Degree/Major: Bachelor of Electrical and Electronic Engineering (BEng Hons)

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Design and Implementation of a Smart Glove Wearable Aid for Hand Gesture Recognition

1. ABSTRACT

Gestures encompass expressive and concise form of human motion that can involve signals of the fingers, hands, arms, head, face, or body and act as a communication technique to be reconstructed by the recipient [2]. In modern times, extensive research and various approaches have been taken towards Hand Gesture Recognition (HGR), where its applications hold significant importance across various sectors, notably gaming, medical and auto driving systems [1]. This research project aims to address the communication barriers faced by impaired individuals, by providing an intuitive and accessible means of expression. This is performed through the design, implementation and evaluation of a gesture recognising smart glove wearable device for practical applications such as Sign Language Recognition (SLR). This smart glove contains a sensor network compromised of Inertial Measurement Units (IMUs) and flex sensors which are captured by a microcontroller for feature extraction, gesture classification and mapping onto speech synthesis technologies.

Index Terms—Hand Gesture Recognition (HGR), Finger Tracking, Sign Language Recognition (SLR), Wearable Internet of Things (IoT) Devices, Sensor Networks.

2. BACKGROUND

Communication is commonly described as the transmission of information between individuals or groups. It comprises of a sender, a message, and a receiver with the purpose of an understanding [9]. Non-verbal communication, utilising hand gestures, facial expressions and body language can be used to assist individuals with speech or hearing impairment to communicate amongst themselves and with others. Sign languages, such as Australian Sign Language (Auslan), use manual communication through an organised collection of such gestures [9]. These languages are continually evolving over time due to cultural and linguistic norms, and to meet the communication needs of deaf and mute individuals [9]. The problem arises due to the lack of sign language knowledge amongst verbally communicating individuals. This can be solved using a technology-driven solution to facilitate seamless communication and translate gestures into widely spoken languages such as English.

2.1. Anatomy of the Human Hand

The human hand is comprised of the carpus (palm) region, the metacarpus (in between the carpus and the knuckles) and the fingers. The four fingers are divided into three phalanges (segments) and the thumb contains two phalanges [5]. Starting from the fingertip, these are described as the distal (proximali), middle (medialis), and proximal (proximalis) phalanx [5]. The two hinge joints separating the phalanx on the four fingers are called distal (DIP) and proximal (PIP) interphalangeal joints respectively [5]. The saddle joint connecting the metacarpals to the phalanges are called metacarpal-phalangeal (MCP) joints. The thumb consists of a distal and proximal phalanx, a single hinge MCP joint as well as a spheroidal ball (thumb-carpo-metacarpal, T-CMC) joint connected to the carpals with three degrees of freedom [5]. The anatomy model of human hand movement can be classified into abduction/adduction finger movement, ulnar/radial deviation of the wrist, wrist extension and wrist flexion as well as finger flexion and finger extension [5].

2.2. Implementation of Human Gesture Recognition

Similar to a generic human sensory information processing model, the HGR process for the smart glove can be described four key steps: data collection, feature extraction, classification, and mapping [4]. Data collection is described as the input of raw sensor data. In the case of HGR, this can be performed using a conventional ambient sensor (i.e., images) approach or a wearable sensor system approach [1, 3].

2.2.1. Ambient Sensors

In previous studies non-contact-based systems analyse a series of sensory data through Deep Leaning methods captured through integrated environmental sensors, such single cameras, and stereo cameras [3]. Modern algorithms such as Media Pipe Hands and InterHand2.6M are modern machine learning solutions that operate using a single RGB camera and feature extract a human hand based on a training set [1,3]. Image based HGR solutions are restricted to pre-definition contexts, requiring specific lighting and environments such as rooms and apartments. It would also not be feasible for use in places such crowded areas as there would be interference from other individuals. Comparatively, they tend to be less user-friendly and are not a feasible portable solution and might increase users' privacy concerns.

2.2.2. Wearable IoT Device

The second method includes wearable devices such as smart gloves, bands and mobile devices [1]. In recent years, Internet of Things (IoT) devices have become increasingly prevalent, as they become more affordable, integrated with standalone microprocessors, memory, Wi-Fi, and loaded with capabilities such as microphone, IMUs, light sensors etc [1]. IoT can be implemented in such a way to generate a modular, portable unit that utilises a smart sensor system for real-time motion tracking of the finger and wrist joint movements as well as the location of the hand in reference to the body of the individual, capturing the required data for HGR.

3. METHODOLOGY AND METHODS

As discussed in section 2.2, the solution derived by this research paper will contain an implementation of each of the four stages that contribute together to form the final HGR processing prototype. To simplify the model, this research paper will first focus primarily on one handed gestures. The purpose of this paper is to discuss and investigate the most feasible solution dependant on an ideal criterion. The methods prescribed in this section will be used for iterative prototype development and each will be compared in the final report.

3.1. Methodology criterion

The methodology for the smart glove will be evaluated using the following criteria, assessing its practicality in the use case of SLR. This following list is ranked in order of importance and will be discussed further in the literature review.

1) Gesture Recognition accuracy.
2) The results must be reliable and reproducible and robust to environmental conditions.
3) The smart glove must be user friendly.
4) The cost of sensory and computational hardware and scalability in manufacturing.
5) Adaptability with user requirements such as hand size.
6) Components must be energy efficient for battery-powered constraint.

3.2. Data Collection

Several methods have been researched for the collection of data to track the position of the hand and the orientation of the phalanx in 3-D space. For proof of concept, the following finger orientation model using flex sensors will be used in the first prototype, and a more accurate model, the IMU sensor network method will then be prototyped for discussion in the thesis.

3.2.1. Finger Orientation Model Using Flexible bend Sensors

A flex sensor can be modelled as a variable resistor, where its total resistance is proportional on its radius of curvature, or the amount of bending [6], and can be used to measure finger joint movements. A flex sensor can be implemented in a voltage divider circuit with its output digitalised by an Analogue to Digital Converter (ADC). The output voltage across the flex sensor can be captured using a microcontroller, such that:

$$V_{out} = V_{in} \frac{R_o}{R_o + R_{flex}}$$

The output voltage value can be used to categorise the posture of the finger, relative to the amount of bending of the DIP, PIP, and the MCP. Bhaskaran's model using a single flex sensor for each finger classifies four discrete voltage ranges dependant on the amount of bending of the combined finger joints [5]. Flex sensors are lightweight and can be a very cost-effective solution, however they lack precision due to the inelastic properties of the plastic component after continual use. The discrete nature of the flex sensor model also poses inaccuracies of the detected posture.

3.2.2. Finger and hand orientation/position with IMUs

Advancement in semiconductor technologies have adopted IMUs, which have been used in some studies to track finger joint movement [5], spine posture and hand movement [6] 3-D space. Typically, smart gloves are equipped with a network of 9-axis IMU sensors, each consisting of 3 accelerometers, 3 gyroscopes and 3 magnetometers that output the acceleration, angular velocity, and magnetic field respectively [8]. The position and orientation of the IMU can be obtained by the integration of the accelerometer and gyroscope data over time, and the relative orientation to the Earth's magnetic field can be obtained using the magnetometer [6]. Integration over time cause drift issues in the calculated data, and hence Filtering such as Kalman and Complimentary can be used for data fusion and the minimisation of error [6]. Recent research has shown that an IMU can be placed on each MCP, PIP and DIP for a more accurate finger joint calculation [5, 6].

3.2.3. Other data collection methods

Other data collection methods such as using a CMOS camera, EMG sensors, a leaf switch-based glove and a copper plate-based glove [6] will also be discussed in the literature review and their suitability discussed in more detail.

3.3. Data Processing and Feature Extraction

Monitor software such as LabView or MATLAB can be used to integrate data received from a connected microcontroller through a serial UART connection and map data to a Graphical User Interface (GUI) for monitoring and analysis [8]. By comparing the results obtained from the various sensing methods with measured values, this paper will aim to determine the most effective solution for obtaining accurate joint angles and hand orientation data.

3.3.1. State Estimation Algorithm

The accelerometer values alongside angular roll, pitch and yaw values can be used to identify the location and orientation of the hand in three-dimensional space [6]. Using these values, the Range of Motion (ROM) of the hand relative to the body can be split into a discrete set of states, each bounded by an area of variable size. The algorithm is then able to classify whether the gesture is static or dynamic depending on whether the hand is in the same position for a given amount of time. Bhaskaran's model [6] pre-defines a set of states and uses an IMU located on the forearm to calculate the position of the hand in a 3-dimensional environment. The program then uses values from the IMU and the flex sensor to find a pattern of states over a given amount as well as their corresponding finger joint positions for any combination of static and dynamic gestures.

4. OBJECTIVES

The main objectives of this research paper are outlined as follows:

- Continuation of background research reflected through a literature review to explore additional modern solutions for data capture, feature extraction, classification, and mapping.
- Criterion analysis of existing solutions to determine the ideal methodology, considering 3.1.
- Prototyping of the smart glove will be a continuous process throughout the development of this research paper, and multiple methods of data collection are to be tested and discussed.
- Development of visual and auditory feedback for the glove through desktop software including a GUI.
- Research and software development of most accurate Feature Extraction methods using chosen sensors.
- Complete evaluation of the usability and accuracy of the smart glove gesture recognition functionality of each the prototypes, and a comparison with alternate solutions.

Sub objectives of this research paper are as follows and will be completed based on project 1 technical progress:

- Development of a wireless communication medium between the smart glove and the parent device for real-time data transmission.

- Development of an accessible user interface through the development of a mobile software application for Android.
- Design of a final Printed Circuit Board (PCB) using computer aided modelling software such as Altium or SolidWorks PCB.
- Evaluate the reliability and usability of the smart glove gesture recognition functionality through user feedback under various conditions.
- Further investigate applicable use cases for the final developed technology.

5. EXPECTED OUTCOMES

The expected outcome of this research paper is to develop a functional prototype of a feasible smart glove capable of clinical accuracy through the detection and interpretation of a predefined set of hand gestures. This smart glove will collect data through a network of sensors, and software development will be implemented onto a microcontroller incorporating sensor fusion and a feature extraction algorithm, which will be used to classify gestures. The final step is to map the recognised gestures onto speech synthesis technologies.

6. RESOURCES

The following resources are required for the testing and prototyping of the smart glove:

6.1. Sensors
- 4×4.5” Flex Bend Sensors for Finger joint measurement prototype.
- 1×2.2” Flex Bend Sensor for Thumb joint measurement prototype.
- 6× GY-9250 IMU for finger joint measurement prototype of two fingers.

6.2. Data Capture
- Arduino nano Altmega328.
- 5×100kΩ Resistors.
- Breadboard.

6.3. Software
- Arduino IDE.
- MATLAB.
- LabView.

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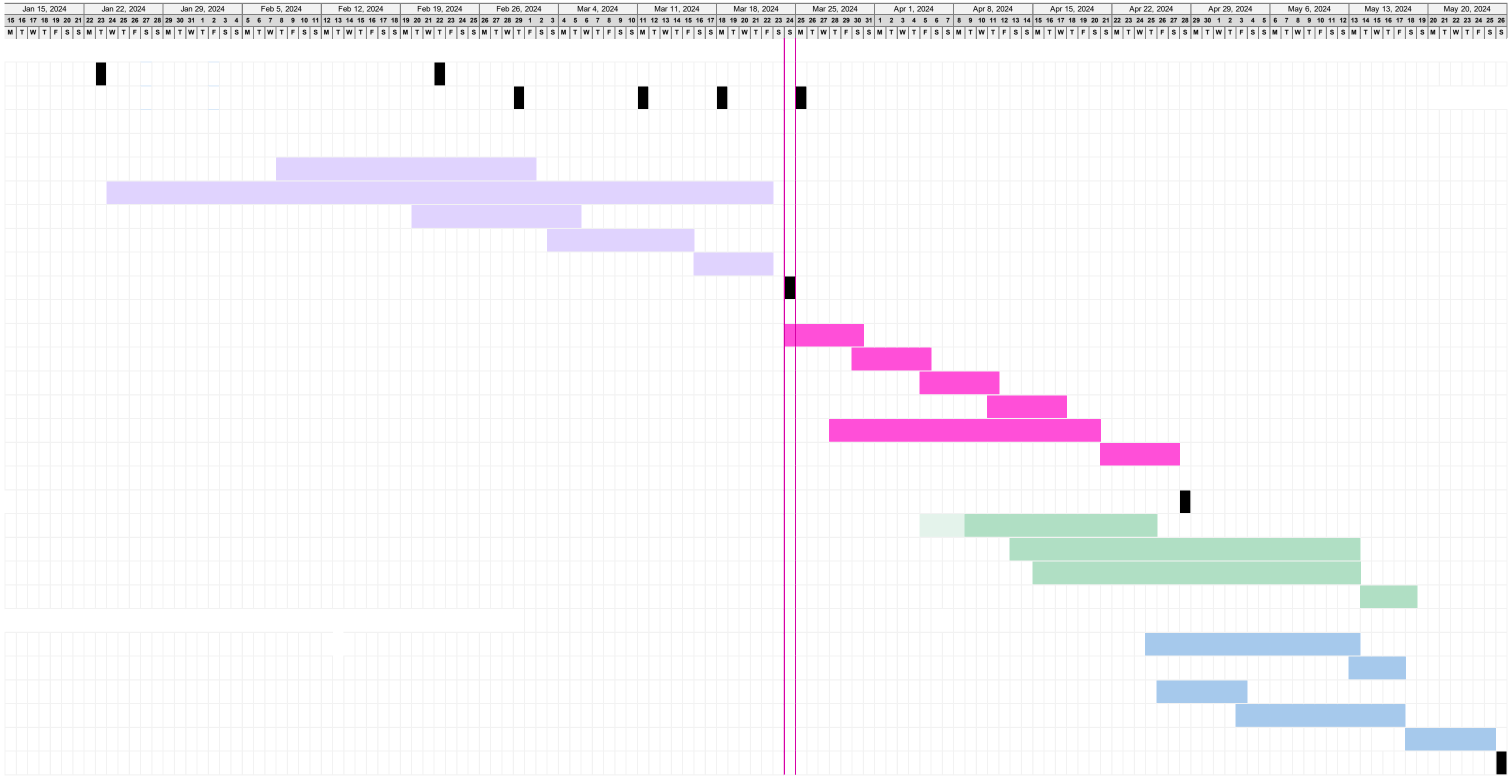
APPENDIX A - RESEARCH PROJECT 1 GANTT CHART

Smart Glove Hand Gesture Recognition **Tue, 1/23/2024**

Research Project 1 Gantt Chart

Khaled Ali Zulfikar 20166322

TASK	PROGRESS	START	END
Thesis Meeting Schedule			
Initial Meetings with Siavash Khakhsar			
Progress Meetings with Wrist Rehabillitation Research Team			
Meeting Summary Report			
Project Proposal			
Problem Identification	100%	2/8/24	3/1/24
Background Research	100%	1/24/24	3/22/24
Indentifying Project Objectives	100%	2/20/24	3/5/24
Proposal Draft	100%	3/3/24	3/15/24
Feeback and Review	100%	3/16/24	3/22/24
Project Proposal Submission		3/24/24	
Literature Review			
Smart Glove Criterion Research	10%	3/24/24	3/30/24
Data Collection Methods	10%	3/30/24	4/5/24
Feature Extraction Methods	10%	4/5/24	4/11/24
Gesture Classification Model	10%	4/11/24	4/17/24
Literature Review Draft	**0%**	3/28/24	4/20/24
Feeback and Review	**0%**	4/21/24	4/27/24
Literature Review Submission		4/28/24	
Project 1 Technical Development			
Purchase Resources for Project 1	20%	4/5/24	4/25/24
Flex Sensor Glove Prototype Development	0%	4/13/24	5/13/24
Feature Extraction Algorithm Software Development	0%	4/15/24	5/13/24
Mapping Software Development	0%	5/14/24	5/18/24
Final Project 1 Report			
Methodology Report	0%	4/25/24	5/13/24
Discussion of Results from Technial Progress	0%	5/13/24	5/17/24
Complete Set of Aims for Project 2	0%	4/26/24	5/3/24
Draft	0%	5/3/24	5/17/24
Feeback and Review	0%	5/18/24	5/25/24
Project 1 Report Submission		5/26/24	



APPENDIX B - RESEARCH PROJECT 2 GANTT CHART

Smart Glove Hand Gesture Recognition

Project start: **Mon, 7/1/2024**

Research Project 2 Gantt Chart

Khaled Ali Zulfikar 20166322

TASK	ASSIGNED TO	PROGRESS	START	END
Project 2 Thesis				
Further Background Research		0%	7/1/24	7/15/24
Secondary Prototype		0%	7/16/24	8/10/24
Results and Discussion		0%	8/5/24	8/19/24
Finalise Thesis		0%	8/20/24	9/19/24
Finalise IEEE Thesis		0%	9/20/24	9/27/24
Feeback and Review		0%	9/28/24	10/5/24
Final Thesis Submission		0%	10/25/24	
Presentation				
Lecture Slides		0%%	10/6/24	10/9/24
Rehearsal		0%%	10/10/24	10/24/24
Final Presentation			TBA