestures. Based on the similarities and findings all 29 gestures can be placed in a table as below:

Table 4. 5 Gesture categorization

Gesture No	Upper Chest	Lower Chest	Use of Little Finger	Wrist Rotation	Shoulder Rotation	Survey majority answer
1	√					No
2	√					No
3	√					No
4	√		√			No
5	√		√			No
6	√					No
7	√		√			Yes
8	√		√			Yes
9	√					No
10	√					No
11	√					No
12		√			√	No
13		√			√	No
14		√			√	No
15		√				No
16	√		√			Yes
17		√		√		Yes
18		√		√		No
19		√			√	Yes
20	√					No
21	√					No
22	√					No
23	√					No
24	√					No
25	√					No
26	√				√	Yes
27	√			√		Yes
28	√					No
29		√				No

Table 4.5 shows the use of the gesture categories based on hand position and design pattern and related to the answeres received from the respondents from the survey. From the table a similarity is found that the when the gestures are using a combination of Upper Chest, Use of little finger when middle finger and ring finger is folder it creates fatigue among majority of the user. Upper chest position and wrist or shoulder rotation combination of gesture also creates fatigue. Lower chest position and wrist or shoulder rotation combination creates comperatively less fatigue as per the result received from the participants. The combination of categories can be listed as below in which fatigue has occured:

1. Upper Chest +Use of Little finger
2. Upper Chest + Wrist Rotation
3. Upper Chest + Shoulder Rotation
4. Lower Chest + Wrist Rotation
5. Lower Chest + Shoulder Rotation

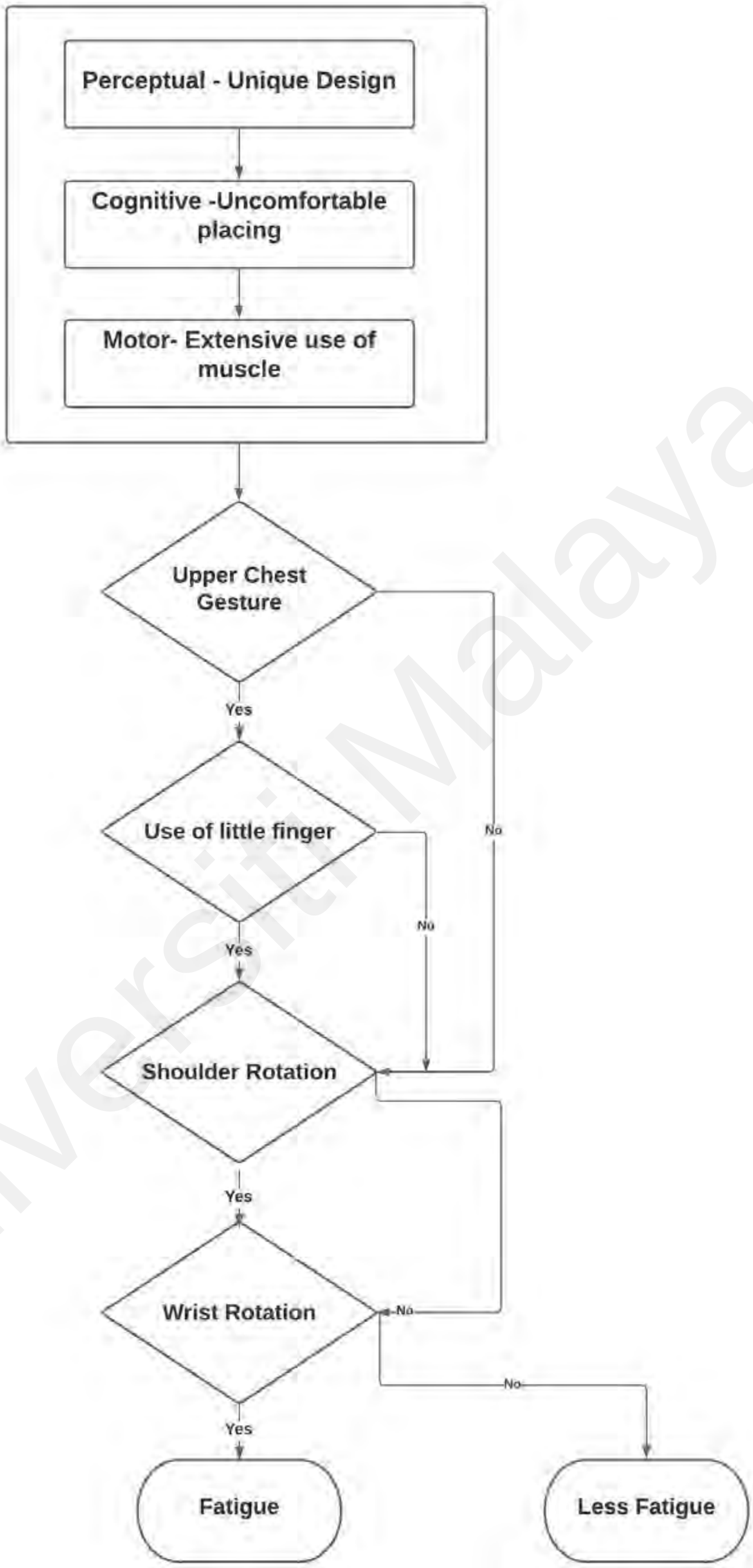


Figure 4. 32: Fatigue prediction process flow

From figure 4.32 fatigue predictive process flow fatigue percentage a calculation can, be done based through which fatigue level can be determined. If each "Yes" decision is marked with 25 points and "No" decision is marked with 0 points the calculation is as below:

Table 4. 6: Gesture combination calculation for fatigue

No.					Total
1	Upper Chest	-	-	-	25
2	Upper Chest	Little Finger	-	-	50
3	Upper Chest	Wrist Rotation	-	-	50
4	Upper Chest	Shoulder Rotation	-	-	50
5	Lower Chest	-	-	-	0
6	Lower Chest	Little Finger	-	-	50
7	Lower Chest	Wrist Rotation	-	-	50
8	Lower Chest	Shoulder Rotation	-	-	25
9	Upper Chest	Little Finger	Wrist Rotation	-	75
10	Upper Chest	Little Finger	Shoulder Rotation	-	75
11	Upper Chest	Wrist Rotation	Shoulder Rotation	-	50
12	Lower Chest	Little Finger	Wrist Rotation	-	50
13	Lower Chest	Little Finger	Shoulder Rotation	-	50
14	Lower Chest	Wrist Rotation	Shoulder Rotation	-	50
15	Upper chest	Little Finger	Wrist Rotation	Shoulder Rotation	100

From table 4.6 based on the received percentage from 0 to 100 and similar findings from the gesture position, gesture design pattern below model can predict the fatigue level in a hand gesture design.

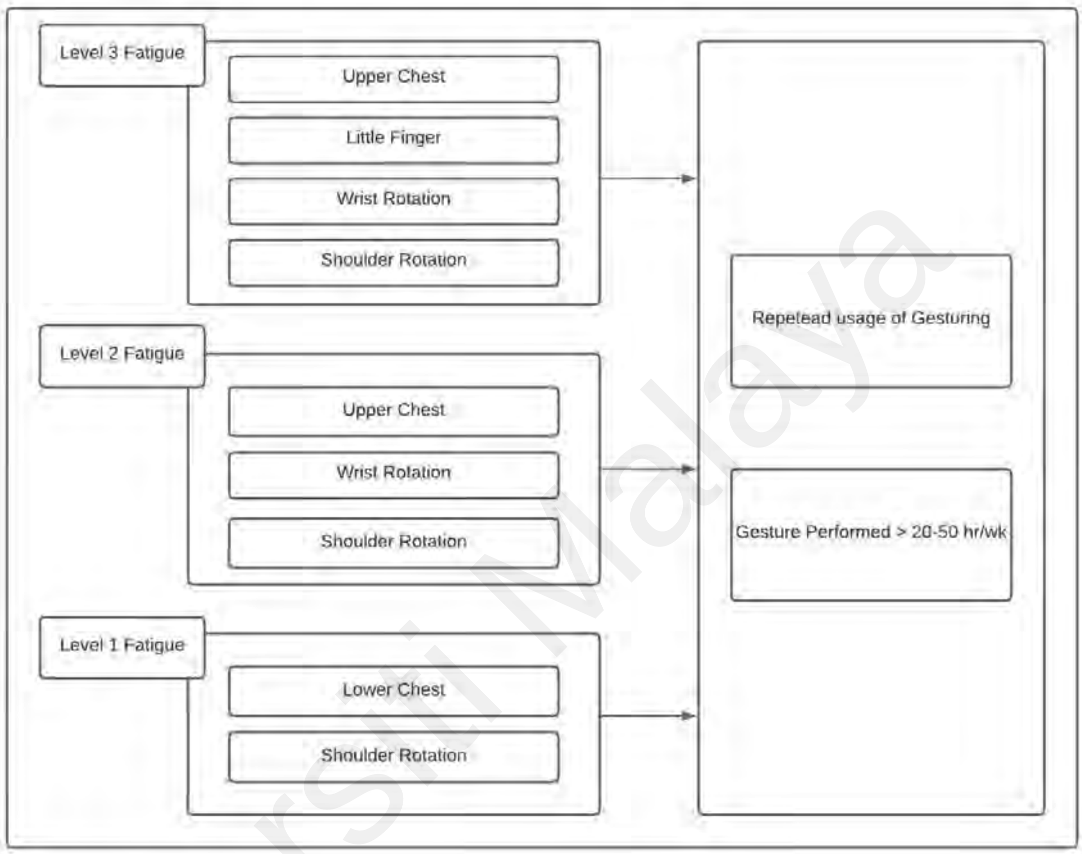


Figure 4. 33: Mid-air gesture interaction fatigue predictive model

Figure 4.33 is the proposed fatigue predictive model. Here 3 level of fatigue is shown. Level 1 fatigue, Level 2 fatigue, and Level 3 fatigue. Level 1 fatigue occurs when hand gesture signal has a combination of lower chest design and shoulder rotation pattern, along with if this type of gesture is used repeatedly and for longer time then the user will start to feel fatigue. This type of hand gestures has less chance off fatigue if done in natural hand position. Level 2 fatigue occurs when combination of upper chest hand gesture position, wrist rotation, and shoulder rotation is working together there is a high chance or fatigue for the user. If this combination is used for a longer time and if the user needs to repeat the gesture in daily life the user will face level 2 fatigue. Level 3 fatigue is a combination of upper chest, use of little finger, wrist, and shoulder rotation. If any hand gesture signal design and pattern, follow this combination there is a confirmed possibility that the user will fell fatigue. And if this combination meets the fatigue criteria of prolong use and needs to repeat the gesture then the fatigue prediction will have hundred percentage possibility.

4.6 Summary

In this chapter, the entire quantitative preliminary study has been done to address the second research question of this thesis. Out of all the existing gestures most of the responses were captured where the participants were having less or some sort of muscle tension or discomfort during the imitation activity. And repetition of these hand gesture signals may increase the change of getting fatigue in long term usage. From this chapter it has been demonstrated that how difficult and turn-twisting curvature of hand gesture movement can create discomfort and muscle tension among users by analyzing the provided data and by comparing the Gantt chart provided by Cogulator tool.

Table 4.3: Muscle strain-based hand gestures based on user perspective

Gesture No	Muscle Tension Response	
	Yes	No
7	45	15
8	42	18
16	37	23
17	29	31
19	32	28
26	29	31
27	32	28

In Table 4.3, Among the 29-hand gestures user faced muscle strain in 7 hand gestures. These gestures were unique to perform, and extensive use of muscle movement is required to imitate the hand gesture to prevent false tracking. Gesture number 7 and Gesture number 8 received the highest number of positive answers from the users. In these type of gestures muscles of wrist, for-arm and arm works all together, also if the hand is imitated outside the center of the body, then it also uses the shoulder muscles resulting in discomfort in performing the mid-air gesture. These seven gestures are also divided in to two separate categories based on the common factors of the gesture design pattern. Among the seven hand gestures majority of the hand gestures were Upper chest hand gestures in which participants marked “Yes” for muscle tension. Also, all of these gestures indicates that if the gesture design has use of little finger, wrist and shoulder twist or rotation the possibility of fatigue increases.

CHAPTER 5: DESIGN AND IMPLEMENTATION

In this chapter, the system design and implementation have been explained in four sections.

5.1 Tool Design

The tool design is elaborated through Model design, System design, Interface, component design, and user Accessibility Scope.

5.2 Model Design

First, the hand gesture signals are selected from the literature review and they were mapped in Cogulator tool to get the Gantt chart and then the standard time to do the hand gesture signal was set in the prototype to build the model of the system.

5.3 System Design

This system design consists of the architectural design of Predict Fatigue in Hand Gesture Recognition system, the functional modules, interface, and Use Case diagram. Finally, the implementation and algorithms are highlighted according to the designed components.

5.4 Architectural Design

The architectural design shows the full structure of the system in Figure 5.1. The gesture recognition sends data to the backend, then the backend fetches data from questionnaire and database then it returns data to the frontend and finally the data is shown on the screen of the gesture recognition system.

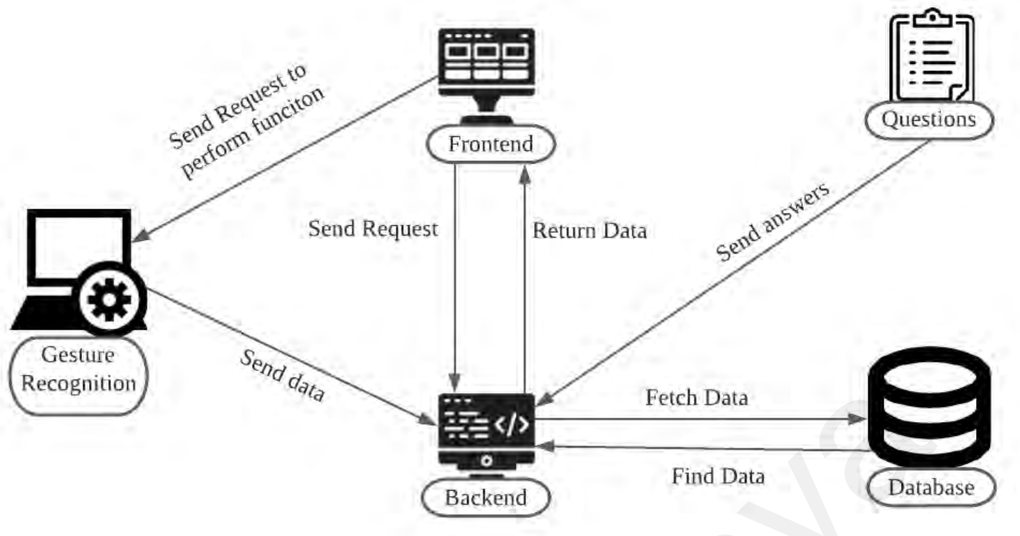


Figure 5. 1:Architectural design of the prototype1

5.5 Use Case

From the use case diagram in Figure 5.2 of the prototype, it is seen that there are 2 types of roles available. One is a user and the other one is an admin.

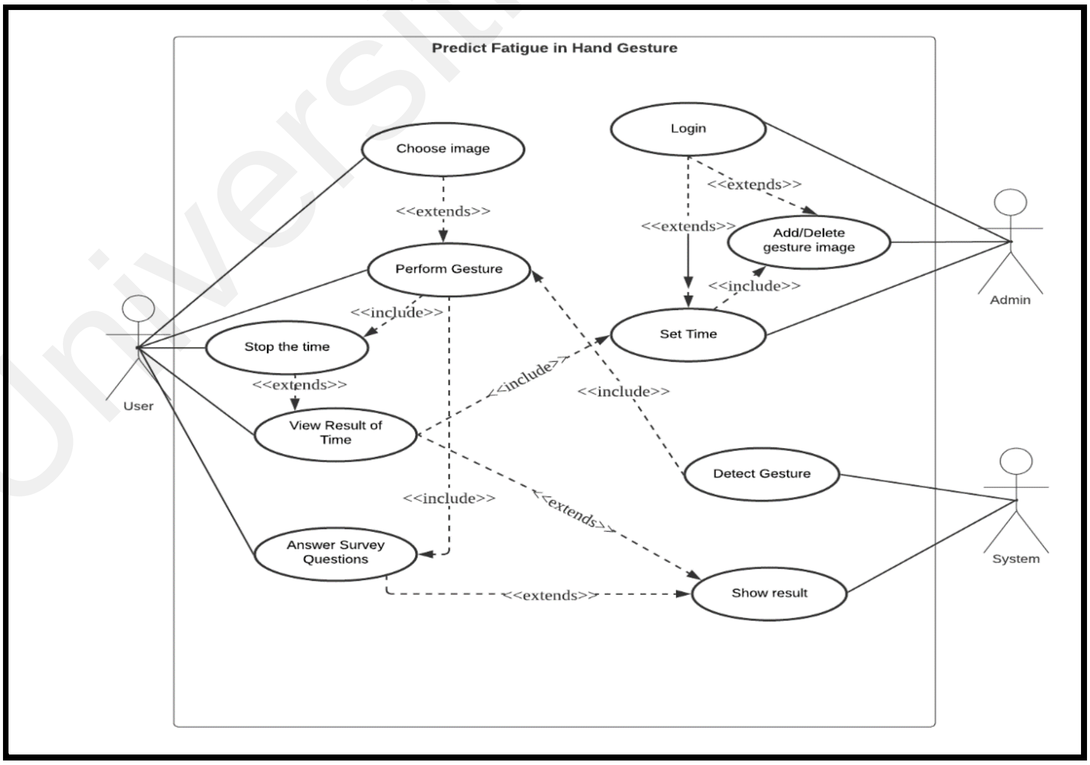


Figure 5. 2:Use case diagram of the prototype

5.6 System Flowchart

The Figure 5.3 illustrates a flowchart of the system. It starts with choose and performs the gesture where the user chooses the gesture to perform it. After the detection the system shows the taken time and then redirects to the questionnaire page, after the answer is provided the outcome is shown in the result.

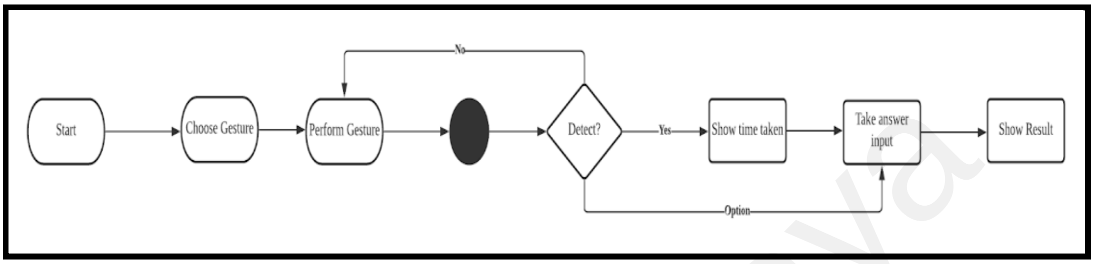
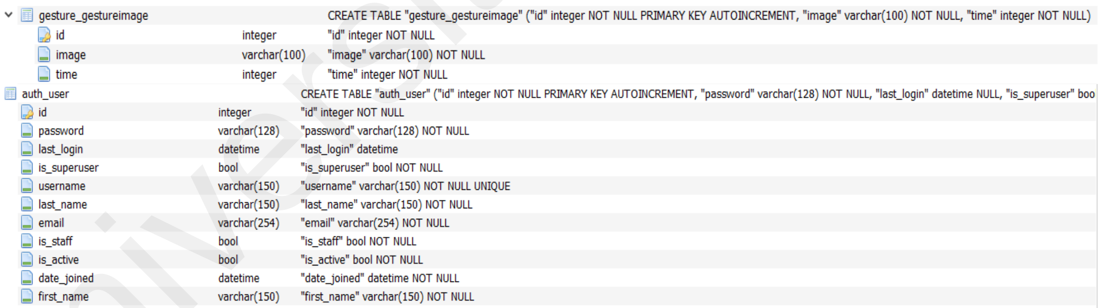


Figure 5. 3:System Flowchart

5.7 Database Overview

This system requires a database containing two tables to manage all the data. Namely, ‘gesture_gestureimage’ and “auth_user”. They are illustrated below:



gesture_gestureimage		CREATE TABLE "gesture_gestureimage" ("id" integer NOT NULL PRIMARY KEY AUTOINCREMENT, "image" varchar(100) NOT NULL, "time" integer NOT NULL)
id	integer	"id" integer NOT NULL
image	varchar(100)	"image" varchar(100) NOT NULL
time	integer	"time" integer NOT NULL
auth_user		CREATE TABLE "auth_user" ("id" integer NOT NULL PRIMARY KEY AUTOINCREMENT, "password" varchar(128) NOT NULL, "last_login" datetime NULL, "is_superuser" boo
id	integer	"id" integer NOT NULL
password	varchar(128)	"password" varchar(128) NOT NULL
last_login	datetime	"last_login" datetime
is_superuser	bool	"is_superuser" bool NOT NULL
username	varchar(150)	"username" varchar(150) NOT NULL UNIQUE
last_name	varchar(150)	"last_name" varchar(150) NOT NULL
email	varchar(254)	"email" varchar(254) NOT NULL
is_staff	bool	"is_staff" bool NOT NULL
is_active	bool	"is_active" bool NOT NULL
date_joined	datetime	"date_joined" datetime NOT NULL
first_name	varchar(150)	"first_name" varchar(150) NOT NULL

Figure 5. 4: System Database

In “gesture_gestureimage” image_id, image and image_timer are stored in these 3 columns. However, auth_user store admin_id, password, last_login,is_superuser, username,last_name,email, is_active, date_joined,first_name details. If the user is superuser, it is considered an admin.

5.8 Interface and Component design

This shows the complete view of the web application in which the functionality was implemented in the backend.

5.8.1 Home page

This is the home page of the prototype where users are able to choose their preferred gesture image to perform.

Figure 5. 5: Home Page

5.8.2 Perform gesture practice

Users can perform gestures according to gestures chosen by them. Moreover, after performing, they can stop the timer and view the time taken result by clicking on Result. The next button will redirect them to the Question module.

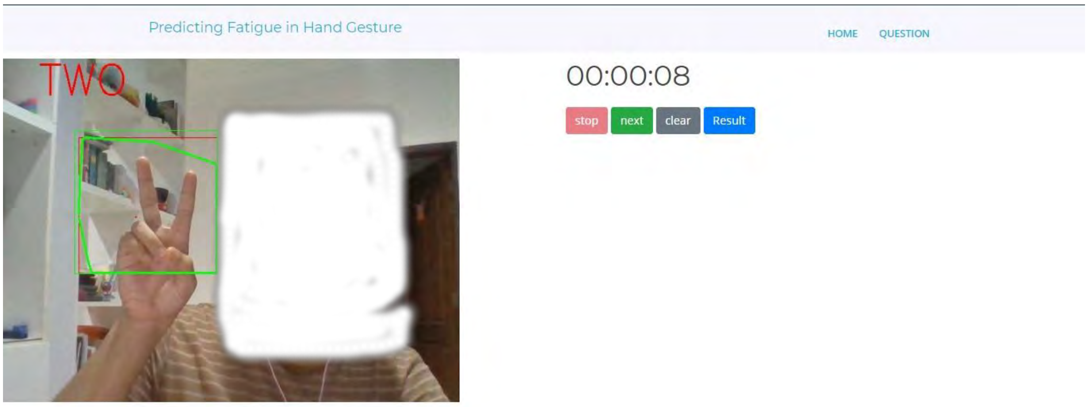


Figure 5. 6: Perform Gesture Page

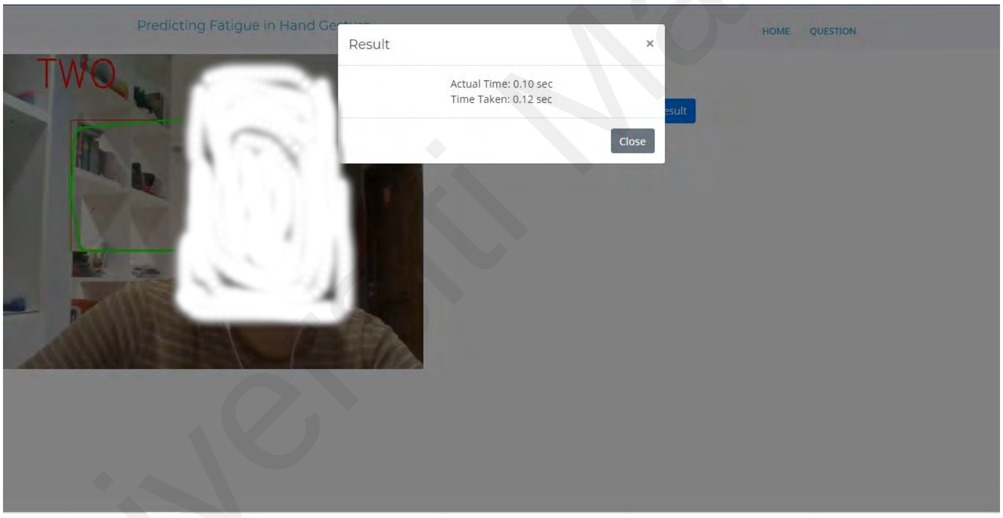


Figure 5. 7: Gesture task timing

5.8.3 Question Module

From the Question module, the user needs to answer the following questions to examine the system about fatigue that occurs in hand gestures during performing. After answering, the user is able to Submit the answer and view results in the Result module.

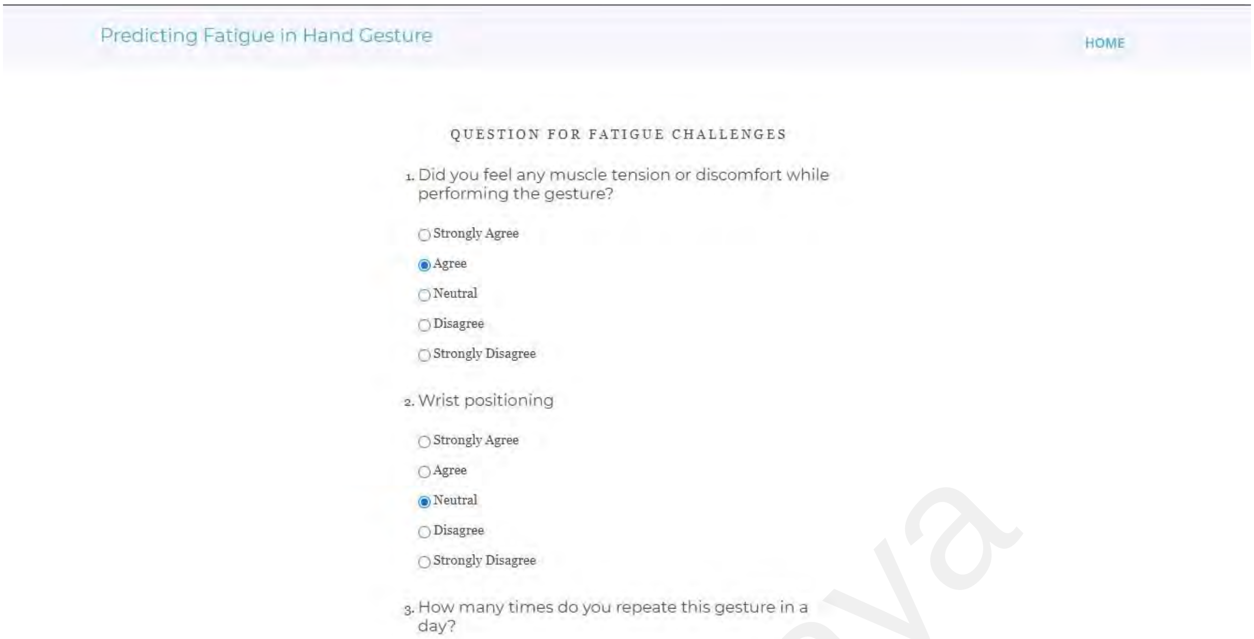


Figure 5. 8: Questionnaire page

5.8.4 Result

In the result module, users can view the fatigue result and additional details about their performance. The indicator visualizes fatigue results from the green zone to the red zone accordingly.

Figure 5. 9: Result Page

5.9 Administrator

5.9.1 Gesture Image List

Admin can view the list of images that are inserted for the user to perform inside the prototype. Moreover, they could delete the specific image by taking the necessary steps.

Figure 5. 10: Gesture image list

5.9.2 Add gesture image

Admin can add/upload gesture images for the user which will display on the user side. Additionally, the admin needs to set a time for performing certain gestures received from the Cogulator tool Gannt chart.

Figure 5. 11: Add gesture image

5.10 User Accessibility Scope

It has accessibility scopes for the user as well as for the admin. It has been demonstrated by using a Use Case diagram.

5.11 Implementation

This section illustrates the implementation of the system in the following subsections.

5.11.1 Tools

The list of tools was selected based on the development of the system's need. The list is shown in Table 5.1:

Table 5. 1: Selected tools

Name	Value	Reason of selection
Database	SQLite	Free, Serverless
Programming language	Python	Agile, OS independent
Frontend framework	HTML,CSS,JavaScript	Platform Independent
Backend framework	Django 3.0.4	Mature MVT with adequate documentation
Server	Apache	Light Weight

5.11.2 Development

Development has been done by using the above-mentioned tools. The following figures show the backend modules of the prototype that has been designed in the design section of this chapter.

5.11.2.1 View Component

Here "gen" function yields the frame to identify the gesture. On the other hand, "video_feed" is able to return the HTTP response for the video camera to the HandGesture.py in Figure 5.12.

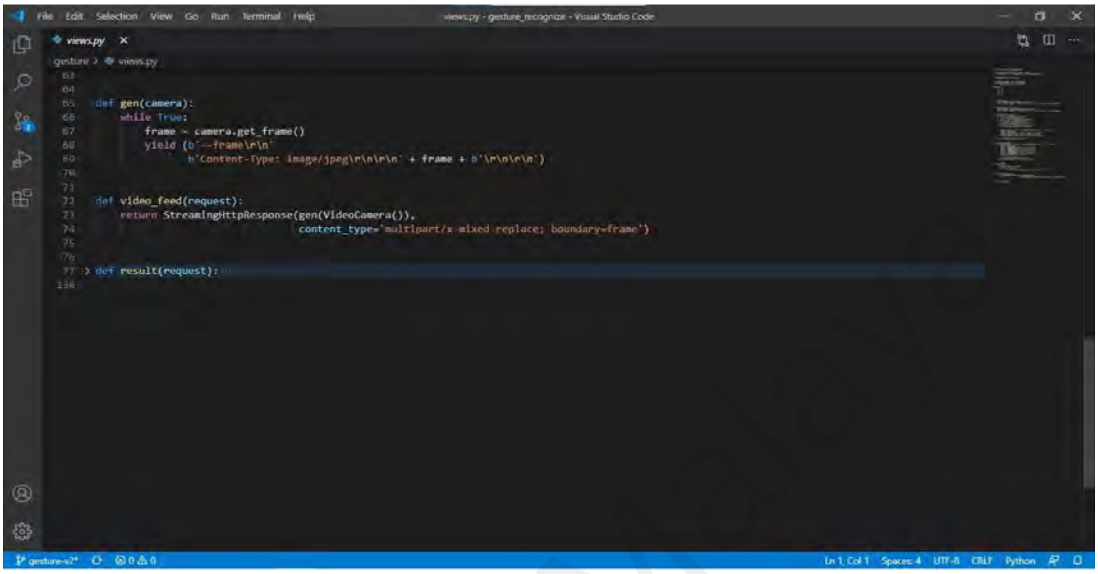


Figure 5. 12: Function of enable the camera and identify the gesture

Based on Figure 5.13, the following function" before_question" is able to remove all the following points, times for the same user whoever wants to continue the gesture practice.

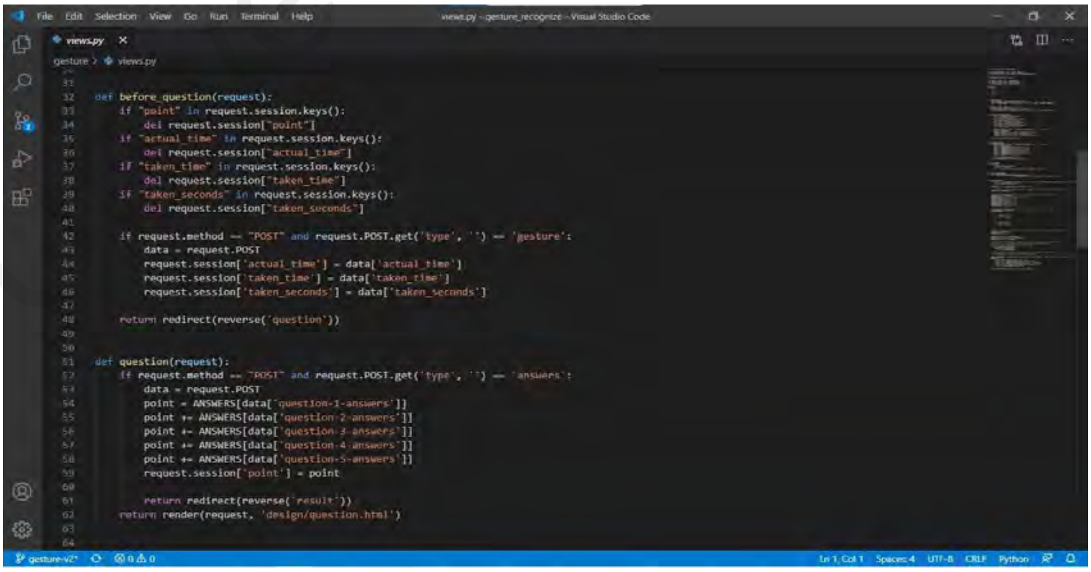


Figure 5. 13: Function of counting points based on user input

Moreover, it generates a new result and records a new time after performing the gesture. The “result” function can take input from the user and generate fatigue results.

5.11.2.2 Model component

The following class contains the essential fields and behaviors of the gesture image and the time for the certain image. Generally, Figure5.14’s this model maps to a database table.

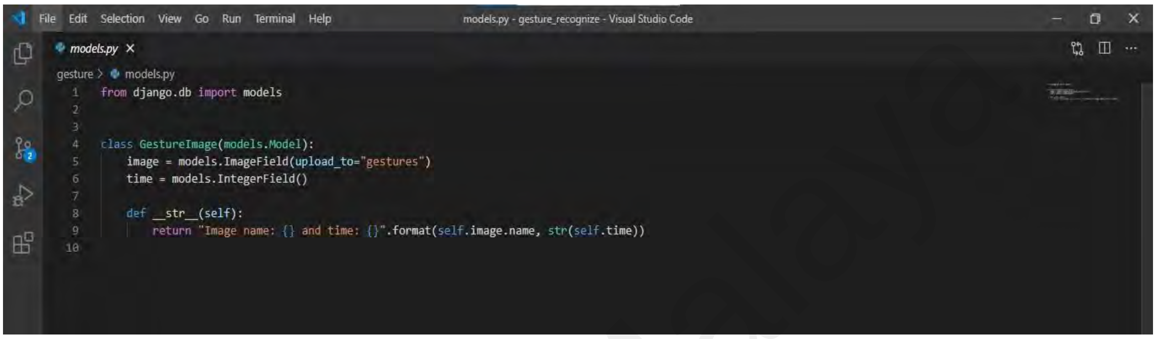


Figure 5. 14: Model Class

5.11.2.3 Template component

The following Figure 5.15 refer to the design and function in the front end of the system.

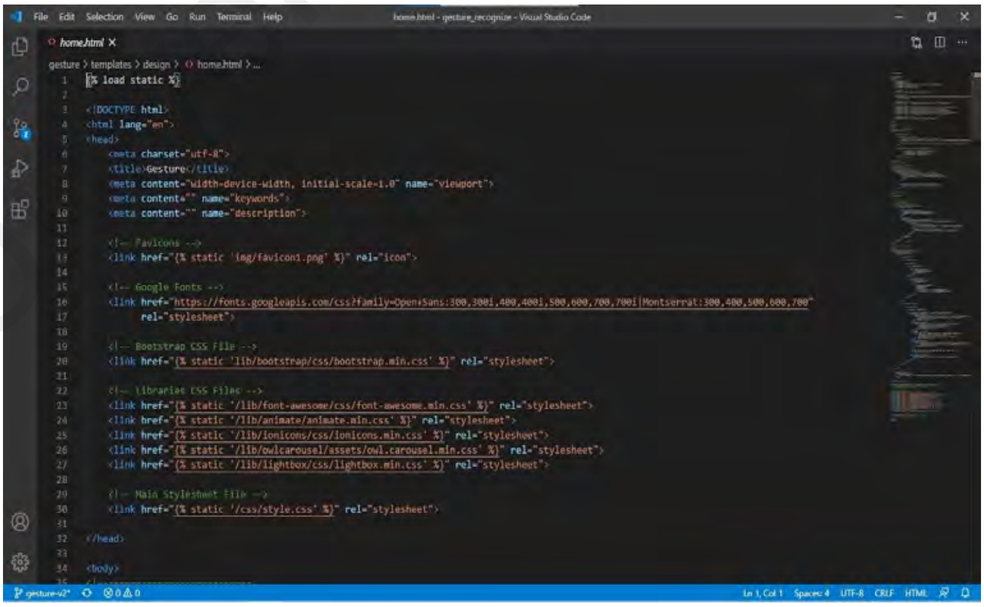


Figure 5. 15: HTML

5.11.2.4 Gesture Recognition Library

The library of gesture recognition is a prerequisite for detecting the condition of the hand, its location, and monitoring it. Functions for managing separate operating system processes are also be included.

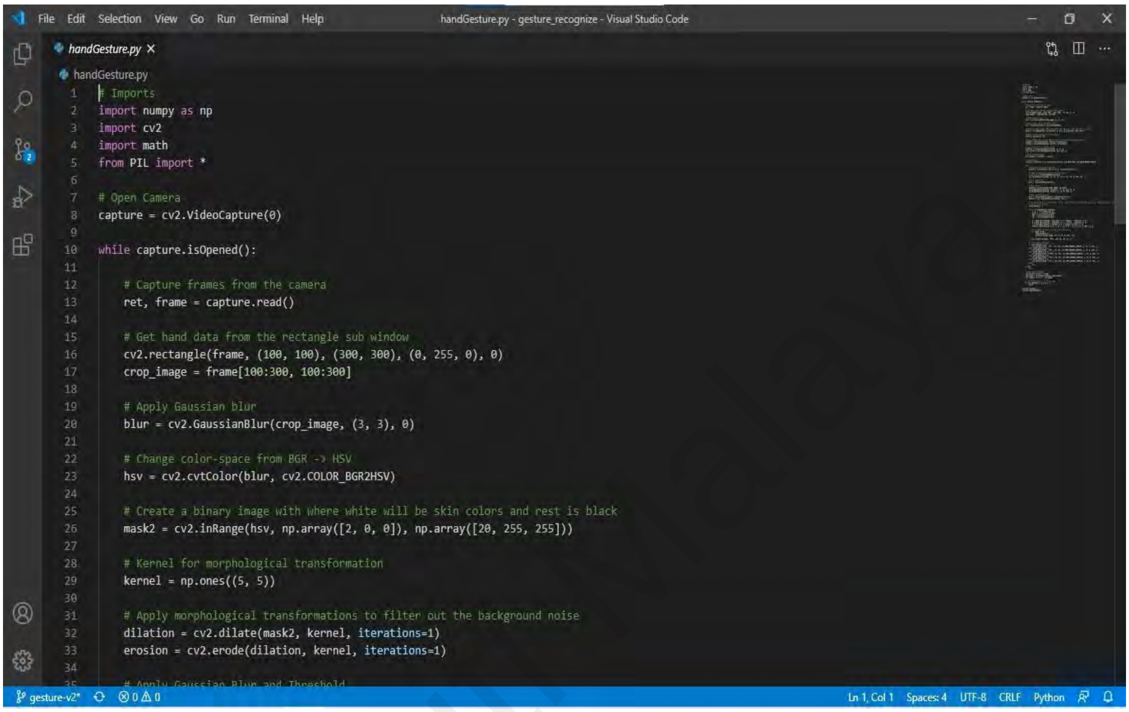


Figure 5. 16: Gesture recognition library

This section discussed and explained the design of the system, the development of the tool, and its implementation. Model design, formula design, device design, interface design, and the scope of user accessibility are explained in the design section. Begins development from scratch using the Python programming language on the MVT architecture of the Django system. In this portion, all significant components of growth are displayed in screenshots.

CHAPTER 6: TESTING AND EVALUATION

For testing of the prototype predicting fatigue in gesture recognition system, three testing methods were used as Unit Testing, System Performance Testing, and Integration Testing.

6.1 Unit Testing

Table 6. 1: Unit testing table with status

Test Case ID	Test Cases	Test Data	Expected Result	Actual Result	Status
TC1	Selecting image	Select "1" to perform the gesture	Retrieve the image id	Retrieve the image id	PASS
TC2		Select "5" to perform the gesture	Redirect to Gesture page	Redirect to Gesture page	PASS
TC3	Start Timer	Automatic start the timer	Timer started	Timer started	PASS
TC4	Enable camera	Camera enables upon landing	Camera On	Camera On	PASS
TC5	Recognize gesture	Show 2 with figure gesture in camera	Gesture Detected	Gesture Detected	PASS
TC6	Stop Timer	Press the "stop" button	Timer stopped	Timer stopped	PASS
TC7	Show result	Press the "Result" button	Actual time and taken time is displayed	Actual time and taken time is displayed	PASS
TC8	Get Time taken	Stop time at 0.10 second	Result: Time is taken 0.10 seconds	Result: Time is taken 0.10 seconds	PASS
TC9	Go to the next page	Press the "Next" button	Go to the Question page	Go to the Question page	PASS

Table 6.1, continued

Test Case ID	Test Cases	Test Data	Expected Result	Actual Result	Status
TC10	Submit answers	Click "Submit"	Answers are submitted	Answers are submitted	PASS
TC11			Redirect to the Result page	Redirect to the Result page	PASS
TC12	Result		View time is taken, actual time, and score	View time is taken, actual time, and score	PASS
TC13		Score is 15	Indicator show result based on the score	Indicator show result based on the score	PASS
TC14	Login	Username: User Password: 12345678	Login successfully	Login successfully	PASS
TC15		Username: User Password: 12345651	Wrong credentials	Wrong credentials	PASS
TC16	Gesture images	Go to "Gesture"	View list of the gesture image	View list of the gesture image	PASS
TC17	Remove image	Select gesture "Image name: gestures/GestureNo10.PNG and time: 10" and press "DELETE"	Delete gesture successfully	Delete gesture successfully	PASS
TC18	Add Gesture	Click "Add Gesture"	Go to add gesture page	Go to add gesture page	PASS
TC19	Upload gesture	Choose gesture for "9"	Uploaded successfully	Uploaded successfully	PASS

Table 6.1, continued

Test Case ID	Test Cases		Test Data	Expected Result	Actual Result	Status
TC20	Set Time	Set timer for the “9” gesture is 0.10 seconds.	Timer set successfully		Timer set successfully	PASS
TC21	View new add gesture	Add new gesture image “9” by admin	Gesture image “9” is visible		Gesture image “9” is visible	PASS

Table 6.1 shows the results obtained from Unit testing.

6.2 System Performance Testing

Test 1 (Figure 6.1):

● Number of threads (number of users connects to the target website): 1

● Ramp-up period (in seconds): 1 (Ramp-Up Period tells JMeter how long to delay before starting the next user)

● Loop count: 100 (1 user connection to the target website 100 times)

Error%=0.00

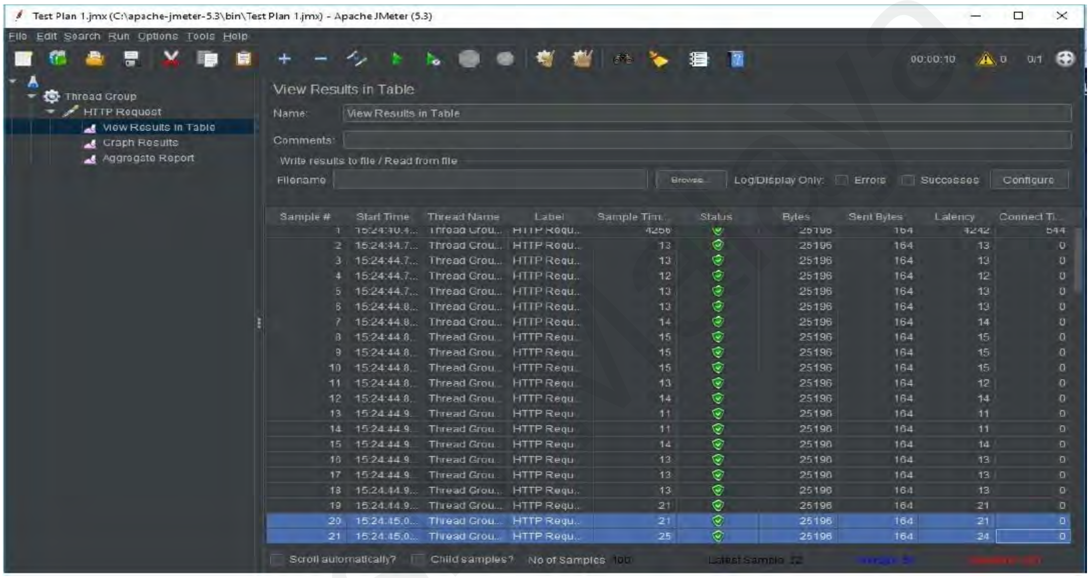


Figure 6. 1: Load Testing 1 result

To analyze the performance of the web server under test, you should focus on 2 parameters Throughput and Deviation. Throughput represents the ability of the server to handle a heavy load. According to Figure 6.2, throughput is 2543.451/minutes. It means this server can handle 2543.45 per minutes. However, deviation has value around 10 is shown in red - it indicates the deviation from the average.

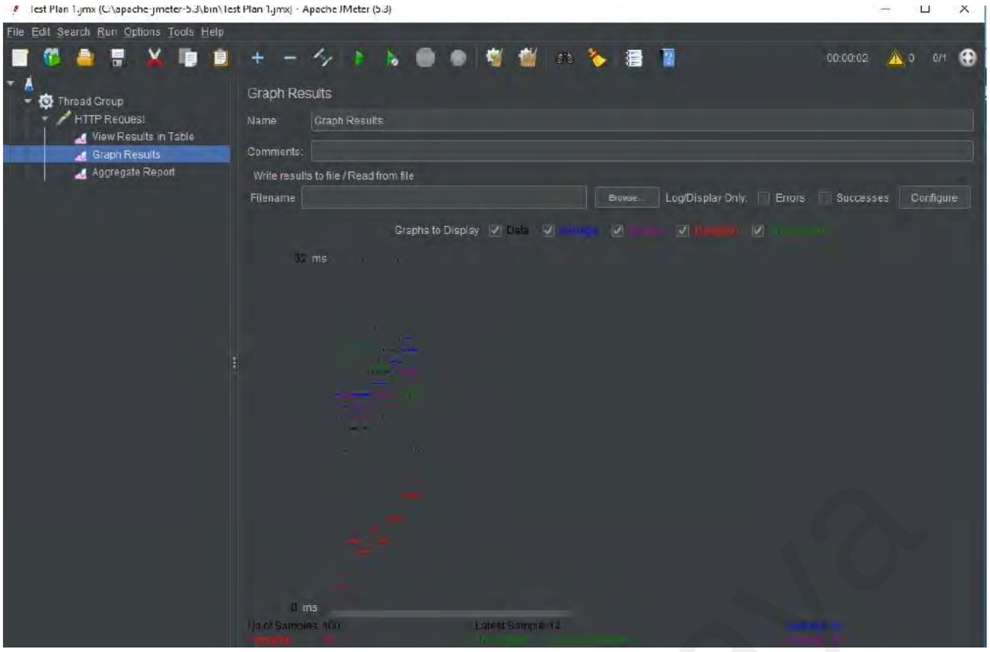


Figure 6. 2: Load testing Graph Result

Test 2 (Figure 6.3):

- Number of threads (Number of users connects to the target website): 5
- Ramp-up period (in seconds): 1
- Loop count: 500

Error%=0.00

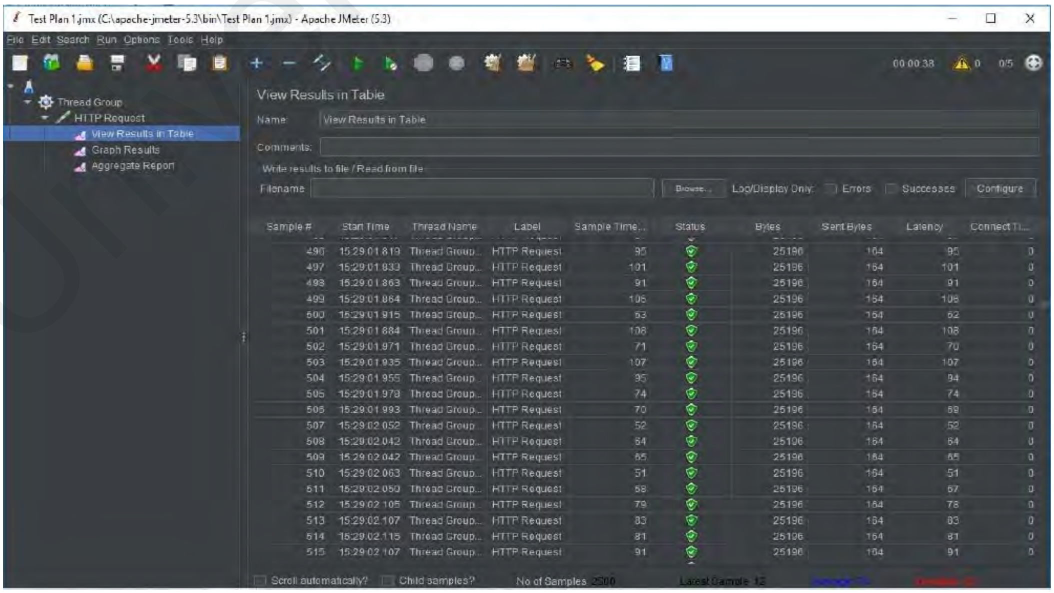


Figure 6. 3: Load Testing 2 result

To analyze the performance of the web server under test, you should focus on 2 parameters Throughput and Deviation. Throughput represents the ability of the server to handle a heavy load. According to Figure 6.2, throughput is 3,723.003/minutes. It means this server can handle 2543.45 per minutes. However, deviation has value around 24 is shown in red - it indicates the deviation from the average.

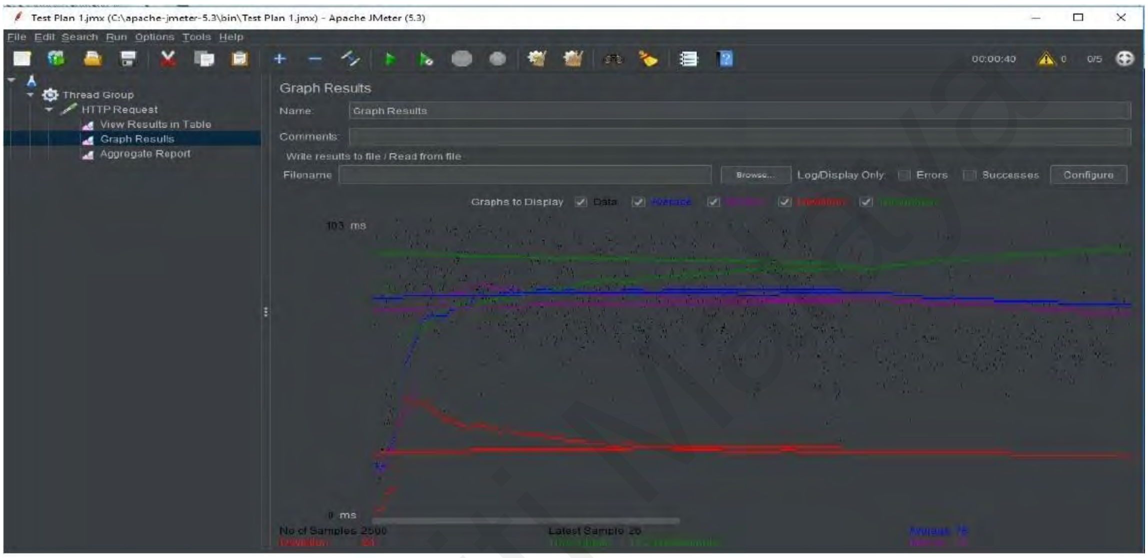


Figure 6. 4: Load testing Graph Result

6.3 Integration Testing

After the module test was done the Predict Fatigue model was integrated within the server and to access frontend HTML, CSS was used. Django views were properly integrated with its template and models. Henceforth, all the values generated by the modules can communicate with each other where necessary, and pass necessary information is tested and found to be accurate. This integration was alpha tested by other developers and admin.

6.4 Usability Testing

Interface for Predicting Fatigue in Gesture Recognition System has been designed to help users to be able to navigate and understand the ultimate objectives without having to prompt externally. There is a questionnaire for the users to fill out and get user data after inputting gestures which helps the user to understand the goal properly. On the final page, a meter is used to show the existence of fatigue that occurred by the given gesture. Questions are attached in Appendix B (II).

5 university students, 5 IT professionals and 4 university lecturers used and checked the functionalities of the software to define usability. The Table has been added at the end of this document in Appendix C. They were requested to fill out a questionnaire after using the tool to evaluate. The evaluation questions were divided into sections based on their aspects. Sections were named as, General Aspect, System Navigation and Evaluating the tool. In the questionnaire the options were given from the scale of strongly disagree to strongly agree where strongly disagree was given the number of 1 on a scale of 5, disagree as 2, neutral as 3, agree as 4 and strongly agree as 5. The average response based on aspects is given in tabular format in the next sections. From the response numbers it is safe to indicate that the participants have agreed upon the usability of the system and reaching the objectives through this.

6.4.1 General Aspects:

The average score of participants' answers in this aspect is 3.925 out of 5 which is 78.5% of the total score. This result indicates the successful ability of this system to pass all the general aspects.

Table 6. 2: Average score of general aspects testing

No	Questions	Average Score
1	Ultimate goal of the system can be easily understood	4.0
2	Adequate content to understand every detail	3.7
3	UI/UX of the system is user friendly	4.1
4	Design of the system defines the objectives clearly	3.9

6.4.2 System Navigation

The average score in this aspect shows to be 4.175 out of 5 which is 83.5% of the total score. This score fairly indicates the acceptance of users in this aspect after using the system.

Table 6. 3: Average score of system navigation testing

No	Questions	Average Score
1	Navigations of the system are easily recognizable	4.1
2	Placement of buttons are reasonable	4.2
3	No disintegrated buttons are available	3.9
4	Home button is available in every page	4.5

6.4.3 Evaluating the tool

Average score in this aspect is 3.95 out of 5 which is 79.1% of the total score. This indicates the positive response from the users regarding the evaluation of this system.

Table 6. 4 : Average score of evaluation testing

No	Questions	Average Score
1	System can be used without any external prompt	3.5
2	Inputs are dealt in required order	4.1
3	Response rate of the system is satisfactory	3.7
4	Gestures are explained properly inside the system	4.2

Table 6.4, continued

No	Questions	Average Score
5	Camera in gesture input screen works properly	3.5
6	Questionnaire is relevant with system objective	4.2
7	Fatigue calculation final page shows the ultimate result	4.5

6.5 Summary

The usability test of the system was done in this section to understand the effectiveness of the tool. The test was conducted with 5 university students, 5 IT professionals and 4 university lecturers. The average score in all three of the aspects was ranging from 3.9 to 4. 2 which indicates the complete usability of this system. Usability test results are available at Appendix C.

CHAPTER 7: CONCLUSION

The conclusion instigates with revisiting the objectives of this research. The following are then on the consequence and afterward the research challenges and scope of improvements.

7.1 Research Achievements

The main purpose of the present research was to identify the existing hand gesture signals already in use for human-computer interaction through extensive research in related work and application areas of the gesture recognition system. Through research questions related to hand gesture signals and literatures based on fatigue criteria, using task analysis method results were found for all research questions.

Identifying the fatigue criteria in hand gesture recognition was found through the research questions from the related literatures based on sign language interpreters and survey based on professionals using the hand gesture signals for human-computer interaction.

The second purpose of the research was to design, develop and evaluate a prototype that can take user input of hand gesture signals and identifies the time taken to perform the hand gesture signal and then compare with the standard task time received from the Cogulator tool. After comparing the task time, the user can answer the questionnaires based on fatigue criteria. After receiving all data from the user, the system can predict the fatigue for the hand gesture signal and provide a result at the end of the task. Finally, the entire tool has been successfully built with OpenCV library and Python Django framework.

Objective-1

- **<u>To identify existing hand gesture signals used in Human-Computer Interaction among applications of Gesture Recognition System.</u>**

In literature review all the application area of hand gesture signal was identified, there are seven application areas where hand gesture signals are used. These are described in Section 2.2 in Chapter 2. Among these application areas a total of twenty-nine hand gestures were found (Section 2.3 in Chapter 2) which can be divided into two categories: Upper Chest Gesture and Lower Chest Gesture. These unique hand gestures are in use in different application areas and these hand gestures perform different task under different application area of the hand gesture recognition system.

Objective-2

- **<u>To predict fatigue criteria for hand gesture signals in Gesture Recognition System.</u>**

Fatigue criteria were identified from the literatures related to hand gesture signals and studies on hand, wrist, and arm diseases based on sign language interpreters. In the preliminary stage, participants took part in the survey to answer questionnaires based on fatigue criteria identified from related litterateurs. In section 2.7 of Chapter 2, summary of fatigue criteria is described. In total of 5 fatigue criteria was observed among the users Based on the fatigue criteria a fatigue predictive model is proposed in section 4.5 in Chapter 4.

Objective-3

- **<u>To design, implement and evaluate a prototype to analyze fatigue in a gesture recognition system.</u>**

The prototype developed meets the proposed requirement of objective 3. The standard task time received from Cogulator tool for each 29 hand gesture signals and fatigue criteria was used to calculate the result for the possibility of fatigue during using the hand gesture signals. Using the proposed fatigue predictive model, the tool is capable to provide a result against a particular hand gesture signal if it will cause fatigue for the user or not. The tool will identify the hand gesture in front of the camera and will record the task time, then it will compare with the standard task time recorded from Cogulator tool. Then the participant will be asked to answer 5 questions based on fatigue criteria. After receiving the questionnaire result the prototype will analyze the results from task time and 5-point Likert chart, and it will show the result is a gauge meter. There are 2 zones shown in the gauge meter: Green for non-fatigue gesture and Red for fatigue gesture. If the pointer in the gauge meter indicates to the red zone that means the selected mid-air gesture is fatigue, and if the pointer indicates to green zone that means there is less chance of fatigue. It will allow the manufacturers to choose suitable hand gesture signals to implement in hand gesture recognition system.

7.2 Significant of Study

The literature review study extends existing knowledge about the fatigue issue taking place for doing midair hand gesture signals in the field of human-computer interaction. This study will add immense knowledge on the ergonomics of hand gesture signals. Along with that this study also identifies the criteria of fatigue in various types of hand gesture signals. This study gathers all the existing hand gesture signals that are already in use in the industry, this will help the manufacturers to determine and remove those hand gesture having extensive muscle movement, and this study predicts hand gesture fatigue from program codes through an assistive tool. The novelty in this study is that for the first time a system can predict fatigue for hand gesture signals which could have a much bigger allegation in the human-computer interaction industry by adding deep learning AI function.

Comparing the taken time in the prototype and standard task time and based on the information from fatigue criteria, now human computer interaction industry or manufacturers can easily discovery which hand gesture signal is healthy to implement in the systems and which signals need to be removed immediately.

7.3 Research Challenges

A limitation of the current study is that there are not many papers available on the midair gesture signal, very less study has been conducted on the fatigue issue for hand gesture signals. There are many studies available for sign language interpreters based on fatigue but for the field of Human-computer interaction very less study has been conducted.

The major challenge was to make participants understand the concept of fatigue while performing hand gesture signals. As lot of professional's face fatigue because of hand gesture signals but most of them believes that this fatigue might be a case of other health-related issues they are having.

7.4 Scope of Improvements

The systems functionality is limited to python programming for the moment. Later, other programming languages like Java, PHP can be added as a functioning platform.

In the intervening, it does not verify whether a proposed objective has been achieved through programming, rather it processes based on keywords, functions, loops, conditions etc. used. Hereafter, there is a scope to improve it by confirming whether the proposed objective of the system has been achieved or not.

The system is not able to analyze hand gesture signal postures for the moment, Later, deep learning AI functions can be used to determine hand postures and advise the user to correct the postures.

In future all kind of hand gesture signals can be tested before it is implemented in the industry of Human-Computer Interaction, and it is possible to know if that gesture signal may or may not produce fatigue among users.

7.5 Conclusion

Hand gesture signals are mostly taken from American sign language thus it never went under any testing or proper ergonomics that how the extensive and long hour movement of the hand muscles will affect the end-users. IT professionals may have to use hand gesture signals in near future, hand gesture signals are already implemented in big factories, before hand gesture signals are taking over mouse and keyboard proper hand gesture signals should be adopted in the industry. This study will help to determine the criteria to adopt a hand gesture signal which has less effect in use for long time for IT professionals.

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