3-2-2021

Incorporating Modular Arrangement of Predetermined Time Standard with a Wearable Sensing Glove

Veda Rasmi Mallembakam
University of Windsor

INCORPORATING MODULAR ARRANGEMENT OF PREDETERMINED TIME STANDARD WITH A WEARABLE SENSING GLOVE

By

Veda Rasmi Mallembakam

A Thesis

Submitted to the Faculty of Graduate Studies
through the Industrial Engineering Graduate Program
in Partial Fulfillment of the Requirements for
the Degree of Master of Applied Science
at the University of Windsor

Windsor, Ontario, Canada

2020

INCORPORATING MODULAR ARRANGEMENT OF PREDETERMINED TIME STANDARD WITH A WEARABLE SENSING GLOVE

By

Veda Rasmi Mallembakam

APPROVED BY:

J.Cort
Department of Kinesiology

J.Urbanic
Department of Mechanical, Automotive and Materials Engineering

B.A. Schuelke Leech, Co-Advisor
Department of Mechanical, Automotive and Materials Engineering

E.Kim, Co-Advisor
Department of Mechanical, Automotive and Materials Engineering

October 07, 2020

DECLARATION OF ORIGINALITY

I hereby certify that I am the sole author of this thesis, and that no part of this thesis has been published or submitted for prior publication.

I certify that, to the best of my knowledge, my thesis does not infringe upon anyone's copyright nor violate any proprietary rights, and that any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices. Furthermore, to the extent that I have included copyrighted material that surpasses the bounds of fair dealing within the meaning of the Canada Copyright Act, I certify that I have obtained a written permission from the copyright owner(s) to include such material(s) in my thesis and have included copies of such copyright clearances in my appendix.

I declare that this is a true copy of my thesis, including any final revisions, as approved by this committee and the Graduate Studies office, and that this thesis has not been submitted for a higher degree to any other University or Institution.

ABSTRACT

"Performance" – a common watchword in the present age, and that which is optimized through the most functional methodology of investigating the work procedure. This encompassed the auditing, updating of the tasks, while at the same time, applied automation and mechanization. The Modular Arrangement of Predetermined Time Standard (MODAPTS) is a useful application of a work measurement technique that allow a greater variety of work for manufacturing, engineering, and administrative service activities to be measured quickly with ease and accuracy. The MODAPTS, however, made it extremely difficult for engineers to use because it required an ample amount of time to analyze and code the raw data. A new design was proposed to help resolve the conventional system's inadequacy because in MODAPTS, each task cycle of a minute required about 2 hours to calculate and document, and also, the judgment of the analysts varied for the same task. This study aimed to reduce the time taken for the traditional MODAPTS documentation usually took and produced unified results by integrating MODAPTS with a Sensing Wearable Glove while maintaining the same performance. The objective was to introduce an easy, cost-effective solution, and to compare the accuracy of coding between manual and automated calculated MODAPTS while maintaining the consistent performance. This study discusses the glove and accompanying software design that detected movements using flex sensors, gyroscopes, microcontrollers, and pressure sensors. These movements were translated into analog data used to create MODAPTS codes as an output, which then sent the data wirelessly using the Bluetooth module. The device designed in this study is capable of sensing gestures for various operations, and the traditional method was compared to the proposed method. This was in turn, validated using the two-way ANOVA analysis. It was observed that the sensor-based glove provided efficient and reliable results, just like the traditional method results while maintaining the same performance.

DEDICATION

This Paper is dedicated to my father **-Rama Mohan Mallembakam**, my mother-**Anupama Mallembakam**, my brother-**Adithya Mallembakam** and my well wishers-**Suparna and Sowjanyamma.**

ACKNOWLEDGEMENTS

I want to thank my supervisors Dr. Beth-Anne-Schuelke Leech and Dr. Eunsik Kim, for their constant support and motivation. I want to thank Dr. Beth-Anne-Schuelke Leech for taking me as her student and supporting me in my low sides and guiding me from day one. Dr. Kim, for assisting me with the designs and concepts. I am very thankful for their help and for being available every time I needed their guidance. It would not be possible for me to complete this project without their assistance.

I want to thank Dr. Urbanic and Dr. Cort for serving on the committee panel and providing helpful suggestions.

I want to thank Mr. Calvin Love, an electronics technologist from the University of Windsor, for helping me with the circuits.

I want to show my gratitude to Ganapathi, who helped me with the coding and continually questioning the work, which allowed me to correct my wrongdoings and helped me learn.

I want to thank my parents for their financial and moral support, their belief in me, and for standing by my side during the hard times.

I would also like to thank my friends Adithya, Akil Ravi Varma Mandapati, Bhuvan Shyam Reddy, and Chenna Malleshwar Reddy for supporting me continuously.

Most importantly, I would like to thank God for strengthening me in my difficult times.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Numerous terms used in this thesis have explicitly been defined here to prevent confusion and to provide a richer understanding of the text.

System:

A system is an organized and co-ordinated method or procedure that has been formulated to accomplish a specific task. In the context of this thesis, the system refers to the group of interrelated and interdependent hardware and software components that are functionally connected and grouped together in order to execute the required analyses [1].

Productivity:

It is defined as the measure of efficiency with which an activity converts inputs into value added outputs. Productivity is a relative measure. As a result, the values themselves have little meaning. The values need to be compared with one another in order to be used [2,3].

Traditional measurement:

These are manually performed studies. They are typically the original concept.

Analysts:

Refers to any person that performs out analysis on labourers.

Accuracy:

It is the closeness with which the measurement of an element matches the true or actual value.

Methods-Time-Measurement:

A predetermined time standard used to predict the standard time of performing manual operations – it is one of many PTS systems [4].

Modular Arrangement of Predetermined Time Standards (MODAPTS):

A system of codes used to predict a reasonable time for an action to be completed. MODAPTS is one of many types of PTS systems [5].

Predetermined Time Standard (PTS):

A PTS is a work measurement technique whereby times established for basic human motion are used to build up the time for a job at a defined level of performance [6].

Time standard: The predetermined time in which an action, task or job has to be completed

Get: actions required to grasp an object.

Put: actions required to place an object.

Principal Component Analysis:

Principal component analysis (PCA) is a method utilized for distinguishing smaller number of uncorrelated factors known as main components from a larger set of data. The technique is widely used to emphasize variation and capture strong patterns in a data set [7].

Action recognition:

Activity recognition aims to acknowledge the activities and objectives of one or a lot of operators from a series of observations on the specialist' activities and therefore the natural conditions. Since the 1980's, this analysis field has captured the eye of numerous computer science communities, thanks to its strength in providing personalised support for several different applications and association to wide range of fields of study for example, medical, human-PC connection or sociology.[8]

Wearable technology:

Wearable technology, wearables, style, innovation, tech togs, or design, hardware are smart electronic gadgets (electronic gadget with micro-controllers) that are worn close to and/or on the surface of the skin, where they recognize, break down, and transmit data concerning e.g. body signals such as crucial signs as well as surrounding information and which allow in some cases quick biofeedback to the wearer [9].

Resistor:

A resistor may be a two-terminal electrical part that implements ohmic resistance as a circuit part. In electronic circuits, resistors are utilized to diminish current stream, alter signal levels, to partition voltages, bias dynamic elements, and terminate transmission lines, among alternative uses. [10].

Serial communication:

It is a process of transmitting a bit of data at a time [11].

CHAPTER 1

INTRODUCTION

1.1 Background

There were numerous approaches for measuring and tracking motion and movement in manufacturing and production systems. Work measurement referred to the estimation of the time needed by qualified workers to perform a specific task at a specified level of performance [12].

MODAPTS (Modular Arrangement of Predetermined Time Standards) is a work measurement technique that allows activities to be measured quickly with ease and accuracy [12]. MODAPTS is a third-generation predetermined time system (PTS) used for: a) measuring accurate performance standards, b) increasing the efficiency of an organization, c) analyzing departmental standards, and d) improving employee relations [36]. It consists of predetermined codes for various physical movements – from moving specific parts of the body to performing specific operations, such as using a typewriter. In MODAPTS, these modules represent units of human physical function.

MODAPTS was founded on two principles. The first was that all body movements could be expressed in multiples of a single unit of time, called a MOD. This unit also demonstrated the time required to complete a simple finger movement. A single MOD holds a time value of 129 milliseconds or 0.129 seconds. MODAPTS were frequently used in production activities and non-cycle work environments. The second principle was that actions include some basic actions.

By analyzing how the work was performed, MODAPTS quantified the amount of time required to perform an assembly operation. As an analytical approach, MODAPTS facilitated the accurate measurement of movements, and supported a proactive design process. Although MODAPTS measured work without using a stopwatch, it was accurate enough for setting the labour rates in the industry. Thus, MODAPTS were used in analyzing safety, estimating direct labour costs, controlling quality, and establishing productivity standards. Conducting MODAPTS analysis often required extensive time and effort to yield reliable results because the data collection and evaluation process involved human observations and measurements [13]. This proved to be particularly true in dynamic environments, which involved many physically demanding manual tasks that then created vast amounts of data to collect, analyze, and represent [13-17].

Reliable and detailed results significantly improve interventions or new workplace designs. Accordingly, the development and use of methods to automate, simplify, and increase data collection and analysis accuracy would improve the adoption and use of MODAPTs, benefitting many smaller companies that cannot currently manage the MODAPTs costs. Therefore, this research proposes a low-cost system for evaluating manual operations to achieve more unified and reliable results by maintaining the same performance. The system proposed, involves a glove with a sensor used to automatically collect MODAPTs movement codes.

This research discusses the prototype glove and software design. The glove detects gestures using flex sensors, gyroscopes, microcontrollers, and pressure sensors. These gestures were then deciphered into analog data, which utilized MODAPTS codes, and then remotely sent to a laptop using the Bluetooth module. The device designed during this study detected gestures for numerous operations. In the traditional method, the analyst analyzed the operator's body movements and assigned the MODAPTs codes to these movements to then determine the overall performance. Though the MODAPTs analysts were experts in deciphering movements and assigning MODAPT codes, human analysts still made mistakes. More importantly, the analysis took a significant amount of time [13]. In the method proposed and analyzed in this thesis, the sensors on the glove detected the physical movements and codes were assigned, both automatically.

1.2 Problem Statement

There were many reasons for inconsistency in establishing labour standards using Predetermined Motion Time Study (PMTS). They included:

1. Variations in particular systems, (e.g., not clearly defining motion elements, ambiguous rules for work analysis, insufficient consideration of influential factors or elemental times with non-uniform performance levels).

2. Errors due to incorrect application of a given system, (e.g., when the working analyst did not recognize all motion elements in the course of the analysis or overlooked or misinterpreted certain work complications).
3. The analyst's inexperience in the interpretation of motion, which led to unreliable results. [19-22]

Modular Arrangement of Predetermined Time Standard (MODAPTS) is one of the many PMTS methods useful for explicitly evaluating operating time [23]. However, MODAPTS was a complicated system that took time to learn proficiently. MODAPT's required learning how to interpret the work elements and assign motion classes and MODS consistently, which required considerable focus and effort. [24]. A task time requiring a minute was calculated and documented in an hour by a person with knowledge of the job [22]. For the results of a work assessment to be accurate and to inform practitioners, the assessment method required to have evidence of inter- and intra-rater reliability and validity [25].

1.3 Aim

This thesis aimed to design, develop, and test a prototype glove that produced unified and reliable results, automated the MODAPTS calculation and documentation with a wearable programmable glove while maintaining performance and accuracy.

1.4 Justification

Analysts in the industry spend a significant amount of time gathering and analyzing data relating to the workforce. While MODAPTS was an efficient predetermined time study method in getting a worker's data, they were time-consuming and tedious to compile [24].

Many commercially available tools enable real-time and non-intrusive monitoring of workers [72]. The real-time, non-intrusive data gathering, and analysis systems were based on computer vision. These systems allowed for the extraction of workers' positional data in real-time using live feeds from cameras linked to computers. However, limitations of this method were observed, such as requiring the worker to stay in the camera's field of view, preventing occlusions from machinery or other workers, the existence of sufficient lighting without high reflections, and selecting an appropriate location for the camera [26].Earlier studies focused on workers to stay in the cameras' field of view, whereas the proposed study eliminated the required usage of cameras. However, this study required the person to wear the glove while performing the tasks.

Therefore, in gist, this study proposes a framework to integrate wearable sensor glove with MODAPTS. Tasks were performed using the glove to verify the proposed approach and the effectiveness was evaluated by comparing the proposed results with traditional method results.

1.5 Delimitations

MODAPTS is a free-standing system using several essential elements of motion. An analyst combines these elements to describe and calculate the time MODAPTS takes for an average operator to complete an operation.

One of the limitations of this study was that it limited the operation to fingers, wrist, and forearm, but in the future, this study could extend to the shoulders. The employees working in occupational sitting industries like electronic assembly-line employees, solderers, electronic testers, panel builders, Electro-Mechanical Assemblers, etc. would be assisted by this glove [91].

Secondly, MODAPTS codes were classified into three types:(1) Move actions, (2) Terminal actions (Gets and Puts), and (3) Other elements. The Gets or Puts were further classified into G0, G1, G3, P0, P2, and P5, out of which G3, P2, P5 were considered the high consciousness activities that required feedback. To overcome this concern, the program was coded so that whenever the sensors recognized Put's activity, the Arduino rose a quick alert to the Bluetooth devices (PC/Mobile), which resolved the issue of defining the high conscious activities (P2, and P5). Thirdly, influential factors like noise, vibration, acoustics, and lighting were not considered in this study.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

To gain insight into the application of MODAPTS using wearable sensors, a broad literature review of predetermined time systems, and wearable sensors was first conducted, and their related research was addressed.

Time studies were essential for labour cost control, cost estimation, planning, and scheduling evaluating alternatives, and often served as the basis for incentive plans. Historically, three different techniques were used to determine production standards. These were judgment estimates, historical records, and engineered work measurements [27].

Judgment estimates were supported by intuition, personal experience, and inherent ability to make a confident-sounding response [28-29]. This technique was further categorized into three phases: hunch and guess, educated guess based on semi-quantified experience, and judgment or expert opinion based on organized and quantified information and utilization of more or less precise criteria. In the historical method, production standards were based on the records of previously produced jobs. [27]. Engineered work measurement was divided into time study (direct observation with performance rating), work sampling, standard data, and predetermined motion time systems (PMTS). Time study was one of the most common techniques used to set production standards; however, it has been a subject of criticism over the years. The criticism was mainly due to

1. Subjective assessment of speed and effort, i.e., variation in rating, which may vary not only between firms but also within firms,
2. Ratings based on the assessment of a single worker and a very small number of work cycles,

3. inherent inaccuracies created by the use of a stopwatch in timing very short-cycle jobs, and the unacceptability of a stopwatch study on the part of the employees.[30]

As an alternative to time study, the concept of PMTS was evolved. A PMTS is defined as "an organized collection of details, procedures, techniques, and movement times used to analyze and evaluate manual work elements. The system was communicated as far as the movements utilized, in terms of their general and explicit nature, the conditions under which they happened, and their performance times previously determined" [31].

2.2 Various types of PMTS

Several different PMTS were reported in the literature. The principle of PTS was not a modern technique but not as commonly used or understood as any other work calculation technique. In 1924 A.B. Segur & Company implemented the first pre-determined time system. This method was known as Motion Time Analysis (MTA). Many systems were since developed and applied with differing results. Some of the more commonly recognized pre-determined time systems include the Methods-Time Measurement (MTM), Work Factor, Maynard Operation Sequence Technique (MOST), and Modular Arrangement of Predetermined Time Standards (MODAPTS) [32].

MTM, which was developed by Maynard et al. (1948), is one of the most popular PMTS. MTM-1, the basis of the MTM family, was a detailed PMTS that divided any operation into basic motions (Maynard et al., 1948). MTM-2 was built to further extend MTM to work environments where the MTM-1 information would commercially prohibit its application. The third level of MTM (MTM-3) helped work situations where reduced application cost at the expense of some accuracy made it a better alternative [32]. The accuracy of MTM-3 was within 5%, with a 95% confidence level, when compared with MTM-1 analysis in cycles of approximately four minutes, exclusive of limiting process time, and in operations not utilizing focus and eye travel times. There were other higher levels of MTM, such as MTM-C (for setting clerical standards), MTM-V (for setting labour standards in a machine shop), and MTM-M (for setting standards of work involving magnification for part or all the work).

The Work Factor was created from the theory of Basic Motions, which were characterized as movements including a body part, a specific weight, and a distance. Work Factor had three different procedures: Detailed, Ready, and Brief. Detailed Work Factor was the most detailed PMTS. Ready Work Factor was suited for operations that did not require precise analysis as detailed Work Factor [32]. The accuracy of the ready procedure was within 5 % of the detailed technique. A brief work factor was applied to work situations of less detailed measurement. It varied in accuracy from detailed by 10%.

Zandin (1980) developed the MOST work-measurement method. It consisted of three versions: Basic, Mini, and Maxi. Basic MOST comprised three basic sequence models: General Move Sequence, Controlled Move Sequence, and Tool Use Sequence. In addition to the three basic sequence models, an equipment-handling sequence was available to analyze the movement of heavy objects which required a manually operated crane. Mini MOST, which comprised the general move sequence and controlled move sequence, was designed to measure identical, short-cycle operations. Maxi MOST was originated to measure non-identical, long-cycle, heavy assembly, or machining operations [32]. It required the use of five special sequence models for analyzing long-cycle operations.

MODAPTS stands for Modular Arrangement of Pre-determined Time standards. In 1966 MODPATS, was introduced in Australia by Chris Heyde, and it received instantaneous approval and ranks among the most popular methods in the world. It differed from others as it focused on the body part doing the moving rather than the distance covered by the body part of the object being handled [33]. MODAPTS were used to establish a reasonable and sustainable time to complete a proposed job, determined the best method and workplace layout to perform a given task.

2.2.1 Why MODAPTS?

Out of all PMTS methods, MODAPTS is often a well used method. The Work Factor was developed from the methodology of Basic Motions, which defines as movements involving a body member, a certain weight, and a distance [68].

MTM became the first widely used PMTS. The original MTM system was known as MTM-1. Subsequently, modifications were developed to provide easier and quicker systems by considering and reducing the number of motion options and time values [69]. MTM-2 and MTM-3 were examples of second and third level MTM standards. Besides, the MTM family included MTM-V, MTM-C, MTM-M, MTM-TE, MTM-MEK, and MTM-UAS.

The Work Factor system specified the time of performance expected from an experienced and skilled worker, whereas the MTM was 'designed for the typical or average worker' [68].

As an outgrowth of MTM, MOST is a simplified system due to an extensive review of MTM data. MOST utilizes larger blocks of basic motions than MTM-1 and even MTM-2 used only 16-time fragments for describing manual works. As a result, analysts established standards at least five times faster than with MTM-1 without compromising accuracy [69]. MOST identifies three basic sequence models: 'general move', 'controlled move', and 'tool use' [69]. Although a negligible difference exists between MOST and MODAPTS in overall time; however, there was some disparity within the individual elements. When MODAPTS was used, it paid six values to reach for an object, ranging from M1 (finger) to M7 (trunk). On the other hand, MOST paid an A1 for all movements of the arm. An added benefit of MODAPTS was the ability to differentiate the actual arm movement to restrict associate utilization [71].

Over the years, MODAPTS was preferred by engineers [70]. MODAPTS describes work in humans rather than mechanical terms; it holds many more potential applications than other PMTSs [69]. MODAPTS is used by international companies such as Ford Motor Company and Jaguar Land Rover [70].

MODAPTS was chosen for this study out of all the PMTS methods because of its utilization and potential applications in the industries.

2.2.2 History of MODAPTS

In 1966, G. C. (Chris) Heyde, an experienced work measurement engineer, and consultant took a fresh look at the Predetermined Time Systems that was widely available for several decades and decided to take a radically different approach to the system [33]. Rather than trace the distance of an object moved and correlate distance and movement, it attempted to evaluate movements based upon the observed body member. In particular, the fingers' movements, hand, lower arm, upper arm, and shoulder were analyzed separately. They named the system and copyrighted the system MODAPTS, Modular Applications of Predetermined Time System [34-35].

OFFICE MODAPTS was introduced for clerical work in 1969, followed by TRANSIT MODAPTS for heavy physical tasks in 1974. The three systems were combined into a single system called MODAPTS PLUS in 1981. MODAPTS was described as a procedure for improving efficiency and setting time standards through the definition and classification of motion used or required to carry out a given series of operations and assign predetermined time standards to these motions [37].

The principle of MODAPTS is about multiples of simple finger movements that expressed all body movements. MODAPTS analyzes the body motions in sequential assembly operations and translates them into element class codes and time values expressed as units called MODs. A MOD value is 129 ms, which is the same as the finger moving 2.5 cm (M1). As the experimental findings showed, the time to operate another part of the body was the integer multiples of MOD. For example, a wrist movement was approximately M2 (2 x 0.129 s), forearm movement was M3 (3 x 0.129), whole arm movement was M4 (4 _ 0.129), a walk was W5 (5 x 0.129), eye use was E2 (2 x 0.129) and a press was A4 (4 x 0.129) [37]. MODAPTS summed up to 21 kinds of basic actions, which involved 11 actions for the upper limbs and 10 actions for the lower limbs or additional factors, as shown in Table 1 [38-39].

Table 1 Twenty-one basic actions in MODAPTS for one participant [37-40].

Lower limb and waist		Additional factors actions	
Move actions	Terminal actions	Lower limb and waist	Additional factor actions

M1(Finger move)	G0 Simple touch	F3 Foot act on footboard	L1 weight factor
M2 (Wrist move)	G1 Grasp easily	W5 Walk	E2 Eye use
M3 (Forearm move)	G3(Grasp with attention)	B17 Bend and rise	R2 Correct
M4 (Whole arm move)	P0 (Put easily)	S30 stand and sit	D3 judge and react
M5(Unbend-arm move)	P2 (Put with attention)		A4 Press
	P5 (Put with assemblies)		C4 Circular movement

2.2.3 Identifying and Coding Human Motion

In MODAPTS, there are three main classes of motions: Movement, Terminal, and Auxiliary motions. The Movement class refers to movement through space done by the finger-hand-arm-shoulder and trunk. Usually, a movement refers to an activity that is required to position a part of the arm or body to perform the Terminal activity.

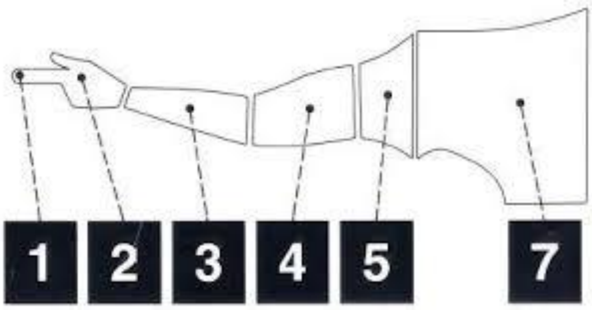

Figure 1 Movement Class [40]

The Terminal class was the activities conducted at the end of a movement that were close to the things that were being performed. This class included two types of activities: Get activities that involved obtaining control of objects and put activities that involved putting objects to destinations. The Gets or Puts were further classified into G0, G1, G3, P0, P2, and P5. Out of which G3, P2, P5 were considered as the high consciousness activities which required vision.

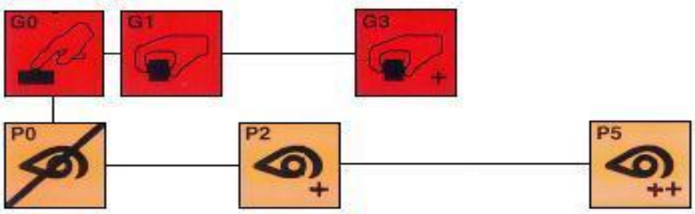

Figure 2 Terminal Class [40]

The Auxiliary form was applied to those tasks which were not carried out by finger-hand-arm-shoulder and trunk. They included activities like walking, bending, and inspections.

In MODAPTS coding, every activity was identified by a two-part code. The first element was an alphabetic portion, which indicated the operation type. A second part was a number, which became the time needed to complete the operation multiplied by 0.00215 minutes.

MODAPTS is not unfamiliar to the transportation industry and is used throughout FORD and UAW-FORD as a method of establishing line task times. It is used for ergonomic purposes, and to establish corporate labour book performance [41].

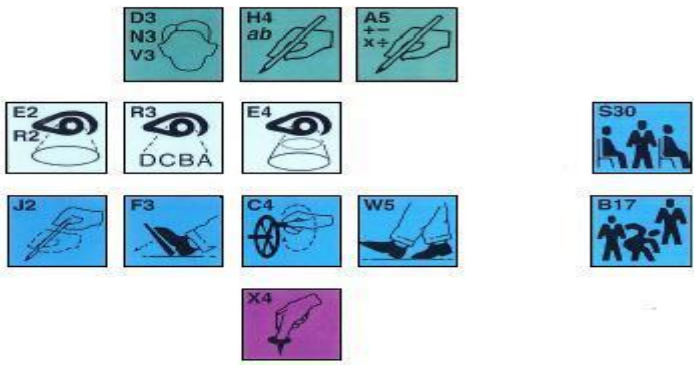

Figure 3 Auxiliary Class [40]

According to the measurement theory, absolute accuracy is defined as the difference between the true value and observed value. The true-time value is not established in work measurement; instead, it is calculated using time analysis, PMTS, work sampling, or standard data techniques [90]. The word "precision" should be used instead of accuracy, as it represented the degree of closeness of the recorded data values with respect to the estimated time value. This claim was reinforced by the fact that, to some degree, defining the time standard using PMTS depended on the applicator's judgment [90]. But inconsistency in the development of labour standards using PMTS (MODAPTS) may be attributed to mistakes due to faulty implementation of the method, e.g., when the working analyst did not understand all motion elements during the study or overlooked or misinterpreted other job complications. The judgment of the individuals varied for the same task. The combination of close monitoring and PMTS experience led to stronger and more consistent standards [90].

2.3 Wearable sensors

Wearable electronics first boomed in the 1960s [42], with significant advances in the last decade. Wearable technologies allow the monitoring of physical activity and actions in humans. Unlike other technological tools, such as laptops and smartphones, wearables are worn on people's bodies and consist of sensors and other technical components that allow activities to be monitored. Therefore, in industrial contexts, one of the critical functions of the wearables is to monitor the behavior and collect valuable data that could be analyzed later [43]. This attracted many companies to wearable devices and inspired the development of new start-ups. Wearables have had tremendous industrial application potential because they could be used to objectivize knowledge. Several ergonomically based wearables were also being used to measure the workers' workplace activities and enhanced their productivity by ensuring health. Numerous studies related to muscle function were carried out. Some programs monitored muscle action of the trunk [44], others measured the operation of the muscle community of the neck-arm-chest [45], and others relied mainly on the hand-wrist group [47].

From the review of these studies on wearable systems and their multiple applications, some were focused on hand-wearable systems [46-47], others were based on health monitoring and prognosis, and others focused on measuring behavioral aspects. There was also a further research category focused on the components of the key wearables [48]. With regard to the studies found in the literature, very few directly looked at the industrial application of these devices [46].

One such product was the wearable glove, commonly used in industrial applications such as sports, television, computer management, robotics, and the medical industries. Such gloves used various types of sensors to collect finger location information. Nevertheless, examples such as ProGlove [49], a smart glove that supported automotive employees in logistics, were found in the marketplace. Other products were used for training staff in different fields, such as Xsens MVN [50] or those produced by BAE systems [51]. Devices have since been developed to protect the health of employees, including the Smart Cap, which gathered fatigue-related data to improve the welfare of employees in fields such as mines or the transportation industry, and the Vandrico hat [52], which provided ventilation for the convenience of athletes, paramedics, surgeons, and pilots. Companies that provide wearable technology included TekSan [53], which developed a system for tracking grip pressure and conducted research focused on textile sensors based on conductive polymers [54].

These wearable glove technologies are broadly categorized into six types. (1) Hall-effect Sensor-based technology (2) Flex Sensor-based technology, (3) Vision-based technology, (4) Accelerometer-based technology, (5) Stretch Sensor-based technology, (6) Magnetic Sensor-based technology. All these techniques were used to make a comprehensive wearable device, which helped alleviate the inaccuracies caused by the manual approaches.

2.3.1 Hall-effect Sensor based technology

Hall-effect sensor-based technology uses hall-effect sensors to accurately measure the flexion/extension and abduction-adduction movement of the fingers' proximal joints. These sensors are based on the magnetic field phenomenon, which are characterized by its polarity and the flux density. When a magnetic field is applied across a hall-effect sensor, its magnetic flux density starts increasing [55]. As the density crosses a pre-set threshold, the sensor detects it and generates an electrical signal as an output voltage known as hall voltage. The generation of the electrical signal based on the applied magnetic field is known as the hall effect. Fig 4 displays the human glove with 20 hall effect sensors, primarily used to test the flexion/extension of the fingers and thumbs and their adduction/abduction activity. The response time for the hall effect sensors is slower compared to that of the accelerometers. Such sensors were distinguished by the form of the feedback signal, respectively, as analog, and digital. In the analog sensor, the output signal was continuous and was directly proportional to the applied magnetic field's strength. The increase in the strength of the applied magnetic field increased the corresponding output voltage until it saturated due to the limitation applied to it by the power supply.

Similarly, in the case of digital sensors, it works as a switch, i.e., if the magnetic field crosses a pre-set value, the output of the sensor switched from state "OFF" to "ON".

Moreover, based on the utilization of the magnetic poles (north and south), the digital hall-effect sensors are categorised as unipolar and bipolar sensors. Hall-effect sensors are low cost.

Moreover, they are not affected by environmental impurities due to their strong sealed packaging and thus could bear severe conditions. Such sensors' operating frequency was up to 100kHz and was therefore, exceptionally good for high-speed operation. These sensors worked in a broader range of temperatures and thus measured a more comprehensive range of magnetic fields. However, there was always a possibility of the magnetic field's interference with the external magnetic field, which could change the resulted output and, in turn, may result in the degradation in performance by compromising the accuracy of the sensed signal.

Figure 4 An Example of a Hall-effect Based Sensor Glove [55]

2.3.2 Flex Sensor Based Technologies

Flex Sensor-based technology, in which various types of resistive bend sensors are mounted in a stretchable glove and adjusted to precisely test the hand joints. Flex sensors are passive resistive devices [55], which are commonly used to measure detection's angle. Flex sensors are generally composed of carbon resistive elements, which are present within a flexible substrate. A bend in a flex sensor results in a change in carbon content in the substrate, leading to a proportional change in the substrate's resistance. Due to the characteristic, flex sensors are also commonly termed as analog resistors.

Figure 5 An Example of a Flex Sensor Based Glove [55]

Fig 5 shows a gesture recognition glove with flex sensors embedded on its fingers. Flex sensor-based technology [55] is the most widely used method in designing wearables associated with hands. The flex sensors operated in a wide range of temperatures (-35 degrees Celsius to +80 degrees Celsius) making them suitable for all environments. Flex sensors are also available in different sizes, making them quite a suitable choice for measuring different joints of the hand. Bending a flex sensor with no protective coating for a relatively longer period resulted in a permanent bend in the sensor that affected its base resistance and required a recalibration. The flex sensors exhibited relatively slow reaction time because of their physical deformation [55].

2.3.3 Vision based technology

Vision-based equipment, in which a glove is specially designed to use motion recognition systems for cameras of various colours and an increasing research trend these days is the use of imagery cameras to recognize hand movements. Real-time hand tracking systems are used to record the hand's freeform movement, and then the captured images are used to calculate the positions of the hand joints and arrangement of movements using image processing techniques, as illustrated in Fig 6. Hand gesture recognition is primarily modeled by using 3D model-based or appearance-based methods [55]. 3D Model-Based approach is computationally quite intensive, and thus, using it for real-time data acquisition, required high-performance computational resources, such as processing speeds and memory.

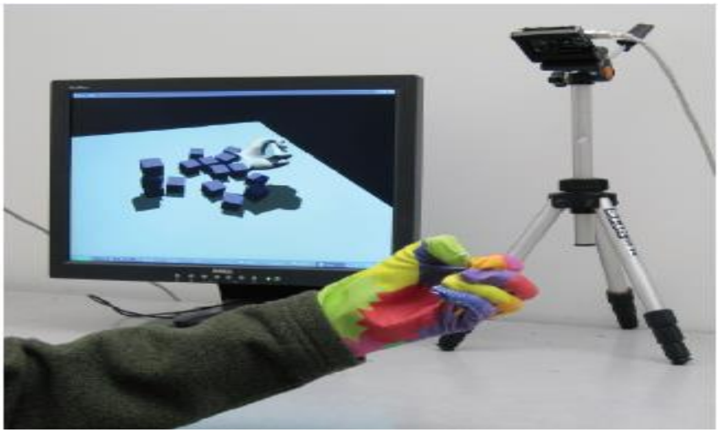

Figure 6 An Example of a vision Based Glove [55]

2.3.4 Accelerometer based technology

Accelerometer-based technology, in which the accelerometers are placed on a glove to calibrate the wrist measurements accurately and accelerometers are used to measure the orientation of an object [55]. Like the flex sensor-based gloves, hand gloves' primary feature based on accelerometer is in gaming and gesture recognition**.** They are used collectively with gyroscopes and magnetometers to form an Inertial Measurement Unit (IMU), which provide quite accurate readings of orientation. The most commonly used accelerometers are Micro-electromechanical Systems (MEMS), which tracked the orientation based on a small proof mass movement on a silicon surface, suspended by small beams.

The second category of accelerometers is based on piezoelectric technology, where the acceleration varies in direct relation to the force applied due to the piezoelectric Fig 7 shows a gesture recognition glove with an accelerometer mounted.

The advantages included fewer hardware requirements and a better data rate as accelerometers give digital output and did not require analog to digital conversion. Also, accelerometers are relatively cheaper and possess a longer lifespan. Moreover, accelerometers generally have a faster response time compared to that of the flex sensors.

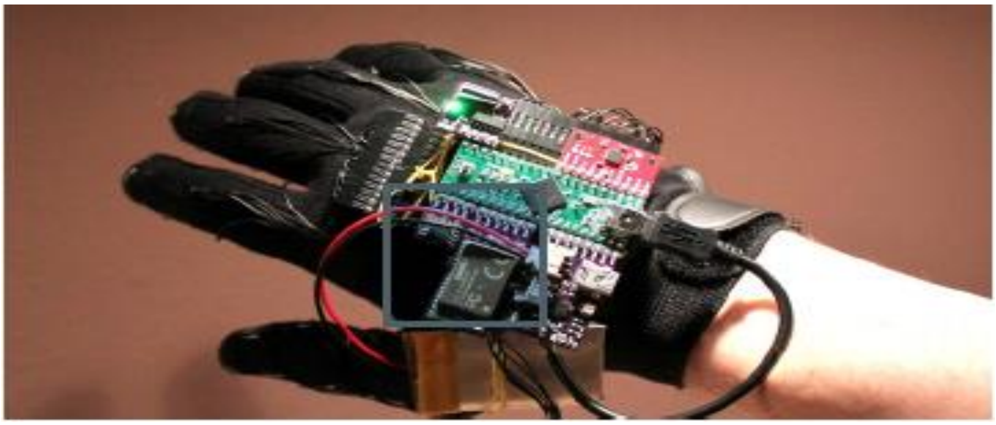

Figure 7: An Example of an Accelerometer Based Glove [55]

2.3.5 Stretch Sensor based technology

Stretch Sensor-based technology, in which the sensor's deformation, i.e., stretching and pressing, allows precise measurement of the motion and joint calculation of the hand and finger. These sensors are used to measure stretch, bend, and force. They are widely used for tracking hand movements in applications ranging from soft robots, Virtual Reality (VR) gloves, biometric displacement reading, and other physical applications. These sensors are typically resistors with resistance values depending on the sensor's deformation, i.e., stretching or squeezing. The sensor's deformation is directly proportional to its stress, i.e., its stretching increased its stress, while its squeezing reduced its resistance [55] equivalents**.**

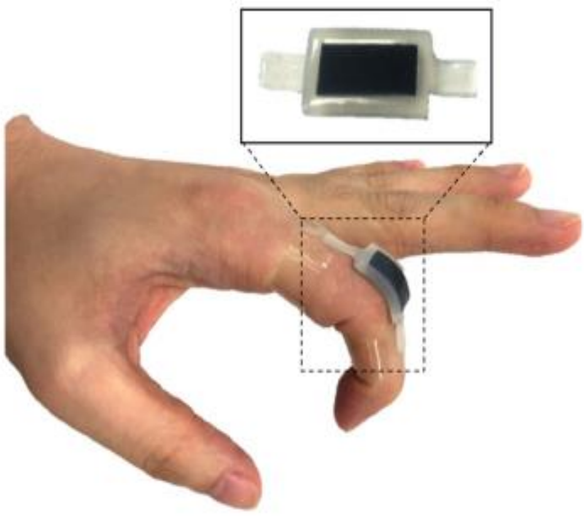

Figure 8 A Soft Stretchable Bending Sensor Placed at a Hand's Finger [55]

Fig 8 illustrates a soft stretchable bending sensor placed at a hand's finger. Due to the stretching ability, stretch sensors are customizable in size and could fit any application. For example, in the case of non-stretchable data gloves, the size of a glove is kept larger than the hand's size so that the sensors can fit into it. Thus, the gap between the hand and glove produced errors in the sensor's output.

2.3.6 Magnetic Sensor based technology

Magnetic sensor-based technology uses magnetic field sensors to monitor the hand's location and orientation. They are widely used in aerospace, geology, and medical sciences [55]. Due to their insensitivity towards the user's hand, these sensors did not require any calibration. Moreover, the data-glove used the magnetic sensor to track the user's hand's position and orientation.

The magnetic sensors had both advantages and disadvantages. One of the main benefits is the variability in their sizes, making them a broader utility in many applications. One of the drawbacks of the magnetic sensors is that their sensitivity changed with their size, resulting in a change in power and cost, i.e., it is directly proportional to all these parameters. Smaller size, low cost, and less energy-consuming magnetic sensors are preferred for the hand joint monitoring and rehabilitation, which lacked in their sensing ability compared to the ones with the larger size. Moreover, the magnetic sensors exhibited a slower response time than the accelerometers and the flex sensors [55].

2.4 Works on Sensor Based Technologies

Cyberglove III [72] is a flex sensor-based glove used for gaming purposes and PC control. It had 18-22 sensors embedded on it with reasonable accuracy of <1 degree. DG5 VHand 2.0 a similar kind of glove used in gesture recognition is used with gaming consoles. These gloves provided appropriate alternatives to gaming console input devices, but the sensor's positionings are not ideal for calculating the corresponding joint movements. Some groups widely explored the option of utilizing flex sensor technology to track the hand joints' movement. The concepts presented in these two gloves, 5DT Data Glove and X-IST Data Glove, are expanded by the Tyndall Institute in Ireland for a more sophisticated wearable glove production [72].

AcceleSpell is an interactive computer game that helped in learning and practicing fingerspelling. The game is based on a decision tree-based recognition algorithm. AcceleGlove used six accelerometers with 3 axes placed at the fingers and back of the palm to provide the angular position of the individual axe on a query Off the Mac. O'Flynn et al. [73] established a System for Inertial Measurement (IMU) smart glove microsystem based on sensors and wireless processors Technology used to communicate with human computers. The glove consists of 16 9-axes IMUs and included a 3-axe accelerometer, a 3-axe gyroscope, and a 3-axe magnetometer and provided a real-time measurement of a range of hand joint movements, including flexion/extension, adduction-abduction, and complex hand movements.

Kapuscinski [74] used the skin-colored section of the captured image to intensity-normalize it with the desired hand region. This way, the gesture is recognized using a Hidden Markov model. YCbCr color model isused by Yu to differentiate skin-colored pixels from the background of the image [75]. Malima [76] used the red-green ratio of the image to detect the skin-colored portion. This way, the hand's center of gravity is determined, which allowed us to find the location of the fingertips that are usually the farthest point from the center of gravity point of the hand. Jackin [75] used a similar gesture recognition procedure. Instead of converting Red, Blue, and Green (RGB) to Hue, Saturation, and Value (HSV), as done by Malima [46], they used RGB as input. Koh [76] considered the shape and color of an image to identify the rough contour of the hand. Fang [74] employed the Adaptive Boost algorithm to detect the hand from the input image. In addition to detecting a single hand, this algorithm also detected overlapping hands. Rekha et al. [72] detected the palm and finger structure by drawing blobs and ridges, and the recognition rate is found to be about 98% accurate. Zabuliset al. [73] proposed a vision-based hand gesture recognition system used for human-computer interaction. It is based on a probabilistic framework that detected the image regions belonging to human hands efficiently using multiple information clues.

Eilenberg et al. [70] presented an adaptive muscle-reflex controller for ankle-foot prostheses. A linear hall-effect sensor is used to estimate the ankle joint angle, which ranged from -0.19 to +0.19 radians. Lee et al. [70] fabricated a stretchable strain sensor for the detection of tensile and compressive strains. This sensor is successfully used in the human wrist and finger motions. It is also used to measure the pressure with high sensitivity. Tognetti et al. [72] developed a prototype, which involved the knitted and woven e-textile stretch sensors and is used to monitor the knee joint's rehabilitation progress. Similarly, Shimada et al. [74] used a stretch sensor in the closed-loop system to restore standing in paraplegia. Shen et al. [74] presented a soft stretchable bending sensor and two sensor gloves.

2.5 Related studies on MODAPTS

There were many computer versions of MODAPTS. MODAPTS PLUS Professional was one of the first systems which consisted of three programs that ran on " PC - compatible" computers [56]. The program was coded using basic computer language. It required the user to enter the codes one move at a time for different tasks until the process was complete. The machine then took these codes, combining them with allowances and other variables to create a standard time for that function in a unit called MOD (0.129 seconds). The program provided a method for editing the input and an output containing the task's steps and the final cycle-time.

CAESAR (Computer Assisted, Engineered Standards, and Rates) was one of the developed MODAPTS studies, a multi-level, standard data, an interactive system designed to improve methods and establish components production rates in the sewn product industry [57].

A more advanced version of MODAPTS was developed, which combined the use of a mouse with data input to ease the process of data and file manipulation. The program consisted of pull-down menus and simple graphical representations of the various codes. This software and the earlier version required the user to memorize the various codes and the way to input them [58].

Secondly, other studies proposed and tested an integrated framework that coupled data acquisition and visualization with analysis of manual operations to enable effective evaluation of those manual operations for a comprehensive ergonomic analysis and simulation model of existing operations, created from video recordings with the help of action recognition method. The action recognition component served as the basis for the simulation model used for productivity analysis and motion generation. However, there were limitations such as requiring the worker to stay in the camera's field of view, prevention of occlusions from machinery or other workers, the existence of sufficient lighting without high reflections, selection of appropriate location for the camera, etc. and secondly, vision-based action recognition working reliably for cyclic tasks. Still, more testing and development were required for non-cyclic construction tasks [59].

Lastly, another study explored Principal Components Analysis (PCA). It was used to segment a motion sequence accurately and was compared with traditional MODAPTS to demonstrate its application to PMTS. PCA-based motion analysis was proved to be an acceptable method. Although the 80.08% accuracy showed that this method produced positive results, when considering the dimensionality reduction of motion data, it was clear that some amount of information was lost, like hand data and head data, which generated incomplete treatment for fine operations. Ignored data may be necessary for detailed assembly work, like electronic instrument assembly or mobile phone screen touching [60].

There were studies conducted on MODAPTS. The studies that were conducted on MODAPTS began with computerizing the analysis. Secondly, technologies such as PCA analysis and Vision-based action recognition methods were applied to make the MODAPTS analysis accurate. But the limitations in computerizing the method included continuous watching of operators working videos resulting in wrongly documenting the data; this was due to misinterpretation caused by continuous watching of videos, leading to a loss in delicate data.

PCA method was used to precisely segment a motion series and was compared with the existing MODAPTS to illustrate its application to PMTS. Evaluation of movement based on PCA was a proven process. Still, the loss of detailed information like the electronic instrument assembly or mobile phone screen touching were not processed using PCA analysis. The Vision based action recognition method, required the workers to stay in front of the camera, which may not be possible since they need to move.

This current study is proposed to eliminate such limitations where the sensitive and vital data will not be lost and save the time a usual MODAPTS technician would take. The sensor-based system might be a solution to the constraints, as mentioned earlier, to eradicate the limitations since the sensor-based glove does not have the constraints discussed above.

There were many available commercial gloves in the market. With regard to the studies found in the literature, very few have directly looked at the industrial application of such devices [77,78]. Nonetheless, there were gloves available on the market, such as ProGlove [79], an intelligent glove to support logistics, automotive workers. Other products were used for training staff in various fields, such as Xsens MVN [80] or those produced by BAE systems [81]. Devices were developed to protect the health of workers, including the Smart Cap, which collected fatigue-related data to improve the safety of employees in sectors such as mining or the transportation industry, and the Vandrico[82] cap, which provided cooling for the comfort of employees. Wearable-technology firms included TekSan [83], Which developed a grip pressure tracking system and conductive polymer-based textile sensor research. There are many glove-based studies conducted on sign language to assist the physically challenged people. Though there are many glove-based studies related to industrial applications, there are no glove-based sensor studies conducted on MODAPTS.

2.6 Conclusion

MODAPTS is a cost and time-effective alternative to evaluate work speed as part of work assessments. It is also complex regarding assisting engineers in understanding because it required much more learning time [24]. And again, a task time requiring a minute was calculated and documented in an hour by a person with knowledge of the job. Suitable wearable technology was needed to incorporate to save and reduce the time to document.

Table 2 presents a comparison of various wearable technologies which are based on their accuracy, performance, cost, and lifetime, that include the most important parameters while designing a glove. It is important to note that the accuracy parameter considered both the sensing ability and the response time of wearable technology, i.e., the desired accuracy meant detecting the movements precisely and efficiently. The numbers 1(desirable), 2(nominal), and 3(worst) represented the level of behavior of the technologies for each of the parameters, and seen that the flexible sensor and accelerometer were the most optimal technologies based on these parameters since they did not exhibit any worst behavior. The flex sensor-based technology provided the best accuracy and lifetime. So, the study used flex-based technology to incorporate it with MODAPTS.

Table 2 Comparison of wearable technology [55]

Technology	Accuracy	Performance	Cost	Lifetime
Flex based	1	2	2	1
Accelerometer based	2	1	1	1
Vision based	2	2	3	2
Hall effect based	3	3	2	1
Stretch sensor based	2	2	1	3
Magnetic sensor based	3	2	2	1

Table 3 Literature Review Gap

S.no	References	Sensor Gloves		Covered Body Part		Dynamic gesture	Sensor based gloves for Industrial purposes
		Bend Detection	Move Detection	One Hand	Two Hand		
1	[92]	*		*			**None**
2	[93]	*		*			**None**
3	[94]	*		*			**None**
4	[95]	*		*			**None**
5	[96]	*		*			**None**
6	[97]	*		*			**None**
7	[98]	*		*			**None**
8	[99]	*		*			**None**
9	[100]	*		*			**None**
10	[101]	*		*			**None**
11	[102]	*	*	*		*	**None**
12	[103]	*	*	*			**None**
13	[104]	*	*	*			**None**
14	[105]	*	*		*		**None**
15	[106]	*	*	*			**None**
16	[107]	*	*	*		*	**None**
17	[108]	*	*	*			**None**
18	[109]	*	*	*			**None**
19	[110]	*	*	*		*	**None**
20	[111]	*	*	*			**None**
21	[112]	*	*	*			**None**
22	[113]	*	*	*		*	**None**
23	[114]	*	*	*			**None**
24	[115]	*	*	*			**None**
25	[116]	*	*	*		*	**None**
26	[117]	*	*	*		*	**None**
27	[118]	*	*	*			**None**
28	[119]	*	*	*			**None**
29	[120]	*	*	*		*	**None**

30	[121]	*	*	*			**None**
31	[122]		*	*			**None**
32	[123]	*	*	*			**None**
33	[124]	*		*			**None**
34	[125]		*	*			**None**
35	[126]	*		*			**None**
36	[127]	*	*	wrist	wrist	*	**None**
37	[128]	*	*		*	*	**None**
38	[129]	*	*	*			**None**
39	[130]	*	*	*			**None**
40	[131]	*	*	*	*		**None**
41	[132]	*	*	*	*	*	**None**
42	[133]	*		*			**None**
43	[134]	*		*			**None**
44	[135]	*			*		**None**
45	[136]	*		*			**None**
46	[137]	*	*	*			**None**
47	[138]	*	*	*			**None**
48	[139]	*	*	*			**None**
49	[140]	*	*	*			**None**
50	[141]	*	*	*			**None**
51	[142]	*	*		*		**None**
52	[143]	*	*	*			**None**
53	[144]	*	*	*			**None**
54	[145]	*	*		*		**None**
55	[146]	*	*	wrist	wrist		**None**
56	[147]	*	*	wrist	wrist	*	**None**
57	[148]		*		*	*	**None**
58	[149]	*	*		*		**None**
59	[150]			*			**None**
60	[151]	*		wrist	wrist		**None**
Current Study		*	*	*	*	*	*

Table 3 illustrates the number of studies conducted on sensor-based gloves. Several researchers focused on discovering an appropriate technique to capture fingers and palm movement, whereas others were interested in developing a recognition engine with good accuracy. In terms of the type of sensor used, (17/60) studies were concerned with the finger-bending measurement using bend detection sensors. Most of the studies (41/60) used both types of sensors to capture finger and hand movements. It was easy to note the significant difference between the number of studies (46/60 papers) on recognizing one hand and the number of studies (9/60 papers) on recognizing two hands. As for gesture type, only (12/60) studies attempted to recognize static and dynamic gestures. Many glove-based studies were conducted on medical fields and other fields, but no studies were conducted for industrial related fields. This current study covered all the above-mentioned features.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter addresses the methodology used to develop and test a prototype glove. The proposed system is a portable glove which focuses on gestures and angles. The system's main goal is to convert hand movements to the desired MODAPTS code through an automated process, eliminating the need for human interpretation and evaluation of the movements. Six flex sensors, two pressure sensors and a gyroscope are used in this study. Five flex sensors are placed on each finger and the sixth flex sensor on the forearm. The pressure sensors are placed on the index and thumb finger. The gyroscope is placed on the wrist. Sensors are connected to different pins of Arduino, which acted as the controlling unit. The sensors send the data input to the controlling element and display the output via PC or Mobile using Bluetooth.

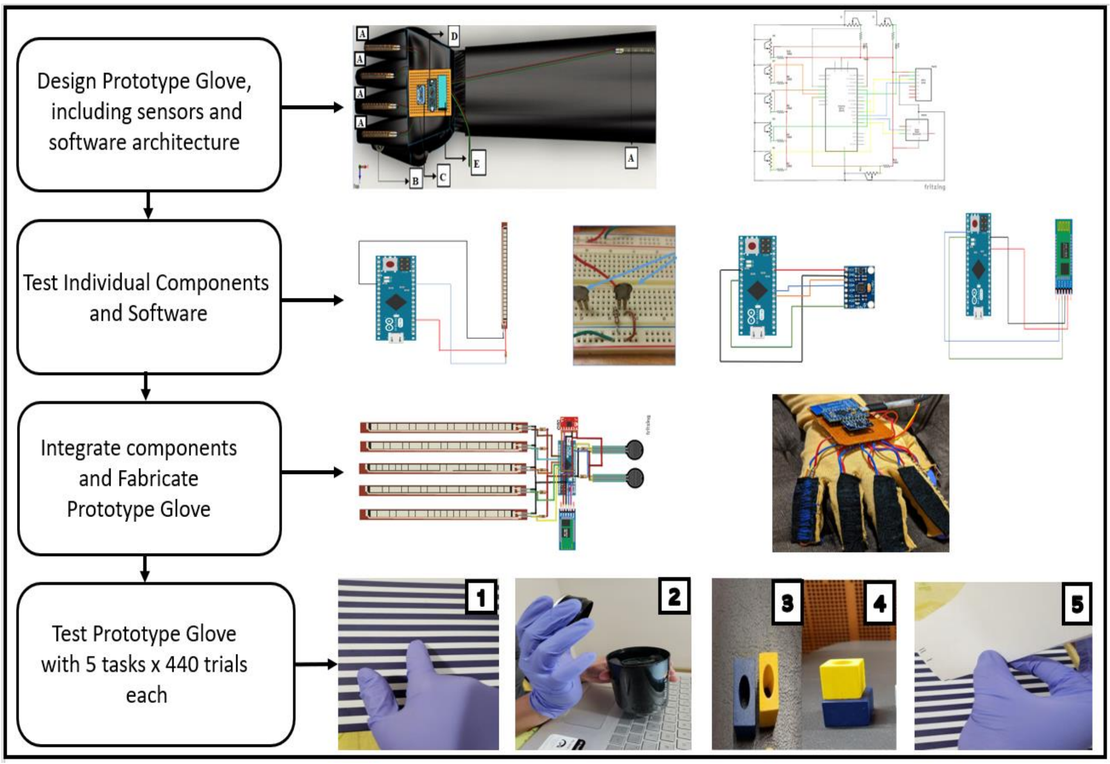

Figure 9: Overview of the study

Figure 9 illustrates the overview of the study. In step 1 glove prototype was designed using grab CAD library and solid works. The schematic of the circuit was developed using the fritzing application. In step 2, individual components were tested with concerned software's. In step 3, all the tested components were integrated and sewn on the glove. In step 4, to test the prototype glove 5 tasks were chosen and to test the glove performance and reliability, each task was performed around 440 times under 4 different temperatures.

3.2 Hardware Design and Implementation

This design consisted of one glove with several subsystems: a flex sensing subsystem, a contact/pressure sensing subsystem, a processing subsystem, and the output subsystem to fulfill the specifications. The type of sensors and their hardware specifications are described in this section.

3.2.1 Flex Sensors (Spectra Symbol)

To determine the finger's movements, a sensor that detected the flexion and extension of the fingers had to be considered. And such components used to detect the flexion were potentiometer, accelerometers (ADX2 335), and flex sensor [55]. Out of the alternatives flex sensor was preferred for this study because potentiometer wires had to remain uniform, which was not viable, and also the life of the potentiometers lasted only a few thousand rotations. Flex sensor were used instead of accelerometers because accelerometers required considerably large power for its operations, and the life of the accelerometers were less when compared to flex sensors [84].

A flex sensor was the suitable sensor compared to accelerometers and potentiometers to test finger flexion due to its reliability and life cycle [84]. Flex sensors were used to measure any Flex, Bent or Angle adjustment. The internal resistance of the flex sensor varied linearly with its flex angle. The flex sensor operated between temperature ranging from -35^{0}c to + 85^{0}c. [84]

Bending a flex sensor with no protective coating for a relatively longer period may result in a permanent bend in the sensor that affected its base resistance.

Flex sensors were resistive carbon parts. One kind of variable resistor was a flex sensor. It measured the amount of deflection or bend. It was a sensor whose output changed when it was bent i.e., The resistance over the sensor decreased as the sensor was flexed. The unit produced a resistor output correlative to the bend radius when bent. The variation in resistance was just about 10K ohm to 30K ohm [61].

The nonlinearity of flex sensors prevented them from measuring large curvatures and the absolute angles of objects. They were also limited in length (maximum, 95.25 mm for the Spectra Symbol flex sensor) and so did not measure a bend change for a large area [152].

A globally organized flexed system has a resistance of 10K ohm. The resistance increased to 30K ohm at 90 degrees when the sensor was bent, and the resistance of the sensor was less when it returned to its original position compared to the resistance value when bent [61].

The device incorporated within the device employed a potential divider network. The flex sensor had two output wires, and the resistance between these two wires varied when the sensor was bent. This change in resistance was one of the key features being used in our project. From figure 10 the variation of sensors at various different angles are observed.

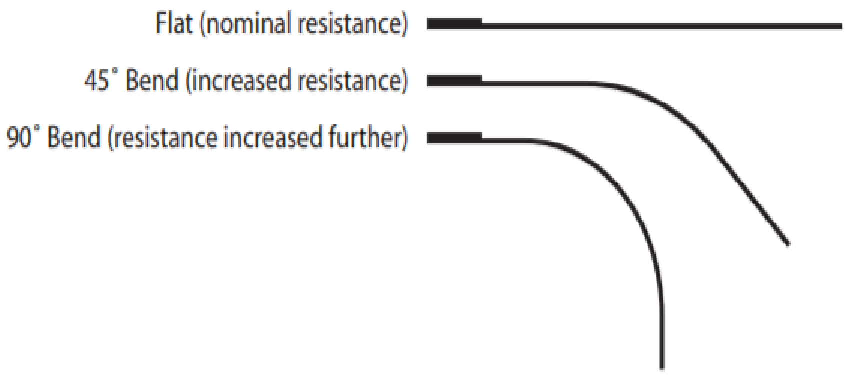

Figure 10 Flex Sensor resistance at different angles [61]

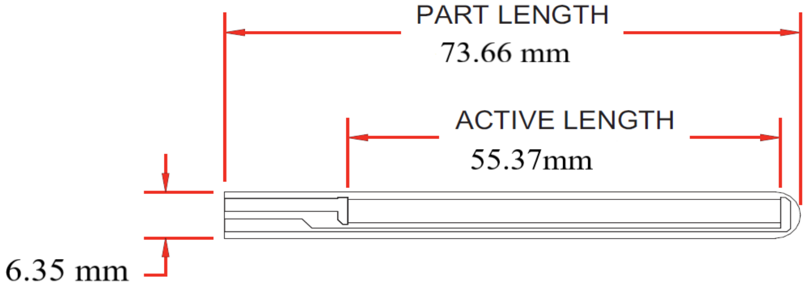

Figure 11 Flex Sensor dimensions in mm.

Flex sensors specifications:

- Life Cycle: >1 million
- Height: 0.43mm (0.017")
- Temperature Range: -35°C to +80°C
- Flat Resistance: 25K Ohms
- Resistance Tolerance: ±30%
- Bend Resistance Range: 45K to 125K Ohms (depending on bend radius)

3.2.1 Pressure Sensors (Interlink Electronics)

In this study, to determine the activities such as Get and Put, pressure sensors were used for detecting the touch and grasp because the pressure sensor had a very long life and a swift response [85]. The pressure sensor was basically a variable resistor whose surface pressure depended on the terminal resistance [85]. The flex sensor operated between temperature ranges from -30^{0}c to + 70^{0}c.

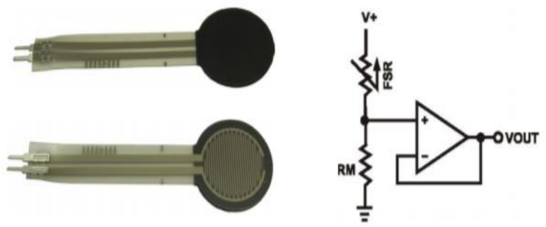

Figure 12 Pressure sensor and its schematic representation

A pressure sensor was a device that tracked pressure and translated it into an electrical signal where the amount depended on the applied pressure. These devices exhibited a decrease in resistance with an increase in pressure applied to the sensor's surface. Applying pressure to the sensing film surface allowed particles to contact the conducting electrodes, which changed the film's resistance. Two pressure sensors were used in this proposed study. As all resistive sensors, pressure-sensing resistors needed a relatively easy interface and operated well in moderately hostile environments.

The advantages of pressure sensors were their size (typically less than 0.5 mm thickness), low cost, and good resistance compared to other pressure sensors [62]. Such force sensitivity was intended to use human touch control of electronic devices, such as automotive electronics, medical equipment, and industrial and robotic applications. The analysis selected a 0.5-inch pressure sensor.

Low precision was the only downside of pressure sensors, with about 10 percent or more difference in measurement performance. Table 4 represents the pressure sensor specifications.

Table 4 : pressure sensor specifications

S.no	Feature	Value
1	**Actuation Force**	0.1 Newtons
2	**Force Sensitivity Range**	0.1 - 10.02 Newtons
3	**Force Resolution[3]**	continuous
4	**Force Repeatability[3]**	±6%
5	**Non-Actuated Resistance**	10M W
6	**Size**	18.28mm diameter
7	**Thickness Range**	0.2 - 1.25 mm
8	**Stand-Off Resistance**	>10M ohms
9	**Switch Travel**	0.05 mm
10	**Hysteresis[3]**	+10%
11	**Device Rise Time**	<3 microseconds
12	**Long Term Drift**	<5% per log10(time)
13	**Temp Operating Range** (Recommended)	-30 - +70 ºC
14	**Number of Actuations** (Lifetime)	10 Million tested

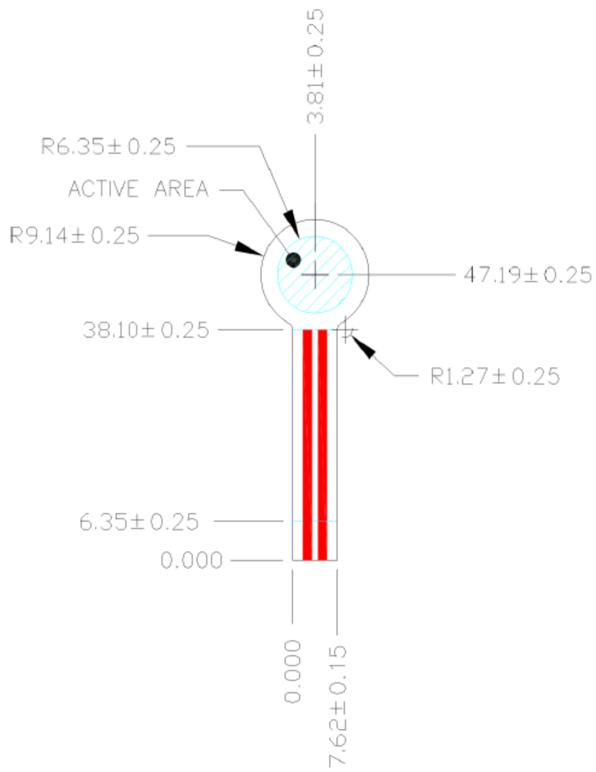

Figure 13: Pressure sensor dimensions

3.2.2 Gyroscopes (MPU-6050) (INVENSENSE)

For studying movements like M2, that is, the wrist, which could rotate about 360 degrees, needed a device that could detect the rotations around the wrist, a gyroscope was necessary. MPU-9150, MPU-6050 were two such finest gyroscopes. MPU-9150 was an improvised version of the MPU-6050 and incorporated a magnetometer - a tiny sensor that measured the magnetic fields. With extra code changes, this was used to neutralize yaw drift over time. The MPU-9150 magnetometer was very "extremely loud"-in short periods, we mean the values that it provided fluctuate rapidly [86]. The MPU-9150 boards were highly expensive. The MPU-9150 boards were more difficult to obtain at a reasonable price or time frame. It was also affected by magnetic fields and could not be placed right next to the speakers. MPU- 6050 was preferred over MPU-9150 due to its cost, fluctuations issues.

MPU 6050 was a MEMS system consisting of a three-axis Accelerometer and three-axis Gyroscope inside [86] allowed us to calculate a device or object's acceleration, velocity, direction, displacement, and many other motion parameters. This module also had a Digital Motion Processor (DMP) inside it, which was powerful enough to perform complex calculations and free up the microcontroller work. After researching its specifications, it was found that this gyroscope could operate under high temperatures (> 85^{o}) and was qualified for a shock tolerance of 10,000g. But over an extended time, MPU-6050 would experience yaw drift [86] and was inevitable and a technological constraint, but it could be reduced. For instance, when a quad-copter drifted by 2 degrees over 1 hour, this may be of significant concern, depending on how far it had travelled. A drift of a few degrees an hour was not a concern [86].

A 3-axis gyroscope was used to define the shift in the acceleration of the hand's movement in distinctive bearings [66]. The MPU6050 was a Micro-Electro-Mechanical Systems (MEMS) system composed of a 3-axis accelerometer and a 3-axis Gyroscope. It helped us to measure a device or object's acceleration, velocity, direction, displacement, and many other parameters related to motion. This module also had a Digital Motion Processor (DMP) inside, which was powerful enough to perform complicated calculations. The MPU 6050 was a functional measurement device that included a gyroscope and an accelerometer to measure the body's movement in space: to calculate angular speeds and linear accelerations. In this study, only one gyroscope was used to determine movement (M2) at the wrist.

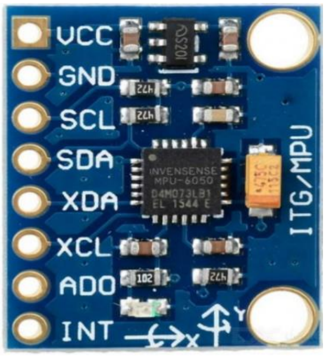

Figure 14 Gyroscope (MPU-6050)

The key difference between the gyroscope and accelerometer was simple - one detected rotation while the other was unable to. The accelerometer gauged the orientation of a stationary object in relation to the surface of Earth.

MEMS technology was making the availability of low-cost gyroscopic sensors a reality, opening the door for many new applications. Although the gyroscope operated at a temperature of 85^{0}c, other factors such as humidity, drift, and vibrations influenced the results of the device. The drift was inevitable and a technology limitation, but it could be narrowed down. Figure 15 represents the dimensions of the gyroscope.

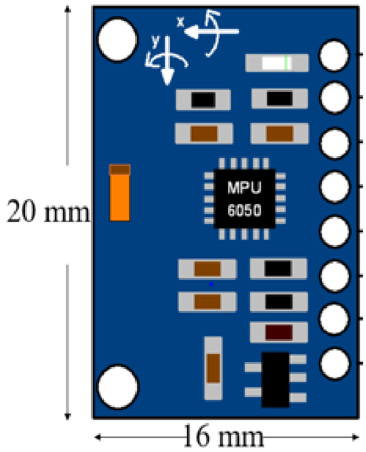

Figure 15:Gyroscope (MPU-6050) dimensions

Gyroscope Specifications:

- The triple-axis MEMS gyroscope in the MPU-60X0 included a wide range of features:
- Digital-output X-, Y-, and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Integrated 16-bit ADCs enable simultaneous sampling of gyros
- Enhanced bias and sensitivity temperature stability reduces the need for user calibration
- Improved low-frequency noise performance
- Digitally-programmable low-pass filter
- Standby current: 5μA
- Factory calibrated sensitivity scale factor
- User self-test

3.2.3 Bluetooth (ITEAD Studio)

A Bluetooth module was essential to the wireless sending of the data [87]. The HC-05 had two operating modes; one was the data mode where one sent and received data from other Bluetooth devices, and the other was the AT Command mode, where one changed the default device settings. Using the key pin, we operated the system in either of these two modes, as described in the pin description [87]. Pairing the HC-05 module with microcontrollers was very simple since it worked using the Serial Port Protocol (SPP).

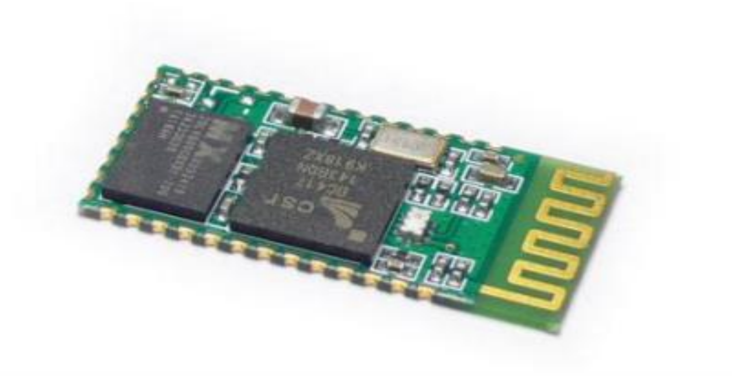

Figure 16 HC-05 Bluetooth module

The HC-05 module was an easy-to-use Bluetooth Single Port Protocol module for transparent single wireless communication. Bluetooth Serial Port module was fully accredited Bluetooth V2.0 EDR (Enhanced Data Rate) 3Mbps Modulation with a 2.4GHz total radio transceiver and baseband [65].

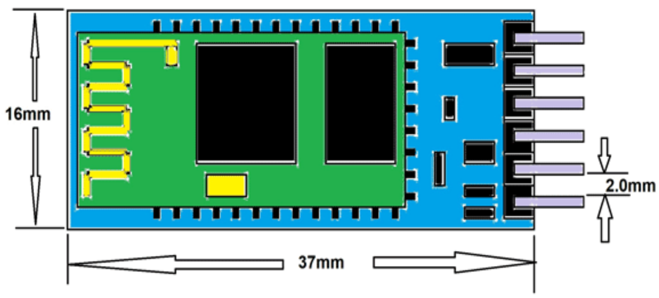

Figure 17 Bluetooth dimension

Uses CSR blue core 04-external Bluetooth single-chip device with CMOS technology and Adaptive Frequency Hopping Feature (AFH). Figure 17 shows the dimensions of the Bluetooth.

Bluetooth Specifications:

- Typical -80dBm sensitivity
- Up to +4dBm RF transmit power
- Low Power 1.8V Operation ,1.8 to 3.6V I/O
- PIO control
- UART interface with programmable baud rate
- With integrated antenna
- With edge connector

3.2.4 Arduino (Pro Micro)

All the Arduino boards were popular for ease of comprehension and application. The Arduino was also an open-source platform where all related data and original schematics of the module were accessed. Depending on the needs, one configured the framework on this platform. Arduino had many types of boards in the market; they came with a range of different features and packages [88]. One may choose the appropriate board, depending on the need. For the systems where the installation was permanent, and the board only needed to be configured once in permanent applications, the PRO MINI was specifically designed. This board had just enough basic hardware for such applications.

The Arduino pro micro was the smallest board. With its comfort size, board costs were considerably lower in mobile applications. To meet the design requirement of a portable, easy to use, the glove components needed to be as compact as possible [88].The Arduino Micro was an ATmega32u4 based microcontroller module, built-in collaboration with Adafruit. It had 20 digital input/output pins, 16 MHz crystal oscillator, a micro USB interface, an ICSP header, and a reset button. It contained everything one needed to help the microcontroller; to get going, simply connect it to a micro USB cable device. It had a form factor that made it easy to put on a breadboard. This specific board was selected due to the number of analog and digital pins.

Figure 18 Arduino pro-micro

The board displays 12 analog inputs (ADC0, ADC1, ADC4, ADC5, ADC6, ADC7, ADC8 ADC9, ADC10, ADC11, ADC12, and ADC13). Communication protocols like serial (RX, TX), SPI (SS, MOSI, MISO, AND SCK) and I2C (SCL AND SDA) were incorporated on the board. PWM output pins were used for getting analog results with digital means.

The 5V was a voltage at which the board worked, while each pin worked 3.3V. The Vin was the voltage supply varying from + 7 to + 12 V, a voltage from the external power source, not a USB port. The frame featured two base pins. The AREF calculated the Analog Reference Voltage, which helped inject a reference voltage from an external power supply into the Arduino. PCINT was the external interrupt on every optical I / O pin. The ICPS head was attached to the board, and it stood for In-Circuit Serial Programming – a function used by another Arduino to program. And if the USB port were not available, it came out handy for connecting the board with a computer for uploading a sketch [62]. All output signals generated from flexure, pressure sensors, and gyroscope were digitalized before, so they were transmitted to a computer to convert the analog signals to the digital output microcontroller was used as the main controller to the hardware.

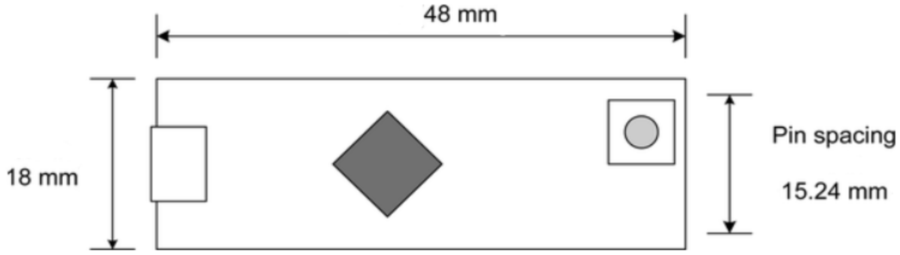

Figure 19 Arduino pro micro dimensions in mm

Arduino pro-micro specifications:

- Microcontroller ATmega32u4
- Operating Voltage 5V
- Input Voltage (recommended) 7-12V
- Input Voltage (limits) 6-20V
- Digital I/O Pins 20
- PWM Channels 7
- Analog Input Channels 12
- DC Current per I/O Pin 40 mA
- DC Current for 3.3V Pin 50 mA
- Flash Memory 32 KB (ATmega32u4) of which 4 KB used by bootloader
- SRAM 2.5 KB (ATmega32u4)
- EEPROM 1 KB (ATmega32u4)
- Clock Speed 16 MHz

The study used flex based, pressure and gyroscope-based technology to determine Movement class and Terminal class activities depending on the standards mentioned in the literature above, flex sensors and gyroscope were the most desirable systems as they showed no worst behavior. From table 2 we saw that the flex sensor-based technology delivered the best accuracy and service life, the best efficiency and cost.

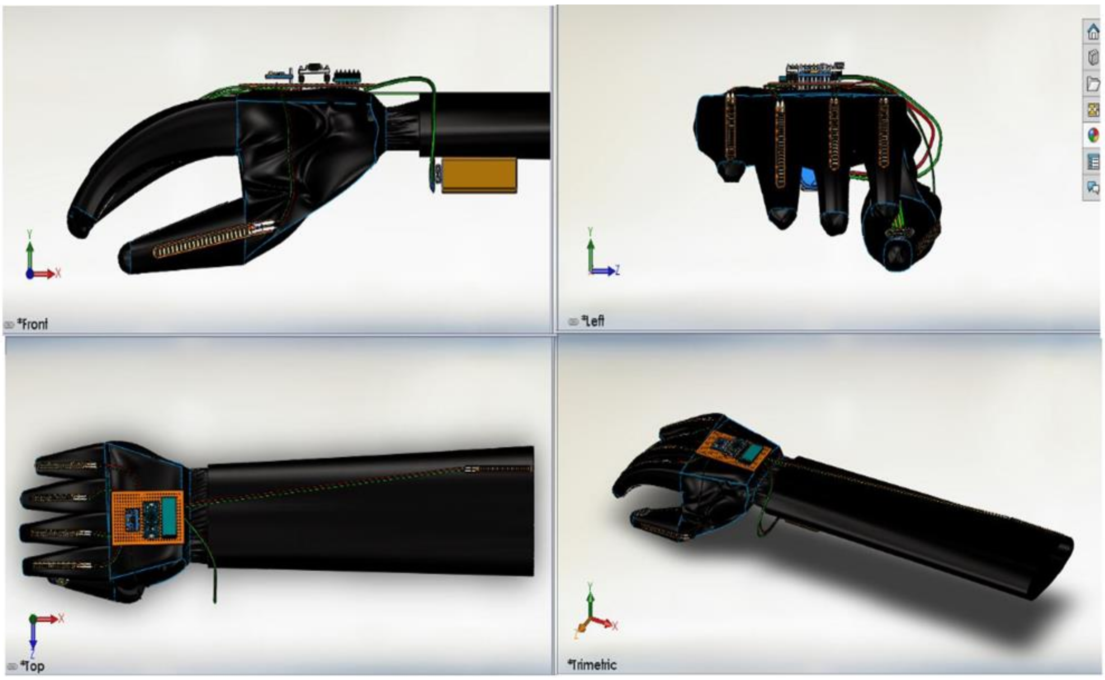

Figure 20 The Proposed Glove design using Grab CAD library and solid works

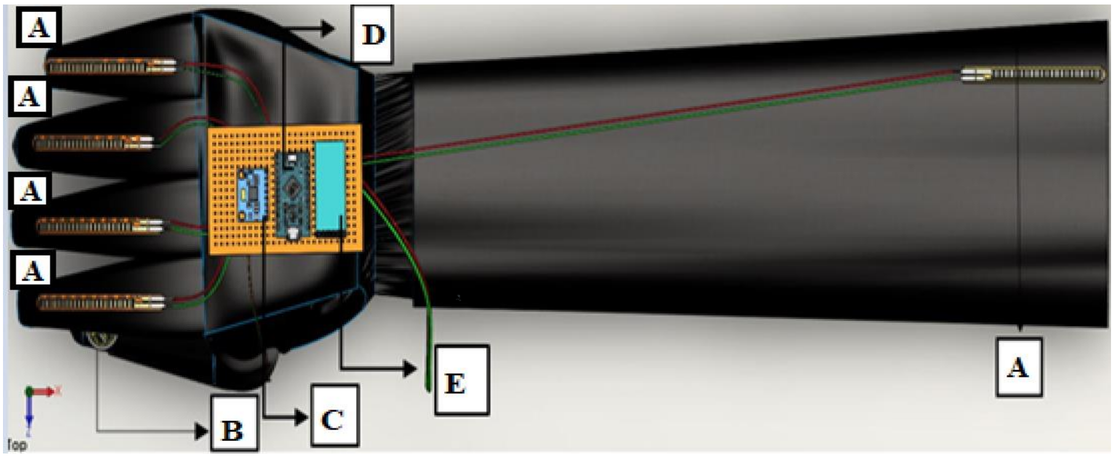

Figure 21 Glove Top View

Figure 21 represents the top view of the glove.

A represents the flex sensors

B represents the pressure sensors

C represents the gyroscope (MPU-6050)

D represents the Arduino pro micro

E represents the Bluetooth.

3.3.1.6 System Architecture and Implementation

The hardware in this system was composed of the flex and pressure sensor subsystem, the glove, gyroscope, and the micro controllers. This section outlined the operations of each subsystem and their incorporation of each into the final glove product.

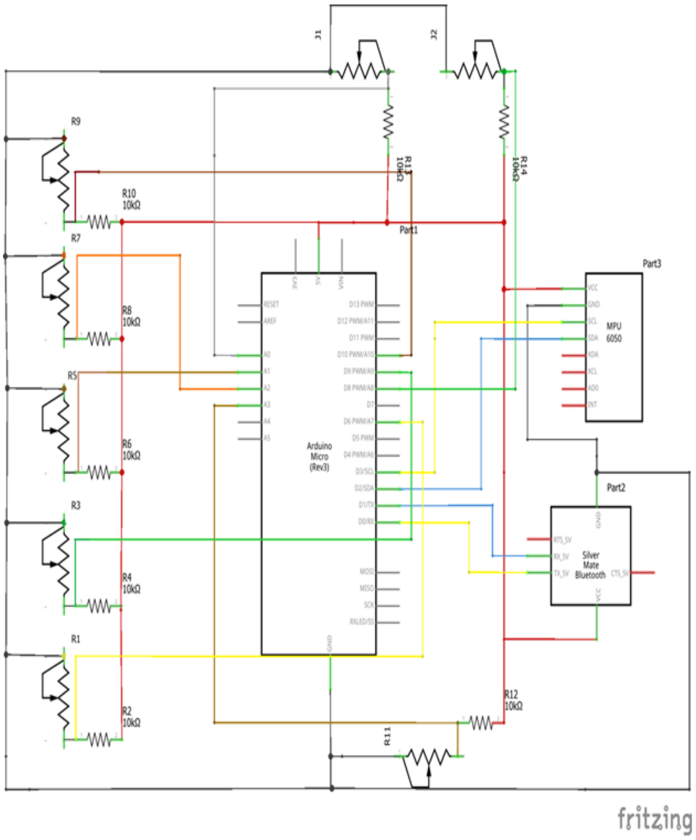

Figure 22 Schematic design

The schematic of the circuit was designed using fritzing application and was simulated. For this simulation, a 5V voltage source was selected to fit the 5V battery pack, which was later used to power the glove and each of the variable resistors were replaced with a simple resistor to make the analysis simpler. Figure 22 illustrates the schematic diagram of the circuit and its connections. After long research, the sensors were selected based on their life, operating temperatures, and sensitivity. The flexible sensors, pressure sensors, and gyroscope were soldered to the master unit that was Arduino micro, and the Bluetooth module was also soldered to the Arduino. The movements detected by the sensors were sent to the Arduino, which acted as a master unit converting the data into the MODAPTS code. The USB port on the Arduino served as an output terminal to transfer the data to the PC as an alternative to transfer the data. One risk common to wearable devices was chemical burns from overheated or poorly constructed batteries [63]. If the batteries were strained or hot, such risks may occur. In the glove, the batteries used were Duracell AAA batteries. The batteries operated at temperatures between -20^0 C and 54^0 C. This project's glove architecture had only one power source, so no voltage spikes above the required 5V voltage.

3.3.1.6.0 Issues and Limitations of the sensors

Though there are many advantages of the sensors used in this system, few limitations affected the system directly or indirectly. The wear and tear might increase, resulting in the deformation of the sensor, although the flexible sensor and pressure sensor's life was long-lasting. Even though the gyroscope worked at 85^{o}c temperature, other factors like humidity, drift, and vibrations might affect the system's results. The drift was unavoidable and a constraint to technology, but it could be narrowed down. For instance, when quad-copter drifted by 2 degrees over 1 hour, then this may be of significant concern, depending on how far it has travelled.

A drift of a few degrees an hour was not a concern. The accuracy of the results might get affected in later stages. After conducting several experiments, a wide range of criteria was considered while designing the algorithm to eradicate the errors mentioned earlier until a certain extinct. Many commercial gloves use filters to reduce the effects, but, in this study, filters were not used. The filters were not considered in this study because the study's main aim was to design and develop a glove that incorporates MODAPTS into a sensing glove, providing unified, and reliable results. In further studies, filters such as the Kalman filter could be used.

3.3.1.6.1 Testing of Flexible sensor

One end of the flexible sensor was connected to the ground, whereas the other end was connected to the A0 (analog input pin) of the Arduino. A 10KΩ resistor was connected between A0 and +5V acted as a voltage divider. From this, it was observed that the higher the bend in the finger higher the resistance value. Arduino library for the flex sensors was created and dumped inside the library file to verify the sensors' working and the microcontroller. After connecting Arduino and circuit to the PC, the flex program was uploaded in the Arduino, and the flex sensor readings were shown on the serial monitor.

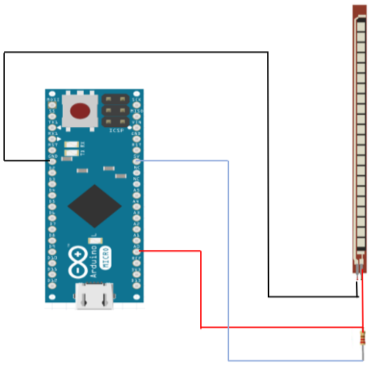

Figure 23 Circuit connections for testing flex sensor and Arduino.

Figure 23 shows the circuit connection of the sensor and the Arduino. The first experiment involved the working of the sensor when placed on the finger.

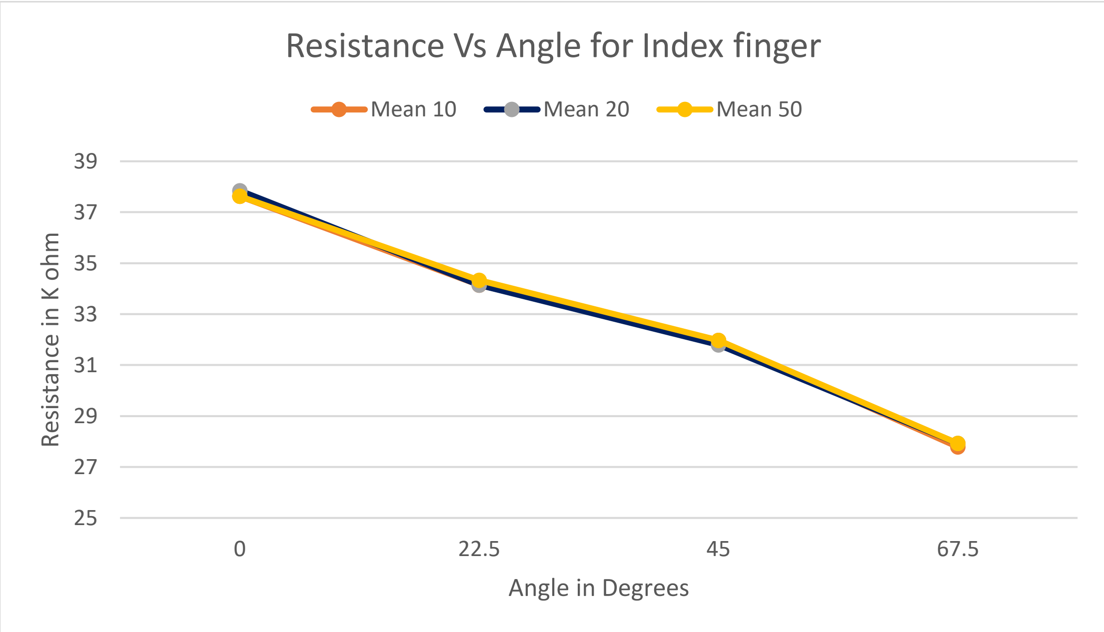

Figure 24 Resistance vs angle (Index finger)

The calibration for flex sensors was done on index finger and thumb. The thumb (consists of one joint and two phalanges) was selected because of it's biomechanism, which was slightly different from the other fingers and the index finger was calibrated as it had a similar mechanism as the other fingers(the other four fingers have two joints and three phalanges) [153]. The flex sensors were calibrated using a protractor and a small metal hinge to hold or keep the sensor in the measuring angle. This setup thus allowed the sensor to bend at the desired angle. For a single degree change in the angle, the corresponding digital value of voltage was measured. The flex sensor's calibration was conducted at 0, 22.5, 45, 67.5, and 90 degrees. From digital value, the resistance was calculated. The relationship between the angles and the resistance is shown in the figure 24. The same experiment was repeated for the thumb finger.

Calibration for the flex sensor was carried out at 0, 22.5, 45, 67.5, and 90 degrees. The resistance was measured from the digital value. The relation between the angles and the resistance was observed in Figure 25.

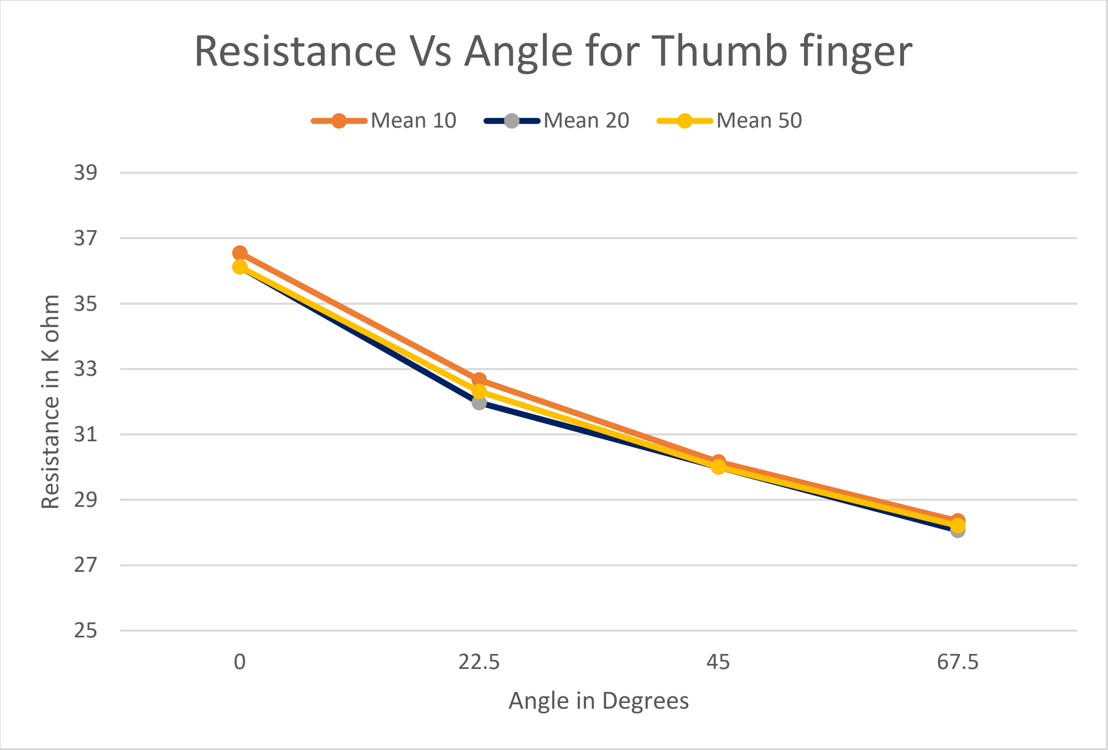

Figure 25 Resistance vs angle (Thumb finger)

3.3.1.6.2 Testing of Pressure sensor

The library for the pressure sensor was created and dumped into the Arduino to verify the sensors' working. Fig 26 shows the circuit connection of the force sensor before testing. And a resistor was connected between the voltage and analog pin. The second experiment involved testing the threshold of 0.5-inch pressure sensors. Only two pressure sensors were used in this study because most of the terminal actions (get or put) involves index and thumb comparatively. This experiment involved tasks like button a switch (requires one sensor) and lifting a coin (requires both sensors). A basic pressure sensor program was dumped in the Arduino to verify the working of the sensors.

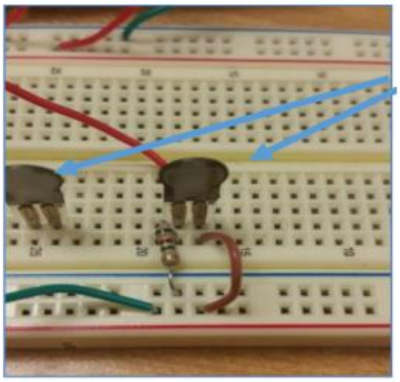

Figure 26 Pressure sensors before testing

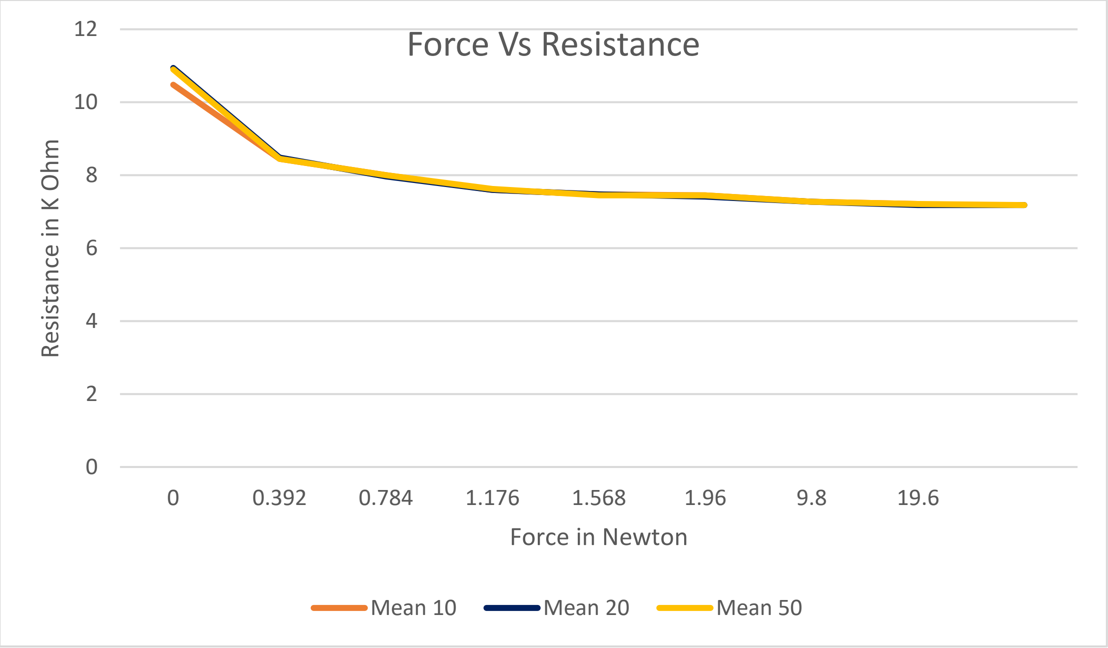

Figure 27 Threshold of one pressure sensor

The force sensor was placed on the weighing machine, and the measured value was removed by using tare. The entire setup was kept in a non-windy room to reduce the error caused by wind. The weights were gradually added from 0 to 5000 grams, and the digital values were calculated for each weight. The corresponding resistance values were measured. The relation between the force and resistance can be observed in the figure 27.

3.3.1.6.3 Testing of gyroscope (MPU6050)

Adding gyroscope functionality to the glove required us to connect it to the Arduino, power it, and configure it in software. For the gyroscope to interface with Arduino, it communicated through I2C protocol. The gyroscope was connected to Arduino, as shown in the Fig28. The power module of the gyroscope was connected to the 5v pin of the Arduino, and the ground of the gyroscope was connected to the ground of the Arduino.

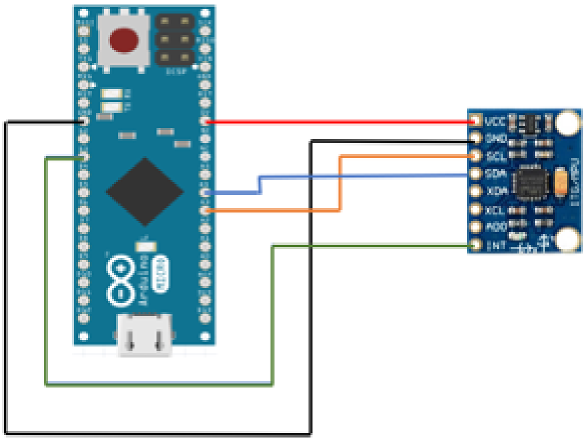

Figure 28 Connections for testing gyroscope and Arduino

INT pin on the gyroscope was connected to any digital pin of the Arduino. To set up the I2C lines SDA pin on the gyroscope was connected to the SDA (pin4) of the Arduino and SCL pin on the gyroscope to the Arduino(pin5) SCL pin. Arduino library for (MPU6050) was created and dumped inside the library folder. After connecting the incorporated circuit of the gyroscope and Arduino to the PC, the program was dumped in the Arduino; the readings appeared on the serial monitor.

3.3.1.6.4 Testing of Bluetooth (HC-05)

The HC 05 Bluetooth worked on serial communication, which transmitted one bit of data at a time. TX (transmit) and Rx (receiver) of the Bluetooth was not connected to the TX (transmit) and Rx (receiver) of the Arduino because there was not a transfer of the data. So, the TX (transmit) and Rx (receiver) of the Bluetooth were connected to the Rx (receiver) and TX (transmit) of the Arduino for the data to transfer. Figure 29 shows the Bluetooth's circuit connection. This study used serial Bluetooth terminal 1.31 applications for mobile purposes. Whereas for the PC, pairing was done to activate.

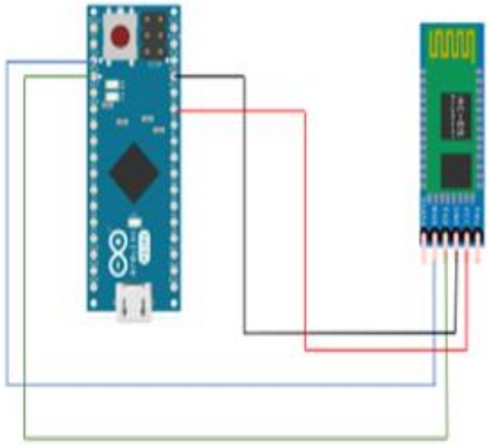

Figure 29 Connection of Arduino and Bluetooth (Testing)

3.3.1.6.5 Software Design and Implementation

In this study, the ATmega32u4 microcontroller needed to be programed. Out of many used program languages, Python and C programs were often used languages. The significant difference between C and Python was that Python was based on C. One can use both programs in multi-threading. C was a compiled language that was easier for a computer to understand, while Python was interpreted that read line by line, making Python slower than C. Python was a general-purpose programming language where C was primarily used for applications related to hardware [89]. The best coding program to use was C language, as the program was user friendly and compiled faster. When the glove detected any motion or any change in the analog value from the sensors and gyroscope, the change in the value was sent to the Arduino micro, which acted as a master, and the sensors acted as slaves. The information sent from the programmed sensors was displayed with the help of Arduino.

In this study, C language was used to program the ATmega32u4 microcontroller. The codes used during the integrations of individual sensors were modified and uploaded in the Arduino micro to test the interface of all the sensors, and the readings of the sensors and gyroscope are shown in Figure 35. Figure 36 describes the flowchart for the working of the glove. The algorithm could be coded in two different ways.

CASE 1: In this case, the algorithm was coded by considering the distance moved by the upper body while performing the task. Sensors like accelerometers needed to be used to measure the linear distances, for which this case needed additional accelerometers. This method increased the glove's weight and made it difficult to accommodate all the sensors in limited space, which increased the complexity to the operator while performing the task.

CASE 2: In this case, the algorithm was coded by setting a criterion. This was achieved by collecting the sensors' digital values while conducting several tasks, which required sensors that measured not only the flexion, rotations, and pressure (for touch or grasp) but also needed to be compact in its size. For this reason, after a wide research of all the alternative options, flex sensors, pressure sensors, and gyroscopes were selected.

Considering the complexity of usage, Case 2 was selected for the algorithm and the sensor's selection.

3.3.1.6.6 Assembly the Glove

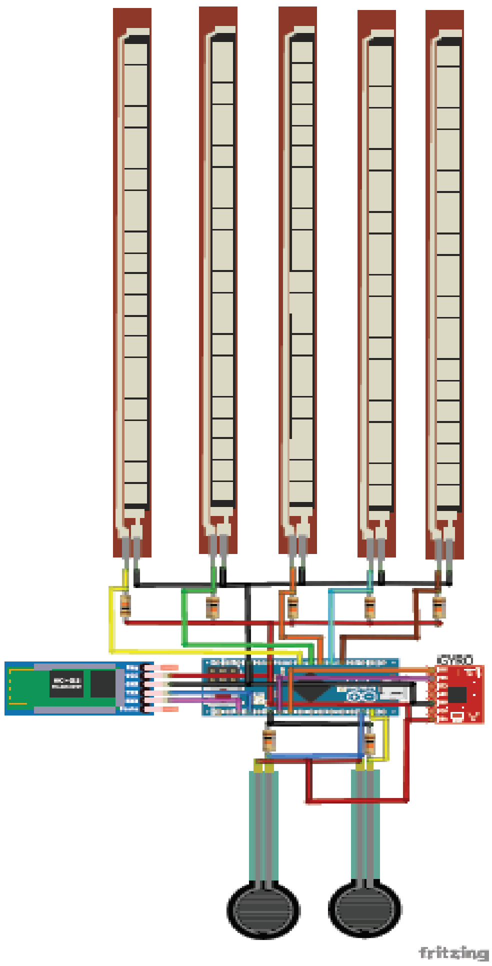

Figure 30 Integrations of all subsystems (testing)

In this study, the glove used the gyroscope for sensing the wrist's motion, the flex sensors for the motion of fingers and forearm, and the force sensor for the index and thumb fingers (Terminal actions). The incorporation of sensors, gyroscope, and Bluetooth were connected using fritzing software, as shown in the Figure 30. Two materials (cotton and blend of polyester & spandex) were chosen for this study. The cotton glove seemed to slacken after few uses, causing a deviation in the thresholds and affecting the results while testing. The second material was a combination of polyester and spandex glove that covered till elbow seemed to work well even after a few uses so, the second material was selected for this study. The aim of programing the glove was by reading the analog values from each sensor when the hand was held at different angles. The sensor values were noted, and the same experiment was repeated to compare and set a threshold range for each activity.

3.3.1.6.7 Determining Movement Class

M1 was termed as the movement of the knuckles. The sensors were placed on the fingers to detect the movement M1. The analog values were noted at different angles, and the range of values varied between 760 to 840.

M2 was the movement of the wrist. The gyroscope was placed on the wrist to detect the motion M2. When the gyroscope was placed on the wrist horizontally, the nominal values of X, Y, and Z were 360^0, 360^0, and 180^0. The threshold movements of the wrist were determined based on the gyroscope readings M2. The threshold limit was set to 600 after repeated experiments. Whenever there was a change in the threshold value, M2 was determined.

M3 was the movement of the elbow. A flexible sensor was placed on the elbow to detect the motion M3. After conducting several experiments, it was determined that if analog values are more than 810, it was detected as M3.

3.3.1.6.8 Terminal Actions Class

The terminal actions were categorized as GETS and PUTS. Pressure sensors were used to determine the values of GETS and PUTS.

Determining GETS

G0 was touch only and requires no consciousness, involved only one sensor, and if the sensor value was less than the nominal value (1023 ADC), the G0 event was recorded.

G1 was an activity that involved picking up objects of a certain thickness. If the sensors' values were combined, and below the 1900 ADC, it was detected as G1.

G3 was an activity that involved picking up flat objects with less thickness or no thickness. It requires high consciousness. If the values of sensors involved were combined, and if it was less than 500 ADC, it was determined as G3.

Determining PUTS

From figure 2 it was seen that P2, P5 were the high conscious activities that required visionary information. On the other hand, P0 was a low conscious activity which could be performed with no visionary help.

P0 was no conscious activity. (This activity does not need any feedback)
P2 was a high conscious activity, which requires feedback (Visionary information).
P5 was a high conscious activity, which requires two feedbacks. (Visionary Information) [40].

Whenever the GET event was not determined, and the analog value was at default, it was considered a PUT event. It sent an alert or prompt, which required feedback from the user or the analyst. Variation in the pressure sensor readings while performing a task determined either a GET or a PUT activity.

Initially, the glove was turned on, and it looked for the variations in the pressure sensors. If there was no change or variation in the pressure sensor's value (no work was done), then the glove waited until any change occurred in the pressure sensors. If there was a variation in the pressure sensor readings, GET events were determined. After the GET activity was recognized, the glove looked for a change in the flex and gyroscope values to determine the movements (M1, M2, and M3). If the sensor’s values were below the threshold, concerning movement (M1) and the Get activity were displayed. If the sensor’s value was above the threshold, then the concerned movement (M2 or M3), followed by the GET event, were determined, and displayed.

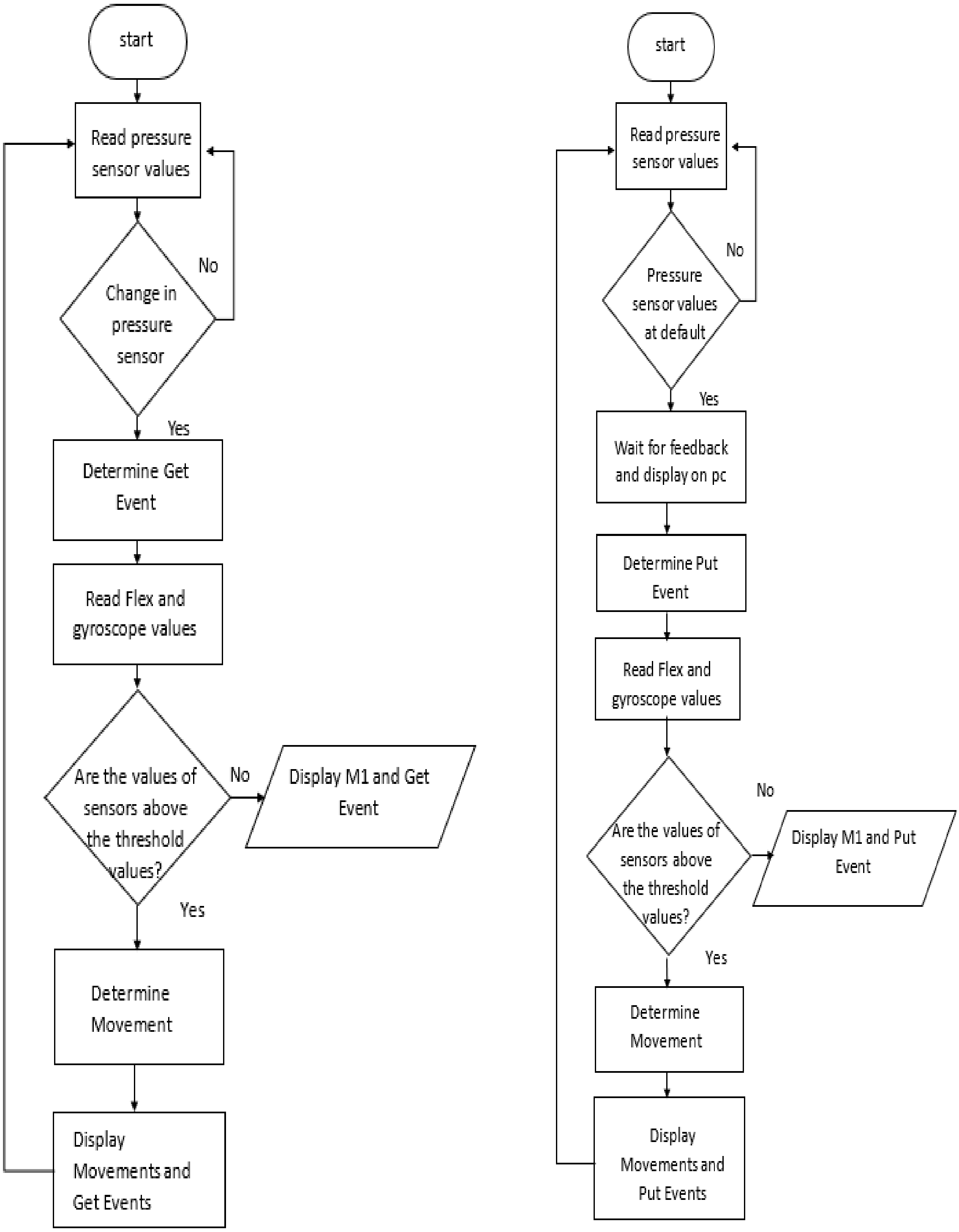

Figure 31 System flow chart

Figure 31 illustrates the program flowchart on how the glove reads the GET and PUT activities.

If the pressure sensor values were at default, the glove sent an alert to the system and waited for the feedback to determine if its p0, p2, or p5. After the PUT was determined, the glove looked for any changes in the flex and gyroscope values; if the values were not above the threshold level, then the movement and the PUT event were displayed. If the readings were above the threshold values, then the concerned movements and the PUT event was determined and displayed.

Figure 32 illustrates the sample of the glove. The sensors are placed on the glove temporarily and secured using the tape to ensure the sensors' positionings were placed accurately. Later the positioning of the sensors was marked and secured by sewing the sensors on the glove. The material of the glove was a mix of polyester and spandex. The weight of the glove does not make the operator restrict from performing complex operations. The sensors' combined life was more than a million life cycles, making the system more durable.

The weight of the gyroscope, 6 flex sensors, 2 pressure sensors, a Bluetooth and a micro controller was2.1 g, 1.62 g, 0.54 g, 3 g and 9.97 g respectively. The estimated weight of the glove including the wires and the flat bread board was around 30 grams.

Figure 32 Sample Glove Prototype

3.4 Sample study

A sample study was conducted to verify the working of the programmable glove. Simple tasks like simple touch and getting an object like a phone from the table were conducted. The results were compared with one of the references for the validation. Table 5 shows the comparison of the results with the proposed method results in this sample study. and Figure 33 illustrates the image of the glove while performing the task.

Table 5 Comparison of proposed method results with a reference.

S.no	Activity	Proposed Method	Reference results
1	Simple touch	M1G0	M1G0 [67]
2	Getting a phone from the table	M3G3	M3G3 [67]

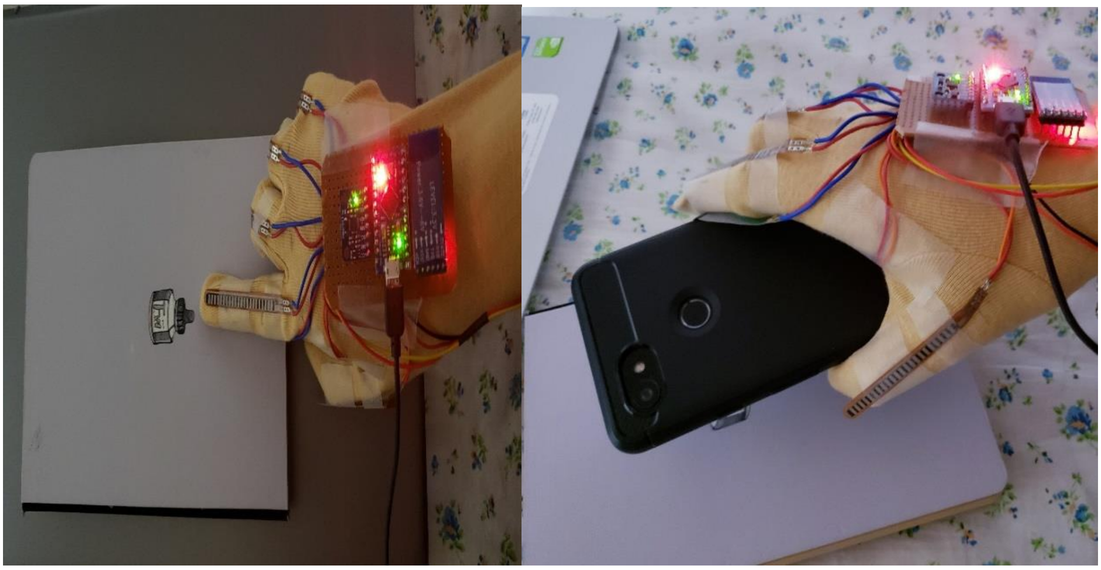

Figure 33 While performing the task using the glove

3.5 Tasks for pilot study

Considering the current pandemic, the study could not be performed on people, which may risk the participants emotionally. So to overcome this issue, this study was performed on the research personnel and the supervisor with the Research Safety Committee's permission.The experiment was conducted only on two members for several times to get adequate data.The sample test was conducted to verify if the current program and the hardware were working. In this section, few tasks were chosen to analyze the proposed method's coding efficiency over Traditional analysis. For this test, tasks involving all the movement and terminal activities were selected to verify the working.

Table 6 : Tasks and elements involved

Tasks	Elements Involved
Simple touch	M and Get,Put activity
Open the lid	M and Get activity
Stack two rectangular blocks	M and Put activity
Pick up Paper from the table	M and Get activity
Unstack the rectangular blocks	M and Get activity

Task -1, a simple touch task. The knuckle was involved in performing this simple touch task. Where the Movement (M) and Get, Put activity was involved.

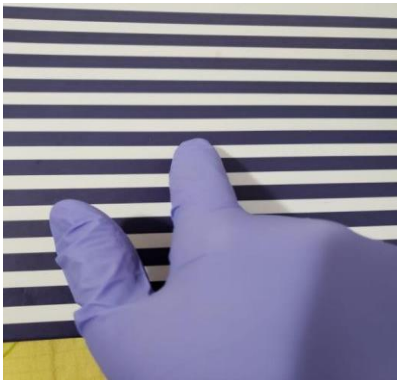

Figure 34: Simple Touch (Task 1)

Task - 2 Opening the lid must be performed. To perform this task, the lid must be opened, and it required movement in the elbow that was movement and Get activity.

Figure 35 : Opening the lid (Task 2)

Task - 3 , Two rectangular blocks were given and they were to be stacked. The height of the rectangular blocks were such that it involved the movement in the wrist and Put activity.

Task - 4 In this task, the rectangular blocks were to be unstacked.This task involved movement of the wrist and a Get activity.

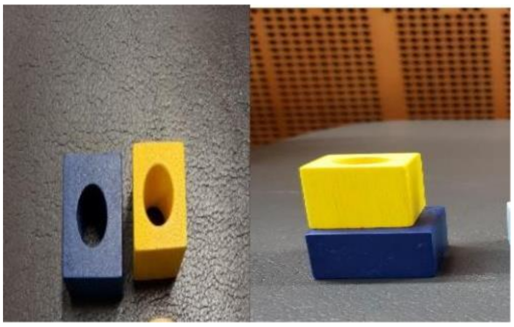

Figure 36: Unstack and stack the rectangular blocks (Task 3 and Task 4)

Task - 5 In this task, a paper was to be picked up from the table. To get the paper of less thickness, it required more contact between the pressure sensors; it involved the elbow, which was movement (M3), and the Get activity.

Figure 37 : Picking up the paper (Task 5)

Figure 37 shows the task that needed to be performed. The program was coded so that when there was more contact pressure detected by the sensors, then the necessary Get activity was displayed.

This study was limited to movements from the fingers up to the forearm and restricted to all other movements and crank rotations. This glove was designed specifically for the occupational sitting employees like solderers, panel builders, circuit inspection, and testing employees since these jobs require precision. Also, analyzing such working employees involved not only higher concentration and effort but also led to miscoding.

These tasks were chosen because they satisfy and address all the GET and PUT activities and the movements (M1, M2, and M3).

This section was categorized into two segments.

Segment-1(Traditional method): In segment 1, all the processes or tasks that were recorded were sent to the analyst, and the tasks in the video were narrowed down to small elements, and lastly, MODAPTS analysis was performed. All these tasks in this segment were performed manually. The tasks were to be analyzed by an Industrial Engineer, who was currently working as a Continuous Improvement Engineer with an experience of three years in the related field.

Segment-2 (Proposed method): In this method, the process needed to be finished using the glove, and the results of the proposed method were compared with the traditional method results.

The study was performed to design a glove that addressed the industrial needs and reduced the time taken to document a specified task and produced unified results. Each task was to be performed 10 times under four different temperatures (cold, warm, hot, room temperatures.) for 10 days. By completing the tasks numerous times, the external factors like temperature and humidity might come into action and play a key role in determining the results. When compiled together, all the results gave a better understanding of the performance of glove and areas that needed to be improvised.

3.6 Validation Test

The traditional method results were compared against the new proposed method to validate the test results. For this study, the concerned analysis or tests were performed. Two-way factor ANOVA analysis was performed to verify the results' consistency under the four temperatures to see if the temperatures affect the results. Also, the traditional and proposed method results were compared with the assistance of the Bar Graph. The traditional MODAPTS analysis was analyzed by the individuals who have knowledge and experience performing the MODPATS analysis. The tests were conducted for ten days under four different temperatures.

For example, Task 1 (Simple Touch) was performed under one temperature (Cold (14^0C)/Hot (>26^oC)/Room Temp(20^0C)/Warm (above 20^0C less than 26^{0C}).

Task performed per day = 10 times under each temperature.

Task performed for 10 days = 100 times under each temperature.

To replicate the temperatures, like room temperature, the thermostat was set to 20^{o} C, and the tasks were performed. Similarly, to replicate the cold temperature, the thermostat was set to 14^{o}C, as this was the lowest temperature that the thermostat could attain. The sensors performed the tasks at much lower temperatures(-30^{o}C) since the operating temperature range of the sensors was between -30^{o}C to -40^{o}C. For the hot and warm temperatures, the temperature above 26^{o}C was considered hot, and any temperature above 20^{o}C and below 26^{o}C was considered warm temperatures. The tasks were performed at specific times following the weather reports. The research personnel backyard was used to conduct the tasks under warm and hot temperatures. The thermostat was set to 14^{0}C to mimic the cold temperatures; the study was conducted in the basement. For the room temperature, the thermostat was set to 20^{0}C, and the experiment was performed in a room.

Approximately every task was performed 400 times (100 times under each temperature) by the research personnel for the precision and verifies if the results can be affected based on the environmental conditions. Factors that influence the results, such as drift, vibrations, and acoustics, were not considered in this current study.

3.7 Conclusion

This chapter began with a summary of the sensors and hardware connections and the glove's design with its hardware. Flex sensors, Pressure sensors, and Gyroscope were tested individually for their responsiveness. The incorporation of all the systems was connected with the help of the Schematics. The program was coded in a simple language and was programmed using analog values. For accuracy purposes, all the analog values used here were tested several times. A sample study was conducted to verify the working of the glove. A validation study will be conducted in the next chapter, and the results of the proposed method will be compared over the traditional method. The results will be validated by comparing the results using the Bar graph and concerned statistical analysis.

CHAPTER 4

RESULTS AND DISCUSSION

For the final prototype glove, the sensors were sewn on the glove after ensuring the sensor’s accurate positioning. Traditional MODAPTS analysis was performed on the given five tasks by an individual who had a decent knowledge on MODAPTS analysis. The standard results were compared over the proposed method results. The experiment was performed on two test subjects (the author and her supervisor) while wearing the glove in the proposed method. Initially, the test was conducted on the researcher. Each task was performed 10 times for 10 days under four different temperatures, starting at room temperature followed by warm, hot, and cold temperatures. As the results of the test subject 1 did not show any temperature and reliability variance, then the experiment on test subject 2 was finished within 1 day, and each task was performed 40 times.

4.1 Traditional and Proposed MODAPTS Results

The time of the converted traditional code was compared over the proposed method. The video of the operator was given to the MODAPTS analyst. The video was analyzed thoroughly and narrowed down to micromovements. Later, these micro-movements were converted into MODAPTS code and further converted into time by multiplying it by 0.129 sec, called MOD'S (all the body movements are multiples of a MOD).

Task 1: simple touch task involved knuckle movement. Hence, the MODAPTS code for this was M1. According to the MODAPTS rule, GET or PUT activity was to be joined with a movement activity. So, the code for task 1 was M1G0M1P0. The total MOD's for this task was 2.

Task 2: According to the analyst, the involved movement was of a forearm. Hence the MODAPTS code for this was M3, the GET activity involved in this task wasG1 (get the object). The MODAPTS code for task 2 wasM3G1. The total MOD's for this task was 4.

Task 3: Unstacking the block task involved a wrist movement, so the code for this movement was M2. The terminal activity for this task was a GET activity. G1 was coded for this activity because it required less consciousness, and also considering the thickness of the object, G1 was chosen. The code for this activity was M2G1. The total MOD's for this activity was 3.

Task 4: Stacking the block task involves a wrist movement, so the code for this movement was M2. The terminal activity for this task was a PUT activity. P5 was coded for this activity because the task required high consciousness while stacking the block. The code for this activity was M2P5. The total MOD's for this task was 7.

Task 5: Pick up the paper task involved forearm, so the movement code for this activity was M3. This task's terminal activity was a GET activity. G3 was coded for this activity because of the object thickness. The code for this task was M3G3, and the total MOD's for this activity was 6.

The sensors were sewn on the glove with normal thread. The tasks were performed by the researcher (Test Subject 1) wearing the glove. Tasks were performed under 4 different temperatures to observe any climate conditions that affected the results indirectly. Five simple tasks were conducted to verify the glove's working and its coding consistency with the collected hand movements data's assistance. Each task was conducted for 10 times under each temperature, and the experiment was repeated for 10 days. Figure 39 shows the final glove prototype.

Figure 38: Final Prototype of the glove

Following the weather forecasts, the tasks were conducted at particular times. The backyard of research personnel was used to carry out the activities at warm and hot temperatures. The thermostat was set at 14^0C to simulate the cold temperatures; the analysis was carried out in the basement. The thermostat was set to 20^0C for room temperature, and the experiment was conducted in a room.

Task 1 was a simple touch where the individual performed a simple tap on an object, and this task was performed by wearing the glove. Whenever the participant touched an object with the index finger, the pressure varied in the sensor and sent the controller's information. No variation in code was observed in task 1. Since the task was performed by the finger, the glove automatically sensed the movement as M1 and followed by a GET, PUT event G0, P0 respectively and the MOD value for this event was 2 MOD.

Task 2 involved an open box lid task, While performing the task, the code variation could be observed, and the most repeated code obtained in this task was M2G1 (at least for 343 times.), and the code of the traditional (M3G1) and proposed method code seemed to vary.

Task 3 involved unstacking and stacking of the rectangular blocks. While performing the task, a variation in codes was observed (Appendix -A), and the most repeated code obtained for this task was M2G1(380/440 times).

Task 4 involved stacking of the rectangular blocks. While performing the task, a variation in codes was observed (Appendix -A), and the most repeated code obtained for this task wasM2G1(380/440 times).

Task 5 involved picking up a paper. While performing the task, variation was seen, and the recurrent code was M3G3 (349/440 times).

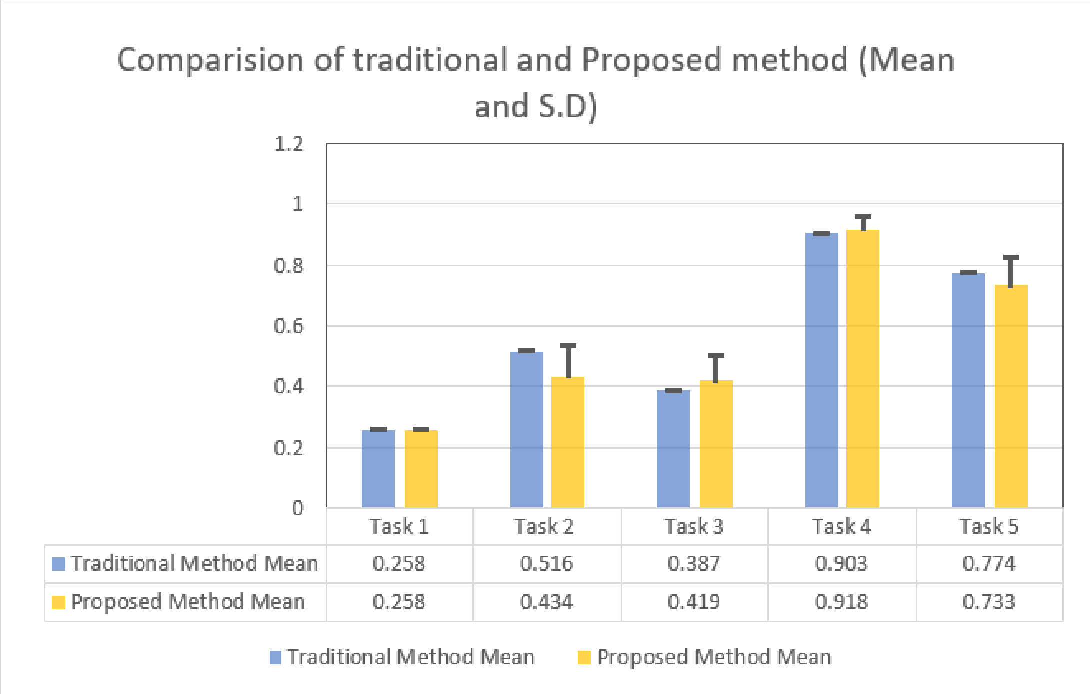

Figure 39 Comparision of traditional and Proposed method mean

Both traditional and Proposed method codes were converted into MOD's to get the time values. Figure 44 illustrates the mean and the standard deviation of the codes converted into time values by multiplying the code by 0.129 (1MOD = 0.129 sec). The mean and standard deviation of task 1 was the same. Variations were observed in task 2, task 3, task 4, and task 5.

From figure 44 ,it was observed that the code for task 2 traditional and raw proposed method was different and to verify the correct code for task 2, the recorded video for task 2 wasconverted into milliseconds.

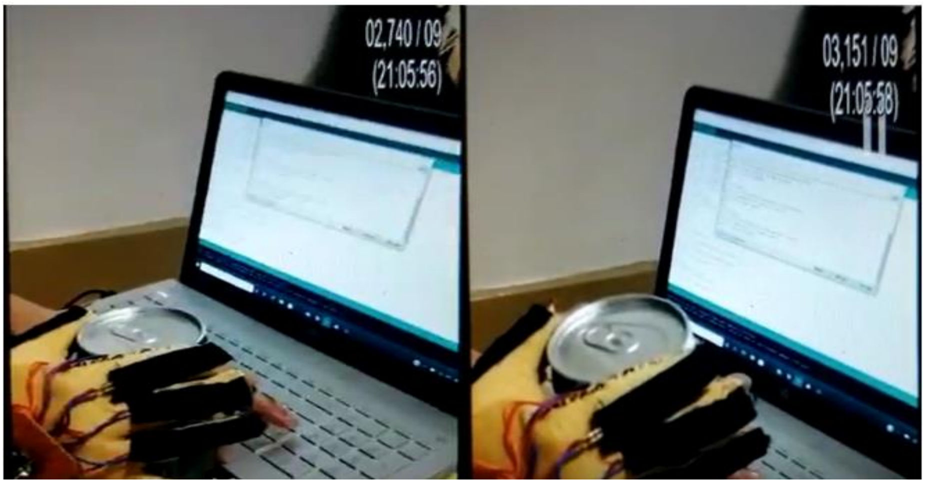

Figure 40 images of the start and end time of the task from the task 2 video.

Figure 45 illustrates the images of the start and end time of the task. The top right side shows the timestamps,in a 9-second video, the task started at 2.740 sec and ended at 3.151 seconds. So the real-time that took to finish the task 2 was around 0.411 sec (3.151 sec -2.740 sec). Out of the traditional (0.516 sec) and proposed method (0.387 sec), the proposed method seemed to be closer value to the real-time (0.411 sec).

The variation in task 2 of traditional MODAPTS analysis was because the results might vary based on the analyst's judgment. Defining the time standard using PMTS depended on the applicator's judgment [90].

4.2 Reliability

The most important design specification that needed to be met for this glove to be complete was its reliability and performance. It was not only necessary for the glove to have some way of outputting a MODAPTS code, but it also had to consistently translate the code correctly. To test the glove's reliability, five tasks were repeatedly performed for 10 days under four different temperatures for 10 times. This study tested each task for about 400 times, where each test involved the movements and the terminal activities. Openness was accorded to the algorithm to avoid any inconsistency that might occur in the results.

The variations in the temperature did not affect the proposed method results because the specification of this gyroscope could be operated at high temperatures and comparing the specifications of the sensors (pressure and flex), the glove used in this study operated from a range of 15 to 40 degrees with no significant change in the results. Vibration might affect the results, but since the criteria set for detecting gyroscope was more 45 degrees, there might be a change for false detection, yet this problem was not faced while conducting the study. Also, factors like acoustic noises will affect the output. The user-friendliness requirement was based on the speed and minimizing the difficulty of accurate translations and battery replacement [73]. The glove can be turned on by pairing up with the bluetooth terminal, and then it automatically translates each gesture. The reliability testing showed a high precision in translating the code.

From appendix C, the average and variance of the tasks under four different temperatures were seen. The variances for all tasks were small. Considering temperature and day as the two independent variables two way ANOVA was performed to compare the results' variation to validate the reliability and uniformity.

Table 7 Two way ANOVA Summary Table for Task 2

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Day	0.029	9	0.003	0.424	0.921	1.905
Temperatures	0.004	3	0.001	0.209	0.889	2.629
Interaction	0.160	27	0.005	0.776	0.782	1.516
Within	2.759	360	0.007			
Total	2.953	399				

Table 7 indicated that there were no significant differences in the task 2 by both number of days of experiment (f (9)=0.424, p > 0.05) and temperature variations (f(3)=0.209, p > 0.05), the interaction between the two independent variables (days and temperatures) didn’t show any effect.

Table 8 Two way ANOVA Summary Table for Task 3

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Day	0.056	9	0.0062	0.47	0.893	1.905
Temperature	0.015	3	0.005	0.40	0.753	2.629
Interaction	0.127	27	0.004	0.35	0.999	1.516
Within	4.792	360	0.013			
Total	4.992	399				

Table 8 had shown that there were no significant disparities in task 3 between the number of days of the experiment (f (9)=0.47, p > 0.05) and the temperature deviations (f(3)=0.40, p > 0.05), and that the relationship between the two independent variables (days and temperatures) had no impact.

Table 8 Two way ANOVA Summary Table for Task 4

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Day	0.010	9	0.001	0.561	0.828	1.90
Temperature	0.001	3	0.0004	0.225	0.878	2.62
Interaction	0.027	27	0.001	0.469	0.989	1.51
Within	0.773	360	0.002			
Total	0.813	399				

Table 9 reveals that there were no significant differences in task 4 between the number of days of the experiment (f(9)=0.561, p >0.05) and temperature fluctuations (f(3)=0.225, p >0.05) and there was also no influence on the relationship between the two independent variables (days and temperatures) (days and temperatures) (days and temperatures).

Table 9 Two way ANOVA Summary Table for Task 5

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Day	0.078	9	0.008	1.649	0.099	1.905
Temperature	0.027	3	0.009	1.733	0.159	2.629
Interaction	0.148	27	0.005	1.044	0.406	1.516
Within	1.900	360	0.005			
Total	2.155	399				

Table 10 clearly shows that there were no significant disparities in task 5 between the number of days of the experiment (f (9) = 1.649, p > 0.05) and the temperature divergence (f(3) = 1.733, p > 0.05), and that the relationship between the two independent variables (days and temperatures) had no effect.

CHAPTER 5

CONCLUSION AND LIMITATION

Wearable technology has caught up to the trend in this fast-paced generation, carving out a niche for itself in numerous sectors of technological applications. While this has been true to sectors like science, health, and communications, there are negligible constructive studies based on its integration into industrial applications.

This study aimed to design and develop a prototype glove with sensors, in order to automatically collect motion data and assign MODAPTs codes to the recorded movement, based on the angles of the movements. The study had several objectives: (1) produce unified, reliable results in an automated fashion; and (2) develop a device that saves time and effort, while maintaining performance and consistency (based on low standard deviation). Currently, there are no studies incorporating wearable technology into the PMTS methods.

This prototype glove requires to be made more robust for a production environment. However, the basic design and construction are appropriate for mass production environments. The results showed that a wearable technology could be used to collect movements and assign MODAPTs codes automatically. This would allow smaller companies that currently cannot afford the usage of professional MODAPT's analysis, to flourish.

Flex sensor, pressure sensor and gyroscope, HC-05, and Arduino pro micro were considered based on the hardware and electrical specifications. All the sensors were individually tested and integrated into one subsystem. The program was coded by collecting analog values. This study has presented flex sensors, pressure sensors, and gyroscopes in forming a wearable sensing glove.

The consistency of the collection and MODAPTs assignments were verified. Some tests were conducted to verify the results by comparing the traditional and proposed methods. The experiment was also conducted under different environmental conditions (e.g., cold, hot, warm, and room temperatures, with different humidity) to determine if ambient temperature affected the results. Each task was performed over 440 times to validate the data. Task 2 traditional results varied from the proposed method results. To verify the correct codes, both results were compared with real-time results. It was observed that the proposed method results were accurate with the real-time results. The variance was found in task 2 of the traditional and proposed MODAPTS analysis. The variation in the results depended on the analyst's judgment since the interpretation of the time standard using PMTS relied on the analyst's assessment. Two-way ANOVA analysis was performed to verify any variation in results when performed under different temperature conditions. The results did not show any significant difference.

The testing was limited to two team members, because of current physical distancing restrictions due to COVID-19. Although the glove was a prototype, it showed that using a glove outfitted with sensors and a microcontroller was able to translate gestures accurately and automatically. It satisfied all of the major requirements. The temperature did not seem to affect the results since the sensors operated at high and low temperatures.

Although several wearable gloves were available in the current market, most of the gloves were sign language - based gloves, commercial (commercial glove-based system is a means to handle the quandary of communication for deaf and mute individuals.) and other gloves [92-151]. Wearable sensors were used in many fields. This study was a combination of both wearable technology and the MODAPTS (PMTS) technique. Automating such techniques aimed at saving time and cost, while ensuring consistency and reliability. This glove could be used for industrial applications by optimizing the glove design and other features.

5.1 Limitations

Due to the current COVID 19 conditions, this study was conducted on the author and her supervisor because conducting experiments on other participants during the pandemic was prohibited. To overcome the issues associated with recruiting the participants, this study collected 440 trials for each task from two test subjects.

MODAPTS codes were classified into three types:(1) Move actions, (2) Terminal actions (Gets and Puts), and (3) Other elements. P2, P5 was the terminal actions that required high consciousness activities that necessitated the feedback. To overcome this issue, the program was coded, so whenever the sensors recognize an activity of Put the Arduino gave a quick alert to the connected Bluetooth devices (PC/Mobile) to overcome the issue of defining the high conscious activities (P2, and P5).

5.2 Future Studies

To help shape the glove into something slimmer and comfortable, designing a PCB (Printed Circuit Board) could be used, and furthermore, replacing the bulky wirings with conductive fabric allowed for less bulky wiring and more conforming lightweight connections. Factors such as acoustic noises, vibrations could be controlled by enclosing the sensors with the denser black foam that acted as the best isolator. External factors such as vibration, acoustics, and drift were not included in the testing and would need to be done in further testing. The glove design was not flexible for everyone to wear because of different body dimensions and the placement of the sensors varied based on every individual, but in this study, this current design did not affect the results. For a production environment, the glove would need to be designed and manufactured for high usage and a variety of hand sizes. In the future, this issue could be sorted out by using fabric sensors glove (fit for all). The prototype glove was designed to test a limited set of movements. The design would need to be modified for greater utility in data collection and MODAPTs assignment. For future purposes, this glove could be used for other PMTS techniques by altering the algorithm and by creating separate library files for each time study.

REFERENCES

[1]Dictionary.com. (2011, March) Dictionary.com. [Online]. http://dictionary.reference.com/browse/effective?s=t

[2] S. Pavlina. (2011, Mar.) Steve Pavlina.com personal development for smart people. [Online]. http://www.stevepavlina.com/blog/2005/10/what-is-productivity/

[3]BuisinessDictionary.com. (2011, March) BuisinessDictionary.com. [Online]. http://www.businessdictionary.com/definition/productivity.html

[4] Laring J, Forsman M, Kadefors R, Örtengren R. MTM-based ergonomic workload analysis. Int JInd Ergon. 2002; 30:135-48.

[5] Kung M, O'Connel M, Tristan E, Dishman B. Simulate the job: Predicting accidents using a work sample. J Organ Psychol. 2012; 12:145-54.

[6] Kanatawy G. Introduction to work study. Geneva: International Labour Office; 1992.

[7] https://www.techopedia.com/definition/32509/principal-component-analysis-pca

[8] https://en.wikipedia.org/wiki/Activity_recognition

[9] https://en.wikipedia.org/wiki/Wearable_technology

[10] https://en.wikipedia.org/wiki/Resistor

[11] https://www.codrey.com/embedded-systems/serial-communication-basics/

[12] Rashid A, Hasan O. Wearable technologies for hand joints monitoring for rehabilitation: A survey. Microelectronics Journal. 2019 Jun 1; 88:173-83.

[13] Golabchi A, Han S, AbouRizk S, Kanerva J. Simulation-based analysis of operational efficiency and safety in a virtual environment. In2016 Winter Simulation Conference (WSC) 2016 Dec 11 (pp. 3325-3336). IEEE.

[14] Tak S, Buchholz B, Punnett L, Moir S, Paquet V, Fulmer S, Marucci-Wellman H, Wegman D. Physical ergonomic hazards in highway tunnel construction: overview from the Construction Occupational Health Program. Applied ergonomics. 2011 Jul 1;42(5):665-71.

[15] David GC. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occupational medicine. 2005 May 1;55(3):190-9.
[16] Golabchi A, Han S, Fayek AR, AbouRizk S. Stochastic modeling for assessment of human perception and motion sensing errors in ergonomic analysis. Journal of Computing in Civil Engineering. 2017 Jul 1;31(4):04017010.
[17] Kadefors R, Forsman M. Ergonomic evaluation of complex work: a participative approach employing video–computer interaction, exemplified in a study of order picking. International Journal of Industrial Ergonomics. 2000 May 1;25(4):435-45.
[18] G.C. David, Ergonomic methods for assessing exposure to risk factors for work related musculoskeletal disorders, Occup. Med. 55 (3) (2005) 190–199, https://doi.org/10.1093/occmed/kqi082.
[19] Burns, J.E. and Simerson, F.W., 1959. Fundamentals of predetermined time standards and a comparison of five systems. Ind. Manage., February: 11-16.
[20] Frederick, C.W., 1960. On obtaining consistency in application of predetermined time systems. J. Ind. Eng., XI (1): 18-19.
[21] Sanfleber, H., 1967. An investigation into some aspects of the accuracy of predetermined motion time systems. Int. J.Prod. Res., 6 (1): 25-45.
[22] Barnes, R.M., 1980. Motion and Time Study, Design and Measurement of Work. John Wiley & Sons, New York.
[22] Konz, S., 1983. Work Design: Industrial Ergonomics. Publishing Horizons, Columbus, OH.
[23] Wu S, Wang Y, BolaBola JZ, Qin H, Ding W, Wen W, Niu J. Incorporating motion analysis technology into modular arrangement of predetermined time standard (MODAPTS). International Journal of Industrial Ergonomics. 2016 May 1; 53:291-8.
[24] Cho H, Lee S, Park J. Time estimation method for manual assembly using MODAPTS technique in the product design stage. International Journal of Production Research. 2014 Jun 18;52(12):3595-613.
[25] Buys T, van Biljon H. Functional capacity evaluation: An essential component of South African occupational therapy work practice services. Work. 2007; 29(1):31-6.
[26] Golabchi A, Guo X, Liu M, Han S, Lee S, AbouRizk S. An integrated ergonomics framework for evaluation and design of construction operations. Automation in Construction. 2018 Nov 1; 95:72-85.
[27] Niebel, B.W., 1988. Motion and Time Study. Irwin, Homewood, 1L.
[28] Air Force Business Research Management Center (AFBRMC), April 1987. Manufacturing work measurement system evaluation. Department of the Air Force, Air Force Business Research Management Center, Wright-Patterson Air Force Base, OH.
[29] Davidson, H.O., 1952. Function and bases of time standards. Research Report, American Institute of Industrial Engineers, Columbus, OH.
[30] Whitmore, D.A., 1968. Work Study and Related Management Services. William Heinemann Ltd., London, England.
[31] Institute of Industrial Engineers, 1983. Industrial Engineering Terminology. Industrial Engineering and Management Press, Norcross, GA.
[32] Wygant RM. A comparison of computerized predetermined time systems. Computers & industrial engineering. 1989 Jan 1;17(1-4):480-5.
[33] Heyde, Chris. (1978) The Sensible Taskmaster. Sydney, Aus.: G.C. Heyde. P. 99.
[34] International MODAPTS Association. (I.M.A.) (1999) MODAPTS Instruction Manual. Washington, D.C.: I. M. A. p 3.
[35] Heyde. Ibid. p. 24
[36] Gerber, D. L. (1989) . MODAPTS PLUS. Walnut Creek, CA: Management Research Frontiers, Inc.
[37] Razmi J, Shakhs-Niyaee M. Developing a specific predetermined time study approach: an empirical study in a car industry. Production Planning and Control. 2008 Jul 1;19(5):454-60.
[38] Wu S, Wang Y, BolaBola JZ, Qin H, Ding W, Wen W, Niu J. Incorporating motion analysis technology into modular arrangement of predetermined time standard (MODAPTS). International Journal of Industrial Ergonomics. 2016 May 1; 53:291-8.

[39] Wygant RM, White BE, Hunt D. Combining ergonomics and work measurement for job analysis. Computers & industrial engineering. 1993 Sep 1;25(1-4):423-6.
[40] M. D., Erwin, W.W. Shinnick, "Work measurement system creates shared responsibility among workers at Ford.," *Industrial Engineering*, vol. 21, no. 8, p. 28, August 1989.
[41] Sicchio, K.; Guler, S.D.; Gannon, M. A Brief History of Wearables. In Crafting Wearables; Aress: Chicago Ridge, IL, USA, 2016.
[42] Sazonov, E.; Neuman, M.R. Wearable Sensors; Sazonov, E., Ed.; Academic Press: Cambridge, MA, USA, 2014.
[43] Plamondon, A.; Delisle, A.; Larue, C.; Brouillette, D.; Mcfadden, D. Evaluation of a hybrid system for three-dimensional measurement of trunk posture in motion. Appl. Ergon. 2007, 38, 697–712. [CrossRef] [PubMed]
[44] Nordander, C.; Balogh, I.; Mathiassen, S.E.; Ohlsson, K.; Unge, J.; Skerfving, S. Precision of measurements of physical workload during standardised manual handling. Part I: Surface electromyography of m. trapezius, m. infraspinatus and the forearm extensors. J. Electromyogr. Kinesiol. 2004, 14, 443–454. [CrossRef] [PubMed]
[45] Dipietro, L.; Sabatini, A.M.; Dario, P. A survey of glove-based systems and their applications. IEEE Trans. Syst. Man Cybern. Part C Appl. Rev. 2008, 38, 461–482. [CrossRef]
[46] Dobkin, B.H.; Dorsch, A. The promise of mHealth: Daily activity monitoring and outcome assessments by wearable sensors. Neurorepair. Neural Repair 2011, 25, 788–798. [CrossRef] [PubMed]
[47] Liang, T.; Yuan, Y.J.; Member, S. Wearable medical monitoring systems based on wireless networks: A Review. IEEE Sens. 2016, 16, 8186–8199. [CrossRef]
[48] ProGlove. Available online: http://www.proglove.de/ (accessed on 11 January 2019).
[49] XSens, Xsens MVN. Available online: https://www.xsens.com/products/xsens-mvn/ (accessed on 11 January 2019).
[50] Bae Systems Q-Sight®Helmet. Available online: http://www.baesystems.com/enuk/product/qsighthelmet-mounted-displays (accessed on 11 January 2019).
[51] Vandrico. Available online: http://vandrico.com (accessed on 11 January 2019).
[52] Teksan. Available online: https://www.tekscan.com/pressure-mapping-sensors (accessed on 11 January 2019).
[53] Tessarolo, M.; Luca Possanzini, L.; Campari, E.G., Buonfiglio, R.; Francesco Saverio Violante, F.S. Adaptable pressure textile sensors based on a conductive polymer. Flex. Print. Electron. 2018. [CrossRef]
[54] G. Saggio, F. Riillo, L. Sbernini, L. R. Quitadamo, Resistive Flex Sensors: A Survey, Smart Materials and Structures 25 (1) (2015) 013001. [55] Rashid A, Hasan O. Wearable technologies for hand joints monitoring for rehabilitation: A survey. Microelectronics Journal. 2019 Jun 1;88:173-83.
[56] Heyde GC. Concepts and history of Modapts Plus. Heyde Dynamics; 1983.
[57] Irwin, W. (1989). CAESAR. New Bern, NC: Industrial Engineering Services.
[58] Shinnick, M. D. (1989). Task Master. Blacksburg, VA: Dynamics Research Group.
[59] Golabchi A, Guo X, Liu M, Han S, Lee S, AbouRizk S. An integrated ergonomics framework for evaluation and design of construction operations. Automation in Construction. 2018 Nov 1; 95:72-85.
[60] Wu S, Wang Y, BolaBola JZ, Qin H, Ding W, Wen W, Niu J. Incorporating motion analysis technology into modular arrangement of predetermined time standard (MODAPTS). International Journal of Industrial Ergonomics. 2016 May 1; 53:291-8.
[61] Stassi S, Cauda V, Canavese G, Pirri CF. Flexible tactile sensing based on piezoresistive composites: A review. Sensors. 2014 Mar;14(3):5296-332.
[62]https://www.theengineeringprojects.com/2018/09/introduction-to-arduino-micro.html
[63] B. Higginbotham (2016). “Behind the Scenes: Assessing Wearable Battery Safety”, UL: Newsroom [Online]. Available: https://ul.com/newsroom/featured/behind-the-scenes-assessing-wearable-batterysafety/ [Accessed: April 4, 2016].
[64]http://site.iugaza.edu.ps/aschokry/files/2010/02/Dr._Abed_Schokry_IU_GAZA_Dep_IE_Determining_Time_[Compat.pdf

[65] https://wiki.eprolabs.com/index.php?title=Bluetooth_Module_HC-05
[66]https://www.electronicwings.com/sensors-modules/mpu6050-gyroscope-accelerometer-temperature-sensor-module
[67]http://site.iugaza.edu.ps/aschokry/files/2010/02/Dr._Abed_Schokry_IU_GAZA_Dep_IE_Determining_Time_[Compat.pdf
[68] Krishna B, Eilon S. A comparison between work factor and methods time measurement systems in work measurement for short cycles. Production Engineer. 1960 Jun;39(6):377-82.
[69] Razmi J, Shakhs-Niyaee M. Developing a specific predetermined time study approach: an empirical study in a car industry. Production Planning and Control. 2008 Jul 1;19(5):454-60.
[70] Harmse S. Evaluating validity of MODAPTS as an assessment method of work speed in relation to the open labour market (Doctoral dissertation, University of Pretoria).
[71] https://www.mikopg.com/faq.html
[72] Cyberglove Systems, http://www.cyberglovesystems.com/ Cyberglove-iii/ (2017).
[73] B. OFlynn, J. T. Sanchez, J. Connolly, J. Condell, K. Curran, P. Gardiner,B. Downes, Integrated Smart Glove for Hand Motion Monitoring, in: Sensor Device Technologies and Applications, 2015.
[74] **Rashid** A, Hasan O. Wearable technologies for hand joints monitoring for rehabilitation: A survey. Microelectronics Journal. 2019 Jun 1; 88:173-83.
[75] C. Yu, X. Wang, H. Huang, J. Shen, K. Wu, Vision-based Hand Gesture Recognition using Combinational Features, in: Intelligent Information Hiding and Multimedia Signal Processing, 2010, pp. 543{546.
[76] T. Kapuscinski, M. Wysocki, Hand Gesture Recognition for Man machine Interaction, in: Robot Motion and Control, 2001, pp. 91{96.
[77] P. Kumar, J. Verma, S. Prasad, Hand Data Glove: A Wearable Real Time Device for Human-computer Interaction, International Journal of Advanced Science and Technology 43 (2012) 15{25.27
[78] J. Connolly, K. Curran, J. Condell, P. Gardiner, Wearable Rehab Technology for Automatic Measurement of Patients with Arthritis, in: Pervasive Computing Technologies for Healthcare, 2011, pp. 508{509.
[79] B. O'Flynn, J. T. Sanchez, P. Angove, J. Connolly, J. Condell, K. Curran, P. Gardiner, Novel Smart Sensor Glove for Arthritis Rehabilitation, in: Body Sensor Networks, 2013, pp. 1{6.
[80] L. Gallo, A Glove-based Interface for 3D Medical Image Visualization, in: Intelligent Interactive Multimedia Systems and Services, Springer, 2010, pp. 221{230.
[81] D. VHand, 2.0 OEM Technical Datasheet, Tech. rep., DGTech Engineering Solutions (2007).
[82] T. G. Zimmerman, J. Lanier, C. Blanchard, S. Bryson, Y. Harvill, A Hand Gesture Interface Device, in ACM SIGCHI Bulletin, Vol. 18, ACM, 1987, pp. 189{192.
[83] L. Simone, E. Elovic, U. Kalambur, D. Kamper, A Low Cost Method to Measure Finger Flexion in Individuals with Reduced Hand and Finger Range of Motion, in: Engineering in Medicine and Biology Society, Vol. 2, IEEE, 2004, pp. 4791{4794.
[84] https://components101.com/sensors/flex-sensor-working-circuit-datasheet
[85] https://components101.com/sensors/fsr400-force-sensor
[86] https://components101.com/sensors/mpu6050-module
[87] https://components101.com/wireless/hc-05-bluetooth-module
[88] https://components101.com/microcontrollers/arduino-pro-mini
[89] https://www.educba.com/c-vs-python/
[90] Genaidy AM, Mital A, Obeidat M. The validity of predetermined motion time systems in setting production standards for industrial tasks. International Journal of Industrial Ergonomics. 1989 Apr 1;3(3):249-63.
[91] Quintana R, Hernandez-Masser V. Limiting design criteria framework for manual electronics assembly. Human Factors and Ergonomics in Manufacturing & Service Industries. 2003 Mar;13(2):165-79.

[92] Das P., De R., Paul S., Chowdhury M., Neogi B. Analytical study and overview on glove based Indian Sign Language interpretation technique; Proceedings of the Michael Faraday IET International Summit 2015; Kolkata, India. 12–13 September 2015.
[93] Sharma V., Kumar V., Masaguppi S.C., Suma M., Ambika D. Virtual Talk for Deaf, Mute, Blind and Normal Humans; Proceedings of the 2013 Texas Instruments India Educators' Conference (TIIEC); Bangalore, India. 4–6 April 2013; pp. 316–320.
[94] Fu Y.F., Ho C.S. Static finger language recognition for handicapped aphasiacs; Proceedings of the Second International Conference on Innovative Computing, Information and Control; Kumamoto, Japan. 5–7 September 2007; p. 299.
[95] Preetham C., Ramakrishnan G., Kumar S., Tamse A., Krishnapura N. Hand talk-implementation of a gesture recognizing glove; Proceedings of the 2013 Texas Instruments India Educators' Conference (TIIEC); Bangalore, India. 4–6 April 2013; pp. 328–331.
[96] el Hayek H., Nacouzi J., Kassem A., Hamad M., El-Murr S. Sign to letter translator system using a hand glove; Proceedings of the 2014 Third International Conference on e-Technologies and Networks for Development (ICeND); Beirut, Lebanon. 29 April–1 May 2014; pp. 146–150.
[97] Praveen N., Karanth N., Megha M. Sign language interpreter using a smart glove; Proceedings of the 2014 International Conference on Advances in Electronics, Computers and Communications (ICAECC); Bangalore, India. 10–11 October 2014; pp. 1–5
[98] Ahmed S., Islam R., Zishan M.S.R., Hasan M.R., Islam M.N. Electronic speaking system for speech impaired people: Speak up; Proceedings of the 2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT); Dhaka, Bangladesh. 21–23 May 2015; pp. 1–4.
[99] Kadam K., Ganu R., Bhosekar A., Joshi S. American sign language interpreter; Proceedings of the 2012 IEEE Fourth International Conference on Technology for Education (T4E); Hyderabad, India. 18–20 July 2012; pp. 157–159.
[100] Fu Y.F., Ho C.S. Development of a programmable digital glove. Smart Mater. Struct. 2008; 17:025031. doi: 10.1088/0964-1726/17/2/025031.
[101] Chouhan T., Panse A., Voona A.K., Sameer S. Smart glove with gesture recognition ability for the hearing and speech impaired; Proceedings of the 2014 IEEE Global Humanitarian Technology Conference-South Asia Satellite (GHTC-SAS); Trivandrum, India. 26–27 September 2014; pp. 105–110.
[102] Aguiar S., Erazo A., Romero S., Garcés E., Atiencia V., Figueroa J.P. Development of a smart glove as a communication tool for people with hearing impairment and speech disorders; Proceedings of the 2016 IEEE Ecuador Technical Chapters Meeting (ETCM); Guayaquil, Ecuador. 12–14 October 2016; pp. 1–6.
[103] Tanyawiwat N., Thiemjarus S. Design of an assistive communication glove using combined sensory channels; Proceedings of the 2012 Ninth International Conference on Wearable and Implantable Body Sensor Networks (BSN); London, UK. 9–12 May 2012; pp. 34–39.
[104] Abualola H., al Ghothani H., Eddin A.N., Almoosa N., Poon K. Flexible gesture recognition using wearable inertial sensors; Proceedings of the 2016 IEEE 59th International Midwest Symposium on Circuits and Systems (MWSCAS); Abu Dhabi, UAE. 16–19 October 2016; pp. 1–4.
[105] Bhatnagar V.S., Magon R., Srivastava R., Thakur M.K. A cost-effective Sign Language to voice emulation system; Proceedings of the 2015Eighth International Conference on Contemporary Computing (IC3); Noida, India. 20–22 August 2015; pp. 521–525.
[106] Bui T.D., Nguyen L.T. Recognizing postures in Vietnamese sign language with MEMS accelerometers. IEEE Sens. J. 2007; 7:707–712. doi: 10.1109/JSEN.2007.894132.
[107] Elmahgiubi M., Ennajar M., Drawil N., Elbuni M.S. Sign language translator and gesture recognition; Proceedings of the 2015 Global Summit on Computer & Information Technology (GSCIT); Sousse, Tunisia. 11–13 June 2015; pp. 1–6.
[108] Sharma D., Verma D., Khetarpal P. LabVIEW based Sign Language Trainer cum portable display unit for the speech impaired; Proceedings of the 2015 Annual IEEE India Conference (INDICON); New Delhi, India. 17–20 December 2015; pp. 1–6.

[109] Arif A., Rizvi S.T.H., Jawaid I., Waleed M.A., Shakeel M.R. Techno-Talk: An American Sign Language (ASL) Translator; Proceedings of the 2016International Conference on Control, Decision and Information Technologies (CoDIT); Saint Julian, Malta. 6–8 April 2016; pp. 665–670.
[110] Jadhav A.J., Joshi M.P. AVR based embedded system for speech impaired people; Proceedings of the International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT); Pune, India. 9–10 September 2016; pp. 844–848.
[111] Phi L.T., Nguyen H.D., Bui T.Q., Vu T.T. A glove-based gesture recognition system for Vietnamese sign language; Proceedings of the 2015 15th International Conference on Control, Automation and Systems (ICCAS); Busan, Korea. 13–16 October 2015; pp. 1555–1559.
[112] Gupta D., Singh P., Pandey K., Solanki J. Design and development of a low cost Electronic Hand Glove for deaf and blind; Proceedings of the 2015 2nd International Conference on Computing for Sustainable Global Development; New Delhi, India. 11–13 March 2015; pp. 1607–1611.
[113] Lei L., Dashun Q. Design of data-glove and Chinese sign language recognition system based on ARM9; Proceedings of the 2015 12th IEEE International Conference on Electronic Measurement & Instruments (ICEMI); Qingdao, China. 16–18 July 2015; pp. 1130–1134.
[114] Oz C., Leu M.C. Linguistic properties based on American Sign Language isolated word recognition with artificial neural networks using a sensory glove and motion tracker. Neurocomputing. 2007; 70:2891–2901. doi: 10.1016/j.neucom.2006.04.016.
[115] Pradhan G., Prabhakaran B., Li C. Hand-gesture computing for the hearing and speech impaired. IEEE MultiMed. 2008;15 doi: 10.1109/MMUL.2008.28.
[116] Mehdi S.A., Khan Y.N. Sign language recognition using sensor gloves; Proceedings of the 9th International Conference on Neural Information Processing; Singapore. 18–22 November 2002; pp. 2204–2206.
[117] Oz C., Leu M.C. American Sign Language word recognition with a sensory glove using artificial neural networks. Eng. Appl. Artif. Intell. 2011; 24:1204–1213. doi: 10.1016/j.engappai.2011.06.015.
[118] Kong W., Ranganath S. Towards subject independent continuous sign language recognition: A segment and merge approach. Pattern Recognit. 2014; 47:1294–1308. doi: 10.1016/j.patcog.2013.09.014.

[119] Iwasako K., Soga M., Taki H. Development of finger motion skill learning support system based on data gloves. Procedia Comput. Sci. 2014; 35:1307–1314. doi: 10.1016/j.procs.2014.08.167.
[120] Kosmidou V.E., HadjileontiadisL.J. Sign language recognition using intrinsic-mode sample entropy on sEMG and accelerometer data. IEEE Trans. Biomed. Eng. 2009; 56:2879–2890. doi: 10.1109/TBME.2009.2013200.
[121] Gałka J., Mąsior M., Zaborski M., Barczewska K. Inertial motion sensing glove for sign language gesture acquisition and recognition. IEEE Sens. J. 2016; 16:6310–6316. doi: 10.1109/JSEN.2016.2583542.
[122] McGuire R.M., Hernandez-Rebollar J., Starner T., Henderson V., Brashear H., Ross D.S. Towards a one-way American sign language translator; Proceedings of the Sixth IEEE International Conference on Automatic Face and Gesture Recognition; Amsterdam, The Netherlands. 17–19 September 2004; pp. 620–625.
[123] Kau L.J., Su W.L., Yu P.J., Wei S.J. A real-time portable sign language translation system; Proceedings of the 2015 IEEE 58th International Midwest Symposium on Circuits and Systems (MWSCAS); Fort Collins, CO, USA. 2–5 August 2015; pp. 1–4.
[124] Fu Y.F., Ho C.S. Development of a programmable digital glove. Smart Mater. Struct. 2008; 17:025031. doi: 10.1088/0964-1726/17/2/025031.
[125] Mohandes M., Deriche M. Arabic sign language recognition by decisions fusion using Dempster-Shafer theory of evidence; Proceedings of the 2003 Computing, Communications, and IT Applications Conference; Hong Kong, China. 1–4 April 2013; pp. 90–94.

[126] Sekar H., Rajashekar R., Srinivasan G., Suresh P., Vijayaraghavan V. Low-cost intelligent static gesture recognition system; Proceedings of the 2016 Annual IEEE Systems Conference; Orlando, FL, USA. 18–21 April 2016; pp. 1–6.
[127] Luqman H., Mahmoud S.A. Transform-based Arabic sign language recognition. Procedia Comput. Sci. 2017; 117:2–9.
[128] Tubaiz N., Shanableh T., Assaleh K. Glove-based continuous Arabic sign language recognition in user-dependent mode. IEEE Trans. Hum. Mach. Syst. 2015; 45:526–533. doi: 10.1109/THMS.2015.2406692.
[129] Sadek M.I., Mikhael M.N., Mansour H.A. A new approach for designing a smart glove for Arabic Sign Language Recognition system based on the statistical analysis of the Sign Language; Proceedings of the 2017 34th National Radio Science Conference (NRSC); Alexandria, Egypt. 13–16 March 2017; pp. 380–388.
[130] Shukor A.Z., Miskon M.F., Jamaluddin M.H., bin Ali F., Asyraf M.F., bin Bahar M.B. A new data glove approach for Malaysian sign language detection. Procedia Comput. Sci. 2015; 76:60–67. doi: 10.1016/j.procs.2015.12.276.
[131] Swee T.T., Salleh S.H., Ariff A., Ting C.M., Seng S.K., Huat L.S. Malay Sign Language gesture recognition system; Proceedings of the ICIAS 2007 International Conference on Intelligent and Advanced Systems; Kuala Lumpur, Malaysia. 25–28 November 2007; pp. 982–985.
[132] Swee T.T., Ariff A., Salleh S.H., Seng S.K., Huat L.S. Wireless data gloves Malay sign language recognition system; Proceedings of the 2007 6th International Conference on Information, Communications & Signal Processing; Singapore. 10–13 December 2007; pp. 1–4.
[133] Adnan N.H., Wan K., Shahriman A., Zaaba S., Basah S.N., Razlan Z.M., Hazry D., Ayob M.N., Rudzuan M.N., Aziz A.A. Measurement of the flexible bending force of the index and middle fingers for virtual interaction. Procedia Eng. 2012; 41:388–394. doi: 10.1016/j.proeng.2012.07.189.
[134] Sriram N., Nithiyanandham M. A hand gesture recognition-based communication system for silent speakers; Proceedings of the 2013 International Conference on Human Computer Interactions (ICHCI); Warsawa, Poland. 14–17 August 2013; pp. 1–5.
[135] Ahmed S.F., Ali S.M.B., Qureshi S.S.M. Electronic speaking glove for speechless patients, a tongue to a dumb; Proceedings of the 2010 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (STUDENT); Petaling Jaya, Malaysia. 20–21 November 2010; pp. 56–60.
[136] Abdulla D., Abdulla S., Manaf R., Jarndal A.H. Design and implementation of a sign-to-speech/text system for deaf and dumb people; Proceedings of the 2016 5th International Conference on Electronic Devices; Systems and Applications, Ras AL Khaimah, UAE. 6–8 December 2016; pp. 1–4.
[137] Alvi A.K., Azhar M.Y.B., Usman M., Mumtaz S., Rafiq S., Rehman R.U., Ahmed I. Pakistan sign language recognition using statistical template matching. Int. J. Inf. Technol. 2004; 1:1–12.
[138] Khambaty Y., Quintana R., Shadaram M., Nehal S., Virk M.A., Ahmed W., Ahmedani G. Cost effective portable system for sign language gesture recognition; Proceedings of the 2008 IEEE International Conference on System of Systems Engineering; Monterey, CA, USA. 2–4 June 2008; pp. 1–6.
[139] Vutinuntakasame S., Jaijongrak V.R., Thiemjarus S. An assistive body sensor network glove for speech-and hearing-impaired disabilities; Proceedings of the 2011 International Conference on Body Sensor Networks (BSN); Dallas, TX, USA. 23–25 May2011; pp. 7–12.
[140] Vijayalakshmi P., Aarthi M. Sign language to speech conversion; Proceedings of the 2016 International Conference on Recent Trends in Information Technology; Chennai, India. 8–9 April 2016; pp. 1–6.
[141] Lokhande P., Prajapati R., Pansare S. Data Gloves for Sign Language Recognition System. Int. J. Comput. Appl. 2015:11–14.

[142] Harish N., Poonguzhali S. Design and development of hand gesture recognition system for speech impaired people; Proceedings of the 2015 International Conference on Industrial Instrumentation and Control (ICIC); Pune, India. 28–30 May 2015; pp. 1129–1133.
[143] Trottier-Lapointe W., Majeau L., El-Iraki Y., Loranger S., Chabot-Nobert G., Borduas J., Lavoie J., Lapointe J. Signal processing for low cost optical data glove; Proceedings of the 2012 11th International Conference on Information Science, Signal Processing and their Applications (ISSPA); Montreal, QC, Canada. 2–5 July 2012; pp. 501–504.
[144] Kanwal K., Abdullah S., Ahmed Y.B., Saher Y., Jafri A.R. Assistive Glove for Pakistani Sign Language Translation; Proceedings of the 2014 IEEE 17th International Multi-Topic Conference (INMIC); Karachi, Pakistan. 8–10 December 2014; pp. 173–176.
[145] Hoque M.T., Rifat-Ut-Tauwab M., Kabir M.F., Sarker F., Huda M.N., Abdullah-Al-Mamun K. Automated Bangla sign language translation system: Prospects, limitations and applications; Proceedings of the 2016 5th International Conference on Informatics, Electronics and Vision (ICIEV); Dhaka, Bangladesh. 13–14 May 2016; pp. 856–862.
[146] Kong W., Ranganath S. Signing exact english (SEE): Modeling and recognition. Pattern Recognit. 2008; 41:1638–1652. doi: 10.1016/j.patcog.2007.10.016.
[147] López-Noriega J.E., Fernández-Valladares M.I., Uc-Cetina V. Glove-based sign language recognition solution to assist communication for deaf users; Proceedings of the 2014 11th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE), Ciudad del Carmen; Mexico. 29 September–3 October 2014; pp. 1–6.
[148] Kim J., Wagner J., Rehm M., André E. Bi-channel sensor fusion for automatic sign language recognition; Proceedings of the 2008 8th IEEE International Conference on Automatic Face & Gesture Recognition; Amsterdam, The Netherlands. 17–19 September 2008; pp. 1–6.
[149] Kau L.J., Su W.L., Yu P.J., Wei S.J. A real-time portable sign language translation system; Proceedings of the 2015 IEEE 58th International Midwest Symposium on Circuits and Systems (MWSCAS); Fort Collins, CO, USA. 2–5 August 2015; pp. 1–4.
[150] Bedregal B.R.C., Dimuro G.P. Interval fuzzy rule-based hand gesture recognition; Proceedings of the 12th GAMM-IMACS International Symposium on Scientific Computing, Computer Arithmetic and Validated Numerics; Duisburg, Germany. 26–29 September 2006; p. 12.
[151] Sagawa H., Takeuchi M. A method for recognizing a sequence of sign language words represented in a japanese sign language sentence; Proceedings of the Fourth IEEE International Conference on Automatic Face and Gesture Recognition; Grenoble, France. 28–30 March 2000; pp. 434–439.
[152] https://www.mouser.ca/new/spectra-symbol/spectra-symbol-flex-sensor/#Bullet-1
[153] https://www.lexico.com/explore/is-a-thumb-a-finger

APPENDICES

Appendix A : Raw Data

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2P2	M2G1	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G1
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		1	M1G0 M1P0	M3G1	M2G3	M3P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G3	M2P5	M2G1
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G3	M3P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3

		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
1		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M3P5	M2G3
		3	M1G0 M1P0	M3G3	M3G3	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G3	M2G3	M2P5	M2G3
		1	M1G0 M1P0	M3G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G3	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		6	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M3G1	M2G1	M3P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M3P5	M2G3
		8	M1G0 M1P0	M2G1	M2G3	M3P5	M3G3
		9	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G1
		2	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		3	M1G0 M1P0	M3G3	M2G3	M3P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3

2		1	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M3P5	M3G3
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		6	M1G0 M1P0	M3G3	M2G1	M3P5	M3G3
		7	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		2	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M3G1	M2G1	M2P5	M2G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M3G1	M3P5	M2G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
3		1	M1G0 M1P0	M3G1	M2G3	M3P5	M3G3
		2	M1G0 M1P0	M2G3	M2G3	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		10	M1G0 M1P0	M2G3	M2G1	M3P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		2	M1G0 M1P0	M2G1	M3G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M3G3	M2G1	M3P5	M2G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M3G3	M2G1	M3P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M3P5	M2G3
		3	M1G0 M1P0	M2G3	M2G1	M3P5	M3G3
		4	M1G0 M1P0	M2G3	M2G3	M3P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
4		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G3	M2G1	M2P5	M2G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		1	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M2G3
		8	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M3P5	M2G1

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G3	M3P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G3	M3P5	M3G3
		9	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
5		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M3G3	M2G3	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G3	M2G3	M2P5	M2G3
		2	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M3P5	M2G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G3	M2G3	M3P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M3G3	M3G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
6		1	M1G0 M1P0	M3G3	M3G3	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G3	M2G1	M3P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		7	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M3G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		1	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M3G3	M3G3	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M3G3	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M3G1	M2G1	M3P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		10	M1G0 M1P0	M2G1	M2G3	M3P5	M2G3
		1	M1G0 M1P0	M3G1	M3G1	M2P5	M3G3
		2	M1G0 M1P0	M3G1	M3G1	M2P5	M2G1
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G3	M2G3	M3P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
7		1	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		3	M1G0 M1P0	M2P5	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G3	M3P5	M3G3
		9	M1G0 M1P0	M3G3	M2G3	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G3	M3P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M3G3	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		9	M1G0 M1P0	M3G1	M2G1	M3P5	M2G3
		10	M1G0 M1P0	M3G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		2	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G3	M2G1	M3P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
8		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G3	M3P5	M2G1
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G1
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		2	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G3	M2G3	M2P5	M2G1
		6	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M3G3	M2G1	M3P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G1
		3	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
9		1	M1G0 M1P0	M2G1	M2G1	M3P5	M2G1
		2	M1G0 M1P0	M2G1	M2G3	M3P5	M3G3
		3	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G3	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M3G1	M3G1	M2P5	M3G3
		2	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		4	M1G0 M1P0	M3G3	M3G3	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G3	M2G3	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		9	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3

Day	Temperature	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M2G1	M2P5	M2G1
	Room Temp (20 deg)	5	M1G0 M1P0	M2G1	M2G3	M2P5	M3G1
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G3	M2G1	M2P5	M2G3
		10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		1	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	Cold Temp (-14 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
		9	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
10		1	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		3	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
	Warm Temp (20-26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		6	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
		7	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		8	M1G0 M1P0	M2G1	M2G3	M2P5	M3G1
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
		1	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		2	M1G0 M1P0	M2G1	M2G3	M2P5	M3G1
		3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		4	M1G0 M1P0	M3G3	M2G1	M2P5	M3G3
	Hot Temp (>26 deg)	5	M1G0 M1P0	M2G1	M2G1	M2P5	M2G3
		6	M1G0 M1P0	M2G1	M2G1	M3P5	M2G3
		7	M1G0 M1P0	M2G1	M3G1	M3P5	M2G3
		8	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
		9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
		10	M1G0 M1P0	M2G1	M2G1	M3P5	M2G3

Day	Trial	Simple Touch	Lid Opening	Unstack the block	Stack the block	Pick up paper
	1	M1G0 M1P0	M2G1	M2G1	M3P5	M2G3
	2	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	3	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	4	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	5	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	6	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	7	M1G0 M1P0	M2G1	M2G1	M2G3	M3G3
	8	M1G0 M1P0	M2G3	M2G3	M2P5	M2G3
	9	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	10	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	11	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	12	M1G0 M1P0	M3G3	M2G3	M2P5	M3G3
	13	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	14	M1G0 M1P0	M3G3	M2G3	M2P5	M2G3
	15	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	16	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	17	M1G0 M1P0	M2G1	M2G3	M2P5	M2G3
	18	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
	19	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
	20	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
1(Subject 2)	21	M1G0 M1P0	M3G1	M2G1	M2P5	M2G3
	22	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	23	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	24	M1G0 M1P0	M2G3	M2G1	M2P5	M2G3
	25	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	26	M1G0 M1P0	M3G3	M2G1	M3P5	M2G1
	27	M1G0 M1P0	M3G3	M2G3	M2P5	M2G3
	28	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	29	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	30	M1G0 M1P0	M2G1	M2G3	M2P5	M2G1
	31	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	32	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3
	33	M1G0 M1P0	M3G1	M2G3	M2P5	M2G3
	34	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
	35	M1G0 M1P0	M2G3	M2G1	M2P5	M3G3
	36	M1G0 M1P0	M2G1	M2G1	M2P5	M2G1
	37	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	38	M1G0 M1P0	M2G1	M2G1	M2P5	M3G3
	39	M1G0 M1P0	M2G1	M2G3	M2P5	M3G3
	40	M1G0 M1P0	M2G1	M2G1	M3P5	M3G3

Appendix B: Program

```
int sen1 = A10; // pinky finger
int sen2 = A1;   // middle finger
int sen3 = A2;    // ring finger
int sen4 = A3;    // elbow
int sen5 = A0;    // index finger force sensor
int sen6 = A8;    // thumb finger force sensor
int sen7 = A9;    // index finger
int sen8 = A7;    // Thumb finger
int F1=0,F2=0,F3=0,F4=0,F5=0,F6=0; // variable to store the value coming from the flex sensors
int sensV5 = 0; // variable to store force sensor
int sensV6 = 0;
int G=4,M=1,PUT,M1,code;
const int MPU_addr=0x68;        //MPU6050 I2C Address
int16_t axis_X,axis_Y,axis_Z;
int minVal=265;
int maxVal=402;
double x;
double y;
double z;
#include<Wire.h>
#include <SoftwareSerial.h>

// Define the data transmit/receive pins in Arduino

int event_Get=0;//indication of Get event occurrence
int event_M=1;
int Get_Function(int v5,int v6)
```

```
{
  delay(300);
  int G_Ind=4;//get indication
  if (v5<1020&&v6<1020)//picking object
  {
    if((v5+v6)<1900)// picking small object
    {
      G_Ind=1;
    }
    if((v5+v6)<500)//picking big object
    {
      G_Ind=3;
    }
   }
   else//when not picked the object
   {
    if(v5<1000 || v6<1000)//pressed button
    {
      G_Ind=0;
    }
   }
   return G_Ind;
}
int Movement_detect(int v1, int v2, int v3,int v4,int v5,int v6, double X, double Y,
double Z)
{
  int M_Ind=1;
  if(v4>810)//bend at elbow
  {
    M_Ind=3;
  }
```

```
  else
  {
    if((X>60&&X<300)||(Y>60&&Y<300)||(Z>240&&Z<120))//60 degrees threshold
compare to normal state
    {
      M_Ind=2;
    }
  }
   return M_Ind;
}
void Gyro_get(double &a,double &b, double &c)
{
    Wire.beginTransmission(MPU_addr);
  Wire.write(0x3B);                  //Start with register 0x3B
  Wire.endTransmission(false);
  Wire.requestFrom(MPU_addr,14,true);  //Read 14 Registers
                        axis_X=Wire.read()<<8|Wire.read();
                        axis_Y=Wire.read()<<8|Wire.read();
                        axis_Z=Wire.read()<<8|Wire.read();
                        int xAng = map(axis_X,minVal,maxVal,-90,90);
                       int yAng = map(axis_Y,minVal,maxVal,-90,90);
                       int zAng = map(axis_Z,minVal,maxVal,-90,90);
                      a= RAD_TO_DEG * (atan2(-yAng, -zAng)+PI);
                      b= RAD_TO_DEG * (atan2(-xAng, -zAng)+PI);
                      c= RAD_TO_DEG * (atan2(-yAng, -xAng)+PI);\
 }
 void finger_get(int &a,int &b, int &c, int &d, int &e, int &f)
{
  a = analogRead(sen1);
  b = analogRead(sen2);
  c = analogRead(sen3);
```

```
  d = analogRead(sen4);
  e = analogRead(sen7);
  f = analogRead(sen8);
 }
int get_put()
{
  int PUT_T;
  Serial.println("Enter following");
    Serial.println("press 1 for if need precise positioning and kept correctly");
    Serial.println("press 2 for simple position and kept correctly");
    Serial.println("press 3 for no consciousness");
    //delay(5000);
     Serial.end();
     Serial.begin(9600);//flush the old values
   int case_id=0;//to takefirst byte
   while(case_id<1){
   if (Serial.available()){
    char command = Serial.read();
   switch (command){
   case '1':
   PUT_T=5;
   break;
   case '2':
   PUT_T=2;
   break;
   case '3':
   PUT_T=0;
   break;
    }
  case_id++;
```

```
}
  }
return PUT_T;
}
void setup() {
  // declare the ledPin as an OUTPUT:
  Serial.begin(9600);
  Wire.begin();                    //Initialize I2C Communication
  Wire.beginTransmission(MPU_addr);  //Start communication with MPU6050
  Wire.write(0x6B);                //Writes to Register 6B
  Wire.write(0);                   //Writes 0 into 6B Register to Reset
  Wire.endTransmission(true);      //Ends I2C transmission
  }

void loop() {

  if(event_Get==0)
  {
  sensV5 = analogRead(sen5);
  sensV6 = analogRead(sen6);
  //Serial.println(sensV5);
  //Serial.println(sensV6);
  G=Get_Function(sensV5,sensV6);
  }
  if(event_Get==0&&G!=4)
  {
  event_Get=1;
  Gyro_get(x,y,z);
  delay(1);
  finger_get(F1,F2,F3,F4,F5,F6);
```

```
 M1=Movement_detect(F1,F2,F3,F4,F5,F6,x,y,z);
 Serial.print("M");//
 Serial.print(M1).
 Serial. Print("G");//if get value is 4 then no get occurrence, otherwise get occurred
Serial.println(G).
  }
if(event_Get==1)
{
sensV5 = analog Read(sen5);
sensV6 = analog Read(sen6);

if ((sensV5>1020)&&(sensV6>1020))
{
Gyro_get(x,y,z);
finger_get(F1,F2,F3,F4,F5,F6);
 M=Movement detect(F1,F2,F3,F4,F5,F6,x,y,z);
 PUT=0;
 code=3;
 if(G! =0)
 {
  Serial. Flush();
  PUT=get_put();
  }
Serial. Print("M");//
Serial. Print(M);
Serial. Print("P");//
Serial.println(PUT);
event_Get=0;
 }
}
```

}

Appendix C : Proposed method Average and Variance For each task

Task 1			
Temperatures	Day Trail	Average	Variance
Room	1	0.258	0
	2	0.258	0
	3	0.258	0
	4	0.258	0
	5	0.258	0
	6	0.258	0
	7	0.258	0
	8	0.258	0
	9	0.258	0
	10	0.258	0
Cold	1	0.258	0
	2	0.258	0
	3	0.258	0
	4	0.258	0
	5	0.258	0
	6	0.258	0
	7	0.258	0
	8	0.258	0
	9	0.258	0
	10	0.258	0
Warm	1	0.258	0
	2	0.258	0
	3	0.258	0
	4	0.258	0
	5	0.258	0
	6	0.258	0
	7	0.258	0
	8	0.258	0
	9	0.258	0
	10	0.258	0
Hot	1	0.258	0
	2	0.258	0
	3	0.258	0
	4	0.258	0
	5	0.258	0
	6	0.258	0
	7	0.258	0
	8	0.258	0
	9	0.258	0
	10	0.258	0

Task 2			
Temperatures	Day Trail	Average	Variance
Room	1	0.4386	0.0044376
	2	0.4386	0.0118336
	3	0.4257	0.0075809
	4	0.387	0
	5	0.4644	0.0118336
	6	0.4386	0.0118336
	7	0.387	0
	8	0.4386	0.0081356
	9	0.387	0
	10	0.4128	0.0066564
Cold	1	0.3999	0.0016641
	2	0.4128	0.0066564
	3	0.4128	0.0066564
	4	0.4386	0.0118336
	5	0.4128	0.0066564
	6	0.4128	0.0066564
	7	0.4644	0.0118336
	8	0.4128	0.0066564
	9	0.4128	0.0066564
	10	0.4128	0.0066564
Warm	1	0.4128	0.0066564
	2	0.4128	0.0066564
	3	0.4515	0.0120185
	4	0.4386	0.0118336
	5	0.4128	0.0066564
	6	0.4257	0.0075809
	7	0.4128	0.0066564
	8	0.4644	0.0155316
	9	0.4128	0.0066564
	10	0.4386	0.0118336
Hot	1	0.4644	0.0118336
	2	0.387	0
	3	0.4386	0.0118336
	4	0.4128	0.0066564
	5	0.4386	0.0118336
	6	0.4257	0.0075809
	7	0.4128	0.0066564
	8	0.4386	0.0118336
	9	0.4515	0.0120185
	10	0.387	0

Task 3			
Temperatures	Day Trail	Average	Variance
Room	1	0.4644	0.015532
	2	0.4644	0.015532
	3	0.4386	0.011834
	4	0.4128	0.006656
	5	0.4644	0.015532
	6	0.4386	0.011834
	7	0.4644	0.015532
	8	0.4644	0.015532
	9	0.4386	0.011834
	10	0.4128	0.006656
Cold	1	0.4644	0.015532
	2	0.4644	0.015532
	3	0.4644	0.015532
	4	0.4644	0.015532
	5	0.4644	0.015532
	6	0.4902	0.01775
	7	0.4644	0.015532
	8	0.4644	0.015532
	9	0.4386	0.011834
	10	0.4386	0.011834
Warm	1	0.4128	0.006656
	2	0.4128	0.006656
	3	0.4644	0.015532
	4	0.4386	0.011834
	5	0.4644	0.015532
	6	0.4902	0.01775
	7	0.4644	0.015532
	8	0.4644	0.015532
	9	0.4644	0.015532
	10	0.4386	0.011834
Hot	1	0.4128	0.006656
	2	0.4902	0.01775
	3	0.4386	0.011834
	4	0.4644	0.015532
	5	0.4128	0.006656
	6	0.4386	0.011834
	7	0.4644	0.015532
	8	0.4644	0.015532
	9	0.4644	0.015532
	10	0.4128	0.006656

Task 4			
Temperatures	Day Trail	Average	Variance
Room	1	0.9159	0.001664
	2	0.9288	0.002958
	3	0.9159	0.001664
	4	0.9417	0.003883
	5	0.9288	0.002958
	6	0.9159	0.001664
	7	0.9159	0.001664
	8	0.9159	0.001664
	9	0.9159	0.001664
	10	0.9210	0.001664
Cold	1	0.9417	0.003883
	2	0.9288	0.002958
	3	0.9288	0.002958
	4	0.9417	0.003883
	5	0.9159	0.001664
	6	0.9159	0.001664
	7	0.9159	0.001664
	8	0.9159	0.001664
	9	0.9159	0.001664
	10	0.9159	0.001664
Warm	1	0.9417	0.003883
	2	0.9159	0.001664
	3	0.9159	0.001664
	4	0.903	5.48E-32
	5	0.9159	0.001664
	6	0.9159	0.001664
	7	0.9159	0.001664
	8	0.9159	0.001664
	9	0.9288	0.002958
	10	0.9159	0.001664
Hot	1	0.9159	0.001664
	2	0.9159	0.001664
	3	0.9159	0.001664
	4	0.9417	0.003883
	5	0.9159	0.001664
	6	0.9159	0.001664
	7	0.9159	0.001664
	8	0.9159	0.001664
	9	0.9288	0.002958
	10	0.9417	0.003883

Task 5			
Temperatures	Day Trail	Average	Variance
Room	1	0.7611	0.0016641
	2	0.7611	0.0016641
	3	0.7482	0.0029584
	4	0.7611	0.0016641
	5	0.7611	0.0016641
	6	0.7353	0.0038829
	7	0.7353	0.0038829
	8	0.7482	0.0029584
	9	0.7611	0.0016641
	10	0.6837	0.0186749
Cold	1	0.7611	0.0016641
	2	0.774	0
	3	0.7611	0.0016641
	4	0.7482	0.0029584
	5	0.7611	0.0016641
	6	0.7482	0.0029584
	7	0.7611	0.0016641
	8	0.7482	0.0029584
	9	0.7482	0.0066564
	10	0.7611	0.0016641
Warm	1	0.7482	0.0029584
	2	0.7611	0.0016641
	3	0.7482	0.0029584
	4	0.7353	0.0038829
	5	0.7611	0.0016641
	6	0.7611	0.0016641
	7	0.7353	0.0038829
	8	0.7611	0.0016641
	9	0.7224	0.0155316
	10	0.7482	0.0155316
Hot	1	0.7482	0.0029584
	2	0.6966	0.0599076
	3	0.7482	0.0029584
	4	0.7482	0.0029584
	5	0.7611	0.0016641
	6	0.7482	0.0029584
	7	0.774	0
	8	0.7353	0.0038829
	9	0.7482	0.0029584
	10	0.6321	0.0238521

Appendix D : Bill of Materials

S.no	Materials	Quantity
1	Bread board (Breadboard, General Purpose Non-Plated Through Hole (NPTH) Pad Per Hole (Round) 0.1" (2.54mm) Grid) and Solderless Breadboard Terminal Strip (No Frame) 3.20" x 2.08" (81.3mm x 52.8mm)	2 pcs each
2	Jumper Wires	120 pcs pack
3	Batteries	4 pcs
4	0.2 inch Flex sensors- Spectra Symbol	8 pcs
5	0.5 inch Pressure Sensors-Interlink Electronics	4 pcs
6	Arduino micro and Arduino pro micro Boards	2 boards
7	Bluetooth (Hc-05)- ITEAD Studio	2 pcs
8	Soldering iron kit	1 kit
9	Gyroscope (MPU-6050) - Invensense	2 pcs
10	Others include (tapes, scissors and needles, threads, gloves)	1 pc each
11.	Battery holder and connector (Digi-Key Electronics)	2 pcs

VITA AUCTORIS

NAME:	Veda Rasmi Mallembakam
PLACE OF BIRTH:	India
YEAR OF BIRTH:	1996
EDUCATION:	Narayana Junior College, India 2012
	SRM University, India 2016
	University of Windsor, MASc, Windsor, ON,2020