Smart Glove Calibration and Data Retrieval

Master's thesis in Embedded Electronic System Design

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Work related health issues prevent people from long term service and cause huge financial loss for the companies and individuals. To avoid these health issues, ergonomic studies are being conducted and preventive measures are being taken. Musculoskeletal injuries due to hand movements can be prevented by using a smart glove which can indicate the risk conditions. The smart glove used in this thesis is a glove knitted with Bekinox 50/2 conductive yarns at different parts of it to identify the risk condition. Even though a textile sensor has many advantages, its calibration is a major problem. This is mainly due the deviation caused by textile orientation, inhomogeneity, differences in hand structure of the wearer etc. Therefore the thesis mainly studies the textile-sensor characteristics in order to examine if it can be accurately calibrated with minimum recalibration requirements for the smart glove application. The results show that the current glove, with the force sensor knitted using Bekinox 50/2 can only be used for low force measurement and is not very well suited for smart glove application. It is found that the sensor's repeatability can be improved by providing a stable structure. The wrist-angle sensor in the current glove should be incorporated with more sensors to identify the sideways movement to use it for smart-glove application. An efficient method of communicating sensor values through the Internet was implemented in the thesis using the MQTT protocol. Also, Python scripts for plotting real-time graph and storing data were implemented successfully.

Keywords: Smart glove, Ergonomic, MQTT, Arduino UNO WiFi, Python, Textile sensor, Assembly line workers, Textile sensor characteristics.

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1

Introduction

Nowadays, work related health problems are common in different work sectors due to poor ergonomics. One of the major examples is musculoskeletal disorder found in manual assembly laborers. The statistics of Försäkringskassan in the year 2015 show that in Sweden more than 10,000 individuals are affected by this [1]. The smart-glove project ”Smarta textilier för ett hållbart arbetsliv” funded by Vinnova aims at improving the work environment for manual assembly workers and thereby avoid physical damage due to poor ergonomics. Improving ergonomics will not only provide a healthy work environment for workers, but also save the company from financial loss.

This master's thesis is tied up with different fields such as ergonomics, occupational health research, sensor technology, analysis methods, and it relies on the interaction of these disciplines in the borderline between engineering and medicine. Today's rapid developments in sensor technology, mobile data acquisition, automated data processing and improved risk assessment methodologies allow the development of wearable, textile-based systems that can predict the risk of a workplace, and the individual's risk of injury.

The thesis work is carried out at Swerea IVF, Mölndal as part of the smart glove development project. The smart glove is specially being developed for manual assembly workers in order to indicate the risk conditions. It is being developed by using textile sensors, which senses the force at finger tips, wrist angle and warn the user in a risk situation. An ergonomic study conducted by Scania [2] on assembly-line workers is used as reference for the implementation.

1.1 Aim of the work

The overall aim is to improve ergonomics and safety among assembly line workers. The specific aim of this thesis work is to characterize the newly developed textile sensors for the smart glove application, communicate the sensed data through the Internet and display the data in graphical form. Due to privacy concerns, the data will be password protected. The research interest is how accurately the sensors can be calibrated to measure the finger force value with minimum recalibration requirements. Even for the normal force sensors, recalibrations are necessary to read accurate data. Since textile sensors are having more non-linearities, the study of their recalibration requirement becomes relevant. The data values of interest are finger force value and wrist angle value.

1.2 Context

To ensure efficiency and to decrease occupational hazard, the ergonomics must be improved, in particular for jobs that are physically demanding, e.g. in the construction industry, the food industry and vehicle manufacturing. The socioeconomic burden for musculoskeletal disorders has been estimated to 0.5-2 % of GNP in Europe [3], which for only Sweden means approximately 50 billion SEK per year. The development of the smart glove is in purpose of alleviating this situation. The development process of the smart glove is based on major design considerations such as economy, practicality, robustness and user-friendliness. Factors such as battery life, humidity and temperature the device can withstand are also of interest.

Today, occupational health service personnel, consultants and ergonomists assess the risks for musculoskeletal injuries and disorders by manual observation. The disadvantages with manual observation are lack of validity, high costs for the assessments, high demands of competent and experienced personnel. These factors motivated the idea to develop a system for measuring and analyzing risks for musculoskeletal work injuries. Measurements during full work days are transferred to a computer for analysis and visualization of risks. The analysis first calculates loads on different body structures, activities and movement patterns, and thereafter compares these measures with risk factors found in research for musculoskeletal injuries. In this way, risks from work and workplaces can be assessed automatically, and the need for improvements of work and workplaces becomes visual. The system also allows e.g. assessment of individual movement patterns in order to train new employees in work technique. Assessments, which today are performed manually, can be largely automated, which will improve the quality of the assessments and lower the costs for them. The potential for savings of costs from society, companies and individuals is very high, and so is the potential to improve work related health.

There are smart gloves developed for other applications such as a communication tool for people with hearing impairment and speech disorders [4] and a low-cost smart glove for universal control of IR devices [5], etc. Nevertheless, the smart glove for ergonomics is a new concept. The ergonomics studies carried out for manual assembly line workers show that there are certain static hand postures which pose a health risk condition for workers. Therefore the major research objective of this thesis is to find out how well these conditions can be identified with the smart glove. The analysis and risk assessment are to be quick and the results are to be communicated directly. Measurements are also transferred to a computer for analysis and visualization of risks. The visualization of data also aims at assessment of individual movement patterns in order to train new employees in appropriate work techniques. There can occur many nonlinearities in measurement. Characteristics such as time drift and repeatability are the main causes of errors in textile based sensor systems [6]. As these causes are application specific, the calibration of textile-based sensors is critical.

1.3 System Overview

The overall block diagram of the smart-glove system is shown in Fig. 1.1. The sensor signals from the glove are signal conditioned by a circuit to convert it to a measurable parameter and to provide higher accuracy. The sensors are characterized based on the output from a signal conditioning unit using a microcontroller unit, here we use Arduino UNO WiFi [7]. The microcontroller board is used for calibration studies and further for communicating the measured data to the Internet. The glove is knitted with Bekinox 50/2 conductive yarns on sensor parts. These conductive yarns show a resistance variation with respect to applied force and extensions. The signal-conditioning circuit converts these resistance variations to voltage variations and further it amplifies the signal. These voltage output signals are averaged in Arduino and used to characterize the sensors. The communication of the sensed data to the Internet is implemented using MQTT protocol, which works on publish-subscribe model. The Arduino publishes the data to the MQTT broker, the Python scripts subscribe the data and processes it.

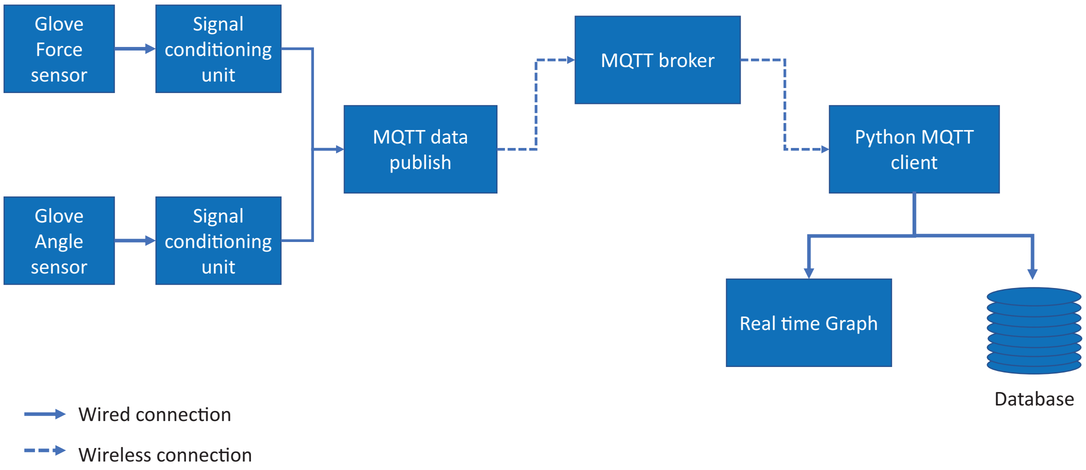

Figure 1.1: Overall block diagram

1.4 Ethics

The thesis work adds to the well being of the assembly-line manual workers. It aims at finding out a cheaper, low-power solution to analyze the work environment, warn the workers about the risk conditions and analyze the data through the Internet. As manual monitoring has several weaknesses such as lack of validity, high costs for the assessments and need for experienced personnel, an automatic solution is necessary. The smart glove developed can be used for the continuous monitoring of the work and training new workers for a sustainable work life. But the smart glove usage may pose a potential problem of using it to monitor the productivity rather than to improve the working conditions for assembly-line workers.

1.5 Limitations

The sensor development is out of scope for this thesis work. The sensor is not characterized for different temperatures and after washing. MQTT protocol performance aspects for more than one sensor were not studied.

1.6 Overview of the chapters

The report is organized in the order as basic theory, implementation and results and conclusion. The second chapter describes the basic information about different fields involved in this thesis. Following three chapters explain the implementation part as signal conditioning circuit, calibration and data retrieval. Finally the report ends with results and conclusion.

2

Basic Theory

This chapter describes the knowledge gathered in the pre-study of the thesis. The first section describes the results of the ergonomic studies conducted among assembly-line workers. It is in the context of these results, the smart glove will be studied. As the smart glove is made of textile sensors, the second section focuses on the calibration problems with textile sensors. Further, it explains some important features of the microcontroller board used for this project, Arduino UNO Wi-Fi.

2.1 Ergonomics

The definition of ergonomics given by Cambridge dictionary is "it is the scientific study of people and their working conditions, especially done in order to improve effectiveness" [8]. As pointed out in the introduction, work-related musculoskeletal diseases are due to unscientifically designed work environments. To prevent work-related hazards like this, the workstations should be ergonomically evaluated and based on these evaluations, scientifically designed.

Scania has conducted an ergonomic evaluation in truck assembly-line work. In automotive assembly-line works, many tasks such as tightening, picking up, lifting and material handling are to be carried out [2]. Assembly-line workers working in an automotive industry is shown in Fig. 2.1. These tasks pose some ergonomic risk conditions such as awkward postures, forceful exertion, repetition, vibration, etc. [2]. Automotive companies have created their own in-house observational methods to identify these ergonomic risks [9]. Scania's in-house ergonomic standard is known as SES (SCANIA Ergonomic Standard). The ergonomic evaluation conducted by Scania on truck assembly work is based on SES and NIOSH lifting equation [2]. The NIOSH equation is a tool used by ergonomists to evaluate the risk conditions in lifting and lowering weights [10]. The results obtained from these evaluations will be used as a reference for this thesis work.

Scania's ergonomic evaluation results, which are relevant for the smart glove devel-

Neutral wrist	Green
Non-neutral wrist	Red
>30°bending upward	
>45°bending downward	
>10°bending sideways	

Table 2.1: Wrist static work posture held >5 seconds [2]

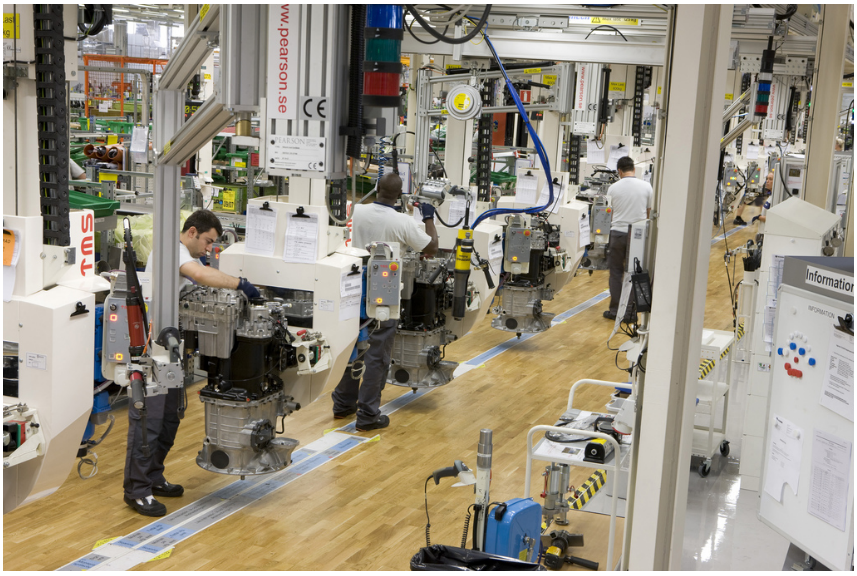

Figure 2.1: Assembly-line workers working on gear box assembly in Scania [18].

Neutral wrist	**Non-neutral wrist**	
<10N	<5N	Green
10-45N	5-25N	Yellow
>45 and <91N	>25 and <51N	Red
>90N	>50 N	Double Red

Table 2.2: Pushing, pulling and squeezing with fingers [2]

opment are given in Table 2.1 and Table 2.2. Based on the intensity of the risk conditions, they are classified into different zones as green, yellow, red and double red. Green zone represents minimal musculoskeletal risk, which is acceptable. Yellow zone represents moderate musculoskeletal risk, which requires attention in the future. Red zone indicates high risk of musculoskeletal disorder, changes are to be done as soon as possible. Double red zone indicates very high risk and these tasks should be immediately stopped. The test concludes that the wrist static posture held more than 5 seconds causes the problems. As shown in Table 2.1, the wrist at $> 30°$ in upward direction, $> 45°$ in a downward direction and $> 10°$ in the sideways direction for more than 5 seconds poses risk condition, which are categorized as non-neutral wrist. Pushing or pulling with finger at >45 N can cause harm for neutral wrist whereas >25 N itself causes problem for wrists in outer position.

2.2 Textile sensors

Research efforts on smart textiles have been continuously increasing during the past two decades. Applications of smart textiles include health monitoring, fabrics to ensure safety and also energy harvesting. Without any inconvenience as caused by other type of sensors, the clothes provide a comfortable way to extract electric signals from the body. Textile sensors can also be made perfect fit to the body, which can ensure effective signal extraction [11]. A smart textile can include different parts such as sensors, actuator, data processing unit, communication unit and energy supply unit [11].

Smart textiles are broadly classified into three classes [12], which are

- *Passive smart textile* : These can only sense the signals
- *Active Smart textiles* : Attached with an actuator kind of device, these respond to the sensor signals.
- *Very active smart textiles* : These can sense, react and also adapt to the current environment by the usage of processors.

Smart textiles are defined as textile products such as fibers, filaments, yarns together with woven, knitted or non-woven structures, which can interact with the environment/user [12]. Different textile sensors can be fabricated using processes such as embroidery, sewing, weaving, non-woven, knitting, spinning, braiding, coating/laminating, printing and chemical treatment [12]. The yarns used for these methods can be [12]

- *Conductive fibers*: 100 % stainless steel or blended with other materials such as cotton and polyester.
- *Treated conductive fibers*: Fibers coated with metals.
- *Conductive fabrics*: By integrating conductive yarns in a textile structure
- *Conductive inks*: By using specialised conductive ink

2.2.1 Calibration of textile sensors

The major performance parameters for sensors are [13]

- *Linearity* : Defines how linear is the output with respect to the input.
- *Drift/Stability* : Defines for constant input for longer time, how significant is the variation of output.
- *Hysteresis* : Defines the variation in output values due to the previous history of input values.
- *Homogeneity* : Defines how similar is the response of two equivalent specimens.
- *Repeatability* : Defines if the sensors can give the same value for repeated measurements of same input.

For textile sensors all of these parameters are critical. Especially in the case of knitted textile sensors, homogeneity cannot be guaranteed as it depends on many parameters such as number of conductive yarns. Also the sensor response varies according to the physical shape of the wearer. Therefore the calibration of these textile sensors is difficult.

2.3 Arduino UNO Wi-Fi

Arduino UNO WiFi is a commercially available board integrated with an Arduino UNO and a WiFi module. The processor is ATmega328P and the WiFi module is ESP8266. The ESP8266 Wi-Fi Module is a self-contained SoC with integrated TCP/IP protocol stack that can give access to the Wi-Fi network [7]. One useful feature of UNO Wi-Fi is support for OTA (over-the-air) programming [7]. The important specifications of the board are given in Table 2.3.

Microcontroller	ATmega328
Architecture	Atmel AVR 8-bit
Flash memory	32 KB
SRAM	2 KB
Clock Speed	16 MHz
Analog I/O Pins	6
Digital I/O Pins	20
Wi-Fi processor	ESP8266
Wi-Fi	802.11 b/g/n 2.4 GHz

Table 2.3: Arduino UNO Wi-Fi Specifications [7]

2.3.1 Board Layout

The board has mainly three power up facilities which are USB power up, 5V Vin power and DC plugging [7]. The board layout is shown in Fig. 2.2.

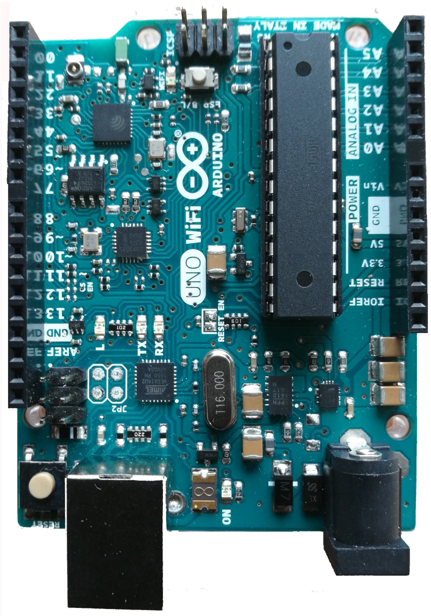

Figure 2.2: Arduino UNO Wi-Fi [7]

2.3.2 Communication

The Arduino board has different communication facilities with a computer or other microcontrollers. ATmega328 provides UART TTL(5V) serial [7]. ATmega16U2 facilitates the USB communication with the computer. The Arduino software (ArduinoIDE) includes a serial monitor which can be used to display data from Arduino board or send data to Arduino board. By the usage of the so called Wire library, Arduino can access I2C facility. By the usage of SPI library, it can access the SPI communication facility. For accessing the Wi-Fi facility, the board can communicate with Wi-Fi module through UART to I2C module as shown in Fig. 2.3.

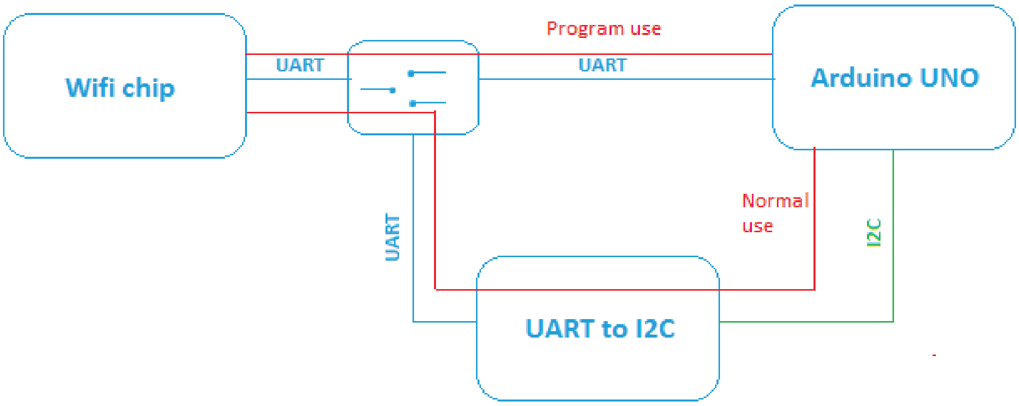

Figure 2.3: Communication of Wifi chip to Arduino UNO [7]

2.3.3 Arduino programming -Arduino IDE

The coding of the Arduino is done by Arduino software, Arduino IDE. The programs written in Arduino IDEs are referred as sketches. Sketches written are based on C/C++. The ATmega328 board is already pre-burned with bootloader that allows uploading of code without the use of external hardware programmer [7].
In this thesis Arduino is programmed to read the analog input data, take its average and publish the data. The command in Arduino program, 'analogRead()' reads the analog input pin and returns a value between 0 and 1023 that is proportional to the voltage at analog input pin. The average of continuous 50 readings is then taken for further analysis.

3

Signal Conditioning Circuit

The signal conditioning refers to the manipulation of the signal such that it is prepared for the next stage of processing [14]. Several sensors require some type of signal conditioning to make its output variation to be in recognizable form. Different signal conditioning types are amplification, attenuation, filtering, excitation and linearization etc. The sensor part of the glove used, varies its resistance to the applied force and also to extensions. For the force sensor, the resistance variation was around 10 Ω and for the angle sensor, it was around 1 kΩ. Therefore the resistance variations of the sensor should be converted to voltage variations to make it to a recognizable form.

3.1 Voltage divider circuit

Excitation is required for many sensor circuits to make their parameter variation identifiable. The textile sensor that we use in this thesis shows resistance variation with respect to force and extension. Therefore, to convert this to voltage variation, an excitation is required. A voltage divider circuit has been used to convert resistance variation to voltage variation.

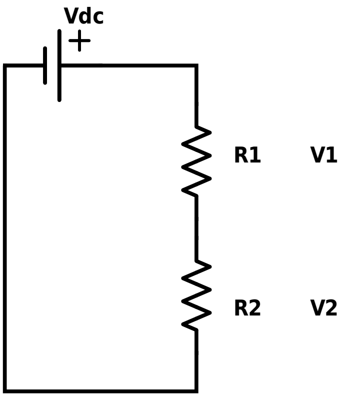

Figure 3.1: Voltage divider

The Fig. 3.1 shows the voltage divider circuit, in which R1 is a constant resistance and R2 is the resistance of the sensor part. The input voltage, Vdc is divided between

R1 and R2 based on their resistance values. The resistance R1 is selected such that it is comparable to R2 value and ensures that the maximum current is within limits. The resistance in force sensitive part is in the order of 10 Ω. Therefore to limit the current, a 100 Ω series resistance was chosen as R1. The voltage across the sensor, denoted by V2 is given by

$$V2 = \frac{Vdc}{R1 + R2} * R2 \tag{3.1}$$

3.2 Instrumentation Amplifier

The voltage signal across the resistor is amplified to improve the resolution of the sensor. The maximum analog input voltage of the Arduino board is 5V. Therefore the signal is amplified such that it is in the limit of 5V. For amplification, we used an instrumentation amplifier, which is a differential amplifier that amplifies the difference signal between input terminals rejecting any signals that are common to both inputs. The instrumentation amplifier has several advantages when compared with an ordinary voltage amplifier, namely

- Extracting very small input signal and amplifying, rejecting the noise signal.
- It has high CMRR (Common mode Rejection Ratio). It is the ratio of differential mode gain to common mode gain.

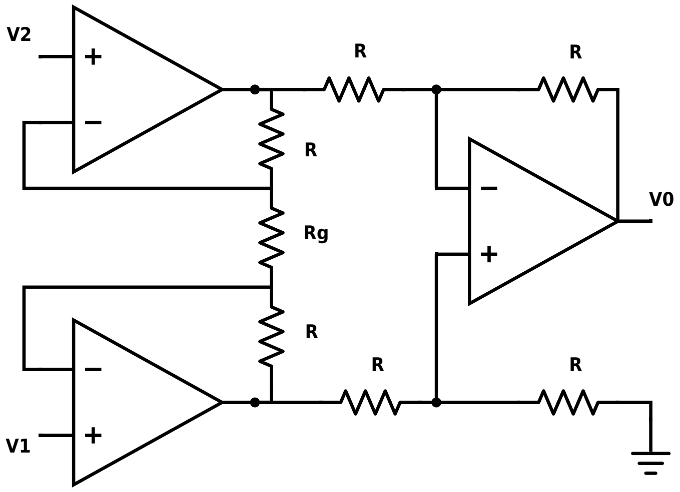

Figure 3.2: Instrumentation amplifier

$$Vo = (V1 - V2) * (1 + \frac{2R}{Rg}) \tag{3.2}$$

The gain of the amplifier is $(1 + \frac{2R}{Rg})$. By adjusting the values of R and Rg, the gain can be altered. Here we have given gain up to 5 for testing.

4

Textile sensor and Calibration

This chapter discusses about the textile sensor and its calibration. Fig. 4.1 shows the glove used for the test. The glove, which is an example of a knitted glove, was developed in Borås Textile University. The sensitive part of the glove, which is darker in shade, is knitted with conductive yarns namely Bekinox 50/2 [19]. Bekinox 50/2 is a blend of stainless steel fibre and cotton and its electrical conductivity is 35Ω/cm. Both force sensor and angle sensor are knitted with Bekinox 50/2 since it is sensitive to both pressure and extension. The angle sensor is knitted with a structure to provide increased extension sensitivity.

Figure 4.1: The glove with textile sensors

Sensors are devices or materials which can produce variation in its output with respect to a specific input parameter variation. Thus, they can detect an input parameter change. In order to get an accurate reading, sensors need to be calibrated with known standard parameters. Calibration ensures the accuracy of the sensor [20]. Sensors may show many non-ideal behaviors such as hysteresis, inaccuracy and drift. The major aim of the thesis is to study the textile-sensor characteristics in order to accurately calibrate the sensor with minimum number of recalibrations. Therefore the important sensor characteristics which will be dealt in the thesis will be accuracy and repeatability.

As mentioned in Chapter 2, the textile sensor provides comfort to the user without any hard edges of the conventional sensors. But the main challenges of textile sensors are

- They need a tight fit to the wearer in order to get accurate values.
- Their disorientation in each wearing can cause variations in the output.
- The inhomogeneity between different textile sensors due to difference in yarn count and its orientation can vary the output.

4.1 Force calibration

The force calibration test setup schematic diagram is shown in Fig. 4.2. A finger like arrangement by inserting a rod to the thumb part was also tested, but a slight jerk while keeping the weight itself caused a variation in the output. Therefore the two layers of the thumb-sensor-part were used together for force measurement by applying the weights over them. In the setup shown in Fig. 4.2, the glove is kept over a weighing machine and the weight reading is reset to 0. Weights are vertically applied over the glove by using a small platform connected to a movable rod inside a fixed pipe. This arrangement ensures that the true force is known during the measurement. The lower edge of the rod was provided with a soft foam pad of 1 cm diameter to resemble the soft tissue of the finger and also to uniformly distribute the weight. Fig. 4.3 shows the calibration setup used. Since the area of the applied force is known, the true average pressure can also be calculated. The textile force-sensor part is connected in series with a resistor to act as a voltage divider circuit. The voltage signal produced by the sensor is then passed through an instrumentation amplifier as described in Chapter 3. The command in Arduino program, 'analogRead()' reads the analog input pin and returns a value between 0 and 1023 that is proportional to the voltage at analog input pin. The average of continuous 50 readings is then taken for further analysis. The delay between each reading is set to 100 ms. When the applied force over the sensor part increases, the resistance reduces and therefore the voltage output reduces.

Fig. 4.4 shows voltage variation with respect to the applied weights. From the figure we can infer that sensitivity is higher for lower force and reduces towards higher force.

On the measuring setup given, different weights are applied in increasing order and the output values corresponding to the weights are noted down. The tests were repeated many times and they consistently showed the same characteristic curve shape.

Five sets of measurements are taken for the following conditions.

1. Starting from initial force 0N for each set of readings.
2. With keeping the initial force a constant for each set of readings. This is done by keeping the rod over which weights applied in permanent contact with sensor part. This also ensures the same contact area.
3. Keeping the initial force to 0N and relaxing the compressed yarns for each set of readings.

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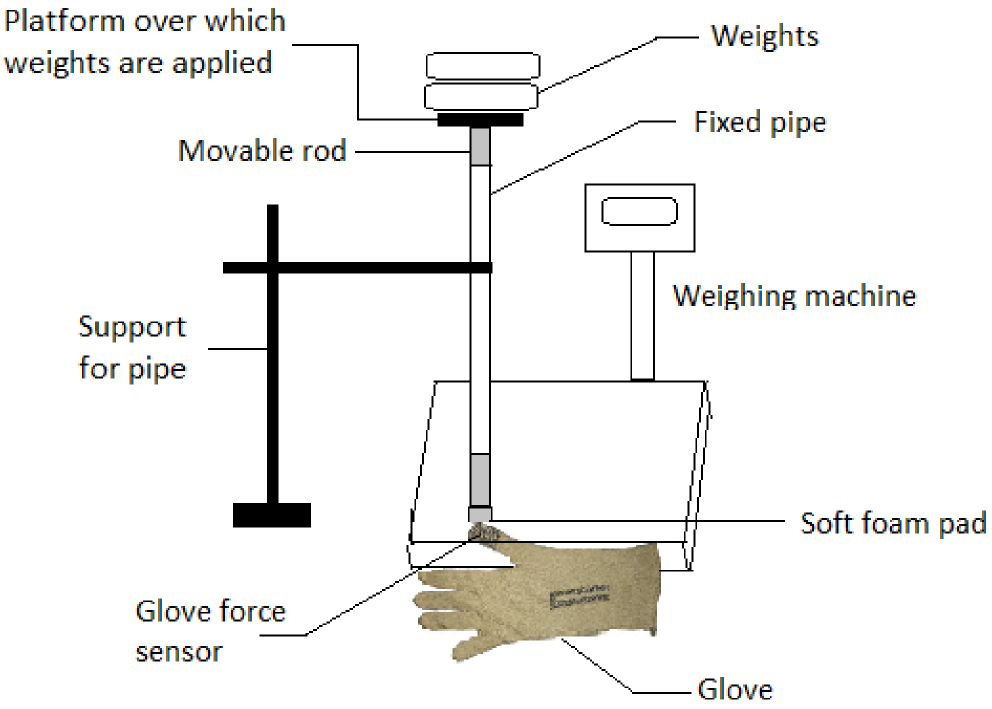

Figure 4.2: Calibration setup schematic diagram

4.1.1 Accuracy

Sensor's accuracy is the degree of closeness of the measured value to the actual value [14]. To quantify accuracy, we have calculated the standard error between values in five sets of readings, for each force input. It was noted that for conditions one and two, for which there was no readjustment of the yarn, the standard errors are comparable and are less than the standard errors of the third condition. The standard error between five sets of value for the three conditions for different force input is shown in Fig. 4.5.

4.1.2 Repeatability

Repeatability refers to the ability of the sensor to respond in the same way on repeated application of the same input. From the output obtained from three conditions, it is observed that standard deviation is less for first and second conditions. Therefore we infer that readjusting the yarns from their compressed state causes less repeatability. For the first condition, the maximum standard deviation was for 2N. The output voltage graph corresponding to that is shown in Fig. 4.6.

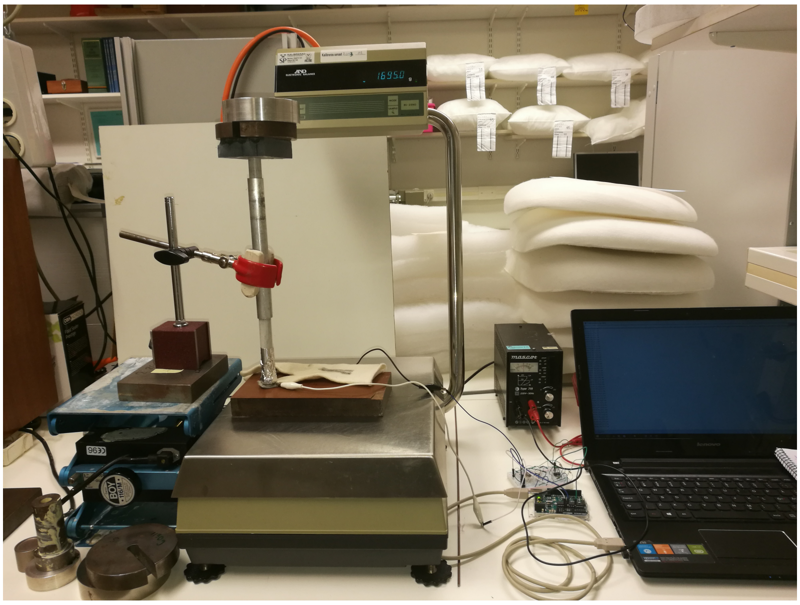

Figure 4.3: Calibration setup

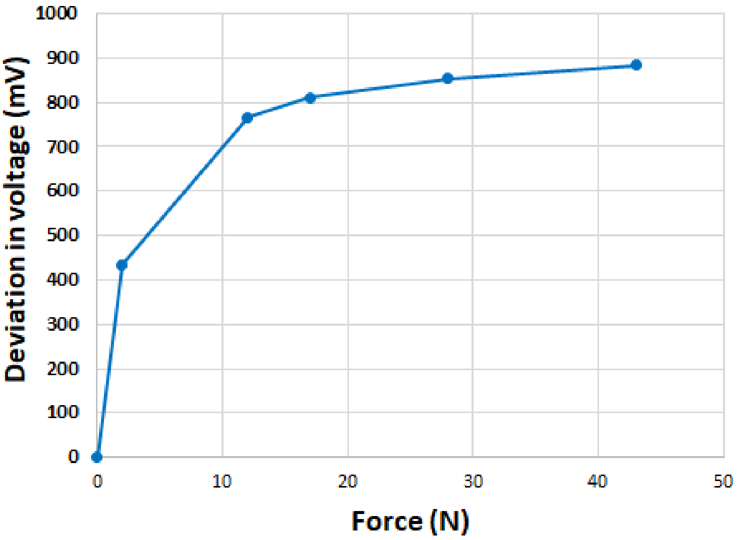

Figure 4.4: Variation of voltage with respect to force

The output response corresponding to the three conditions are given in Fig. 4.7, Fig. 4.8 and Fig. 4.9 respectively. From the plots it is clear that, the spread between values are less for first two conditions and more for the third condition.

4.1.3 Hysteresis

Hysteresis is a non-ideal behavior of a sensor, which indicates how different the sensors respond to loading and unloading of the input quantity. Fig. 4.10 shows the hysteresis characteristics, which depicts that the sensor has different values for loading and unloading force. The unloading resistance value is lesser than the loading

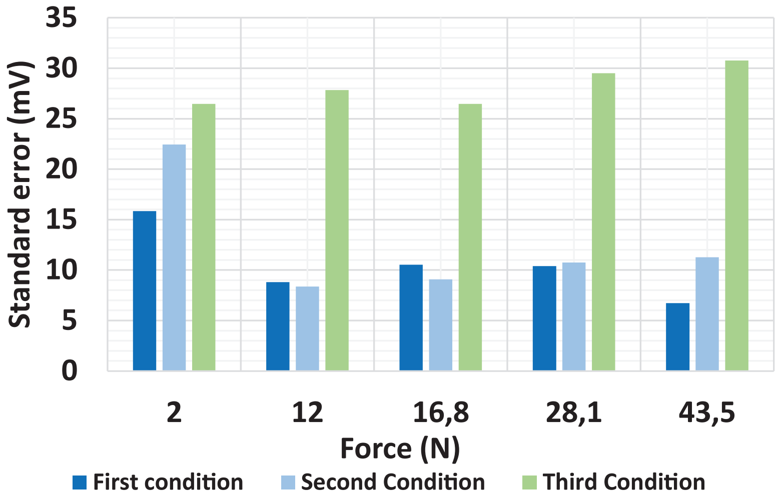

Figure 4.5: Standard error between five set of values for each force unit.

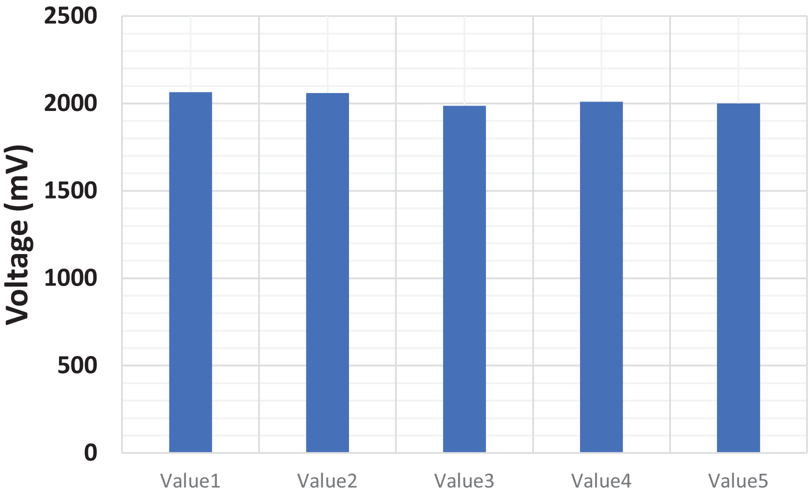

Figure 4.6: Repeatability of readings for 2N

resistance value due to hysteresis.

4.1.4 Drift behavior

Drift behavior is the change in sensor output when the load is applied for a time longer than the measuring time slot. The drift behavior of the force sensor for different force inputs over a time period of 15 minutes are compared in Fig. 4.11. In the figure, the slope of 0N curve is the highest and for higher force values, the slope reduces. This indicates for lower forces drift behavior is more than that for

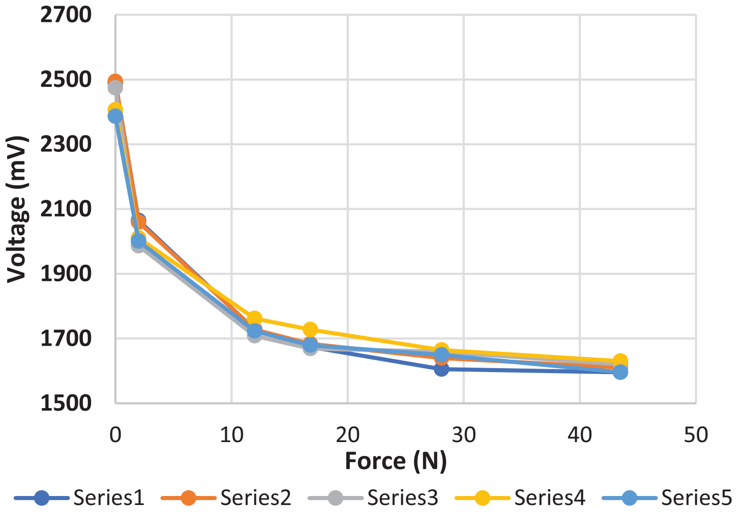

Figure 4.7: Repeatability for measurements starting from 0N

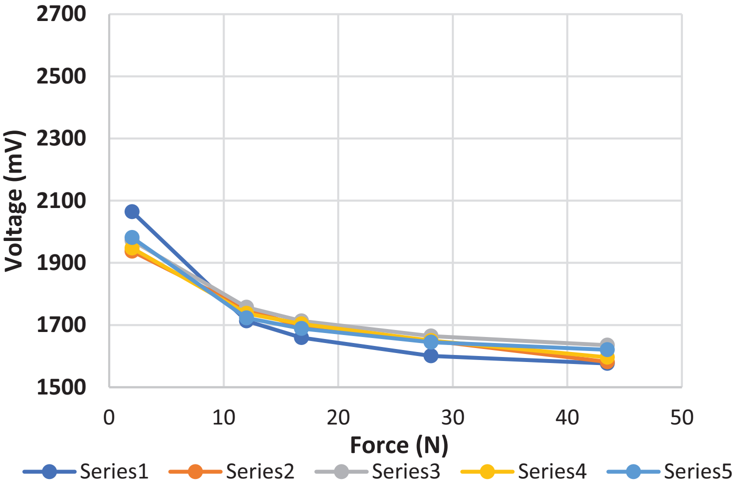

Figure 4.8: Repeatability for measurements with a constant initial force(2N)

higher forces.

4.1.5 Maximum measurement range

As the characteristic curve of the sensor depicts, the sensor reaches a maximum "saturation value" above which the voltage deviation is very low. By increasing the gain of the amplifier, minute difference in voltage can be amplified and detected.

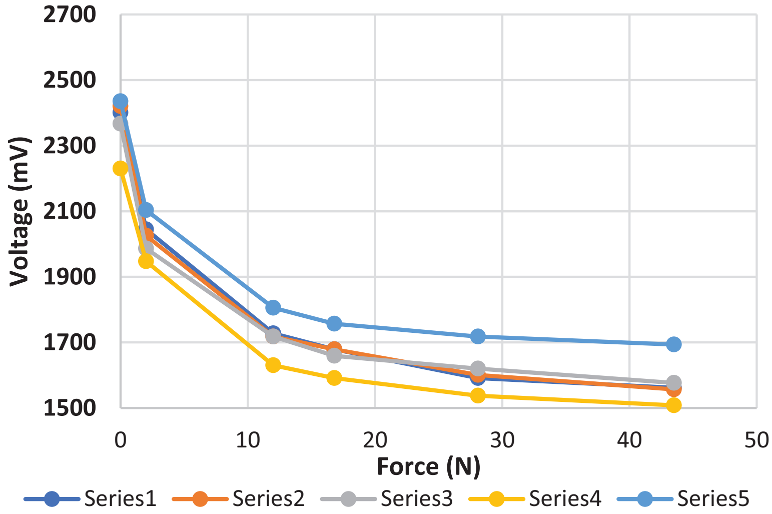

Figure 4.9: Repeatability for measurements with relaxing compressed yarns.

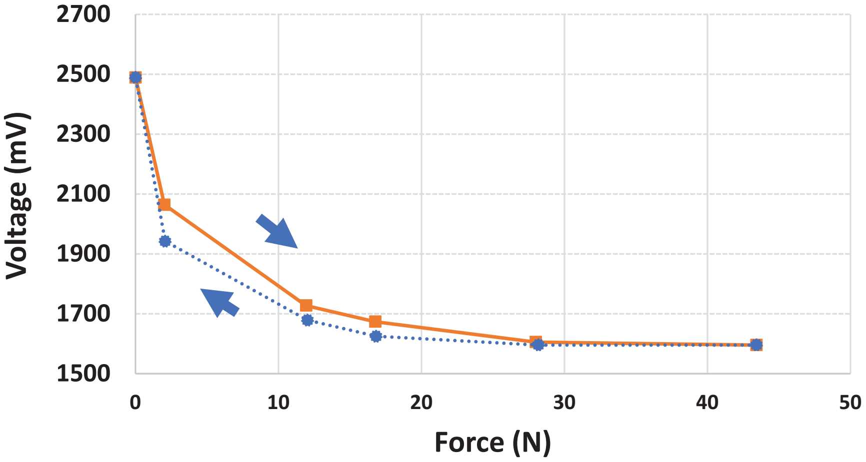

Figure 4.10: Hysterisis characteristics

But it soon reaches the "saturation value". The sensor showed a maximum deviation for 50N for the amplifier gain of 5, the sensor was insensitive for value above this limit. The maximum linear response was observed to be around 12N. By adding many layers of the textile material, the value can possibly be increased.

4.1.6 Observations

The sensor shows statistically different output values for different force inputs, with an increasing slope till around 12N. Therefore the sensor can only be used for small force detection. The measurement range can possibly be improved by adding several layers of sensor fabric. Also, as the sensor fabric is sensitive to stretches, a more stable fabric structure under the finger is desirable.

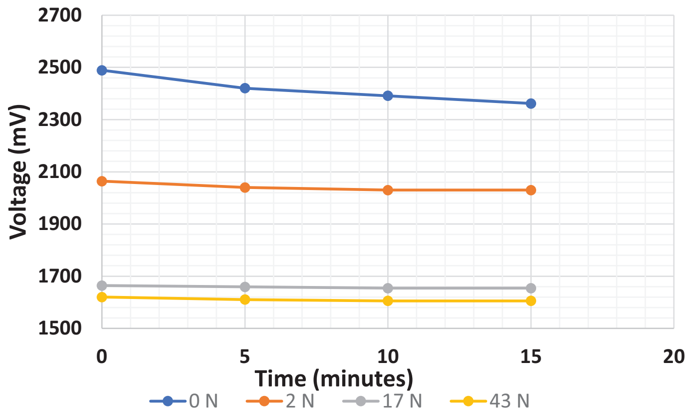

Figure 4.11: Drift characteristics

4.2 Angle calibration

The resistance variations of the wrist angle sensor are noted to be around 1 KΩ. Therefore the series resistance used in the voltage divider is 1KΩ. The angle calibration setup is shown in Fig. 4.12. On a chart marked with different angle values, the gloved wrist is kept at different angles. The resistance variations of the wrist angle sensor are converted to voltage variations using a voltage divider circuit. This voltage values are then averaged in Arduino. For the measurement, the average of 10 readings is taken at an interval of 200ms. The general characteristics of the wrist angle sensor is given in Fig. 4.13. The figure shows that as flexion which is the movement of bending the palm down, towards the wrist increases, ie. as the wrist angle varies from 0° to -90°, the resistance across the sensor increases and therefore voltage increases. Each data point in the figure represents a mean of three readings +/-standard deviation.

4.2.1 Accuracy

Accuracy indicates closeness of measured angle to the actual angle [14]. The standard error between values in three sets of readings were calculated . In different wearings, it showed random variations and could not draw a generalized conclusion from that, as which angle causes the maximum/minimum error. The maximum voltage deviation between nine readings is found to be 320 mV.

4.2.2 Repeatability

Readings were taken with each time removing and re-wearing the glove. Three sets of readings were taken for each wearing. The output response is shown in fig. 4.14. Each data point in the figure represents a mean of three readings +/-standard deviation.

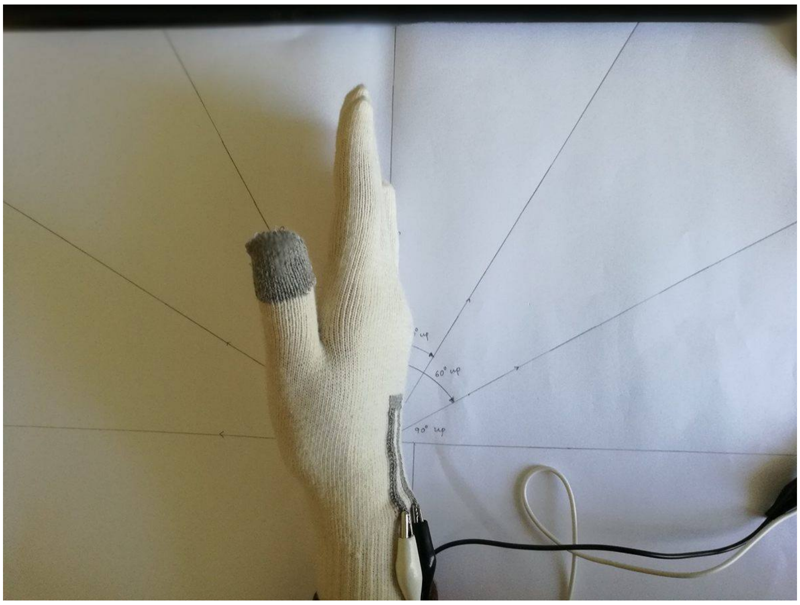

Figure 4.12: Angle calibration

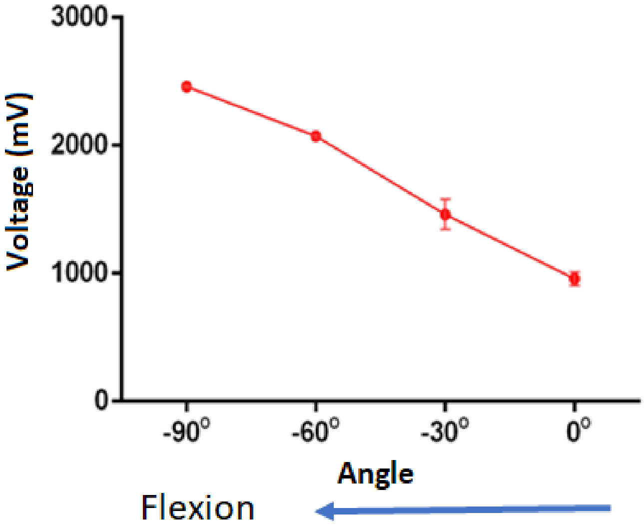

Figure 4.13: Wrist angle sensor general characteristics

4.2.3 Hysteresis

In this case, hysteresis denotes the deviation in output value when the wrist is moved from 0° to −90° and in the reverse direction. The Fig. 4.15 shows the hysteresis characteristics. The figure depicts that the resistance value is higher when the wrist moves back in the reverse direction from −90° to 0°.

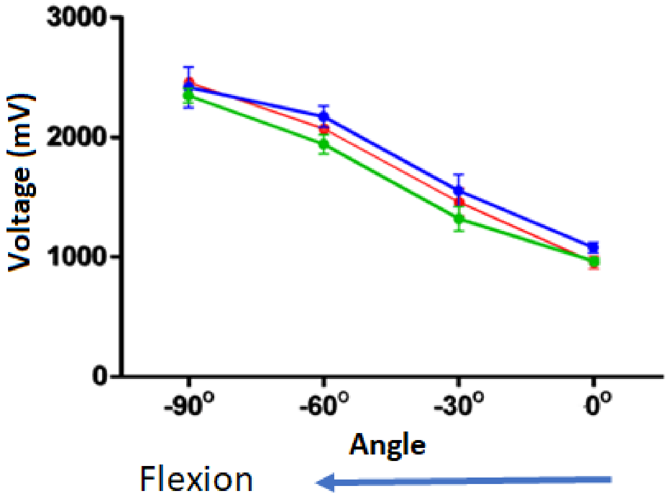

Figure 4.14: Repeatability test in different wearings

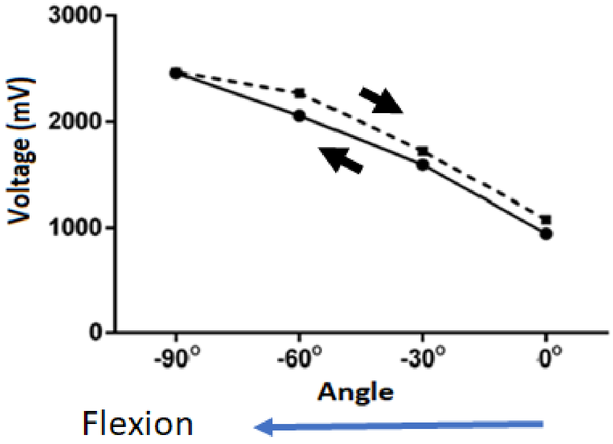

Figure 4.15: Hysterisis in angle characteristics

4.2.4 Drift behavior

The drift behavior for angle sensor was comparatively null when compared to the drift behavior of the force sensor.

4.2.5 Maximum measurement range

The maximum measurement range is from 0°to 90° for flexion. For extension, it also showed some voltage variations, which is due to the foldings made over the sensor part and interconnections thus made.

4.2.6 Sideways movement of the wrist

The values for sideways movement of the wrist were also noted down from 20° left to 20° right. As the wrist angle sensor is similar on both sides with respect to a middle line, a 'V' shaped characteristic is expected. But the output response we obtained is given in Fig. 4.16. This indicates the unpredictability of the textile sensor.

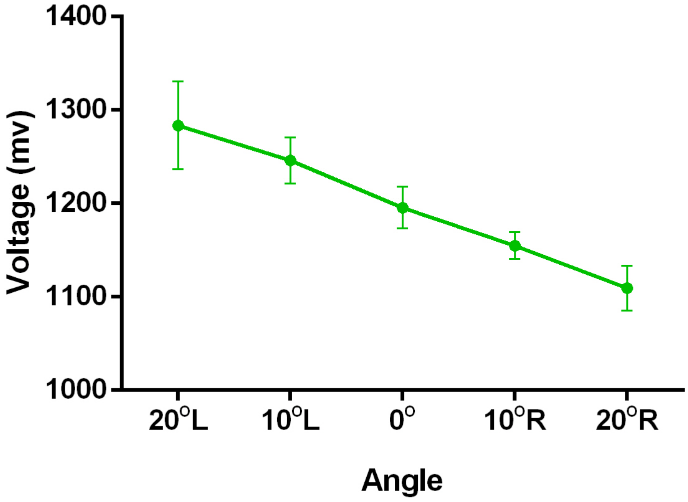

Figure 4.16: Output response for sideways movement of the wrist

4.2.7 Observations

The sensor is suitable for measuring flexion movement of the wrist. But it shows slight differences in values for different wearings. It is also sensitive for the sideways movement of the wrist. Therefore, to get accurate angle values other sensors should be incorporated to identify the sideways movement. Also, unpredictability of the sensor characteristics was observed for sideways movement. Therefore it is better to calibrate the sensor after wearing.

5

Data Retrieval

The data retrieval from the glove is required to be in wireless mode. The data communication between devices are guided by different set of protocols. The general model for data communication is the OSI (Open Systems Interconnection) model, which is having seven functional layers. A simplified version of that consisting of four layers is shown in Fig. 5.1 [22].

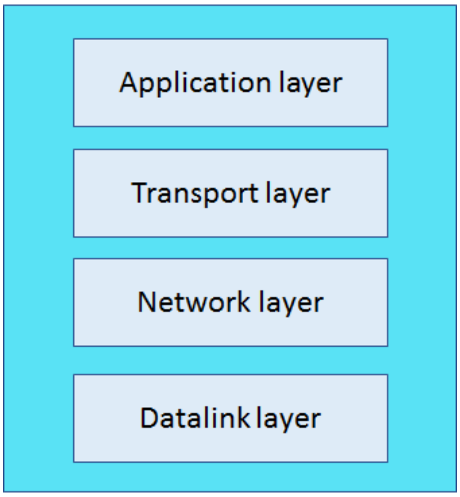

Figure 5.1: Simplified OSI model [22]

The application layer manages data formatting and data flow. There are several application layer protocols suitable for IoT devices viz. Constrained Application Protocol (CoAP), Message Queue Telemetry Transport(MQTT), Extensible Messaging and Presence Protocol (XMPP), Representational State Transfer (RESTFUL Services), Advanced Message Queuing Protocol (AMQP) and Data Distribution Service (DDS). The selection of the protocol is based on the application. As MQTT is a lightweight protocol and is best suited for battery operated devices [21], we implemented the data retrieval using the MQTT protocol.
Some of the advantages of the MQTT protocol are the following [16]

- MQTT is a lightweight protocol. Therefore, it is assumed to consume less communication power than other protocols.
- The communication channel is always open between the devices in MQTT.
- The latency in data transfer is less in MQTT for low sampling rate.
- It supports multicast (one to many communication).
- It minimizes network traffic by reducing transport overhead [21].

The network layer, addresses and routes the data using IP (Internet Protocol) [22]. MQTT uses TCP (Transport Control Protocol) for the transport layer, which generates communication sessions for several applications running.
The functionality of a data link layer is to convert bits to radio signals and vice-versa [22]. The data link functionality can be established through Bluetooth, WiFi, Zigbee etc. In this thesis work, we have used WiFi. The Arduino UNO WiFi board provides WiFi facility.

5.1 Data transmission using Message Queue Telemetry Transport(MQTT) Protocol

The MQTT protocol is based on publish and subscribe model. Multiple clients are connected to an MQTT broker. The clients can publish or subscribe a specific topic. The structure of the MQTT communication is given in Fig. 5.2. Examples of public MQTT brokers are iot.eclipse.org, HiveMQ.com, Mosquitto.com etc.
The basic architecture of MQTT is shown in Fig. 5.2. As the figure depicts, many clients connect to the MQTT broker, some of them publish data and others subscribe to it. The publishers publish data under the specific topic. The subscribers can subscribe to any of these topics. In the diagram, Node 5 Publishes data on the topic, 'hello/world', Node 1 and Node 3 subscribe to it. Therefore the message "Hi" published by Node 5 reaches Node1 and Node3.

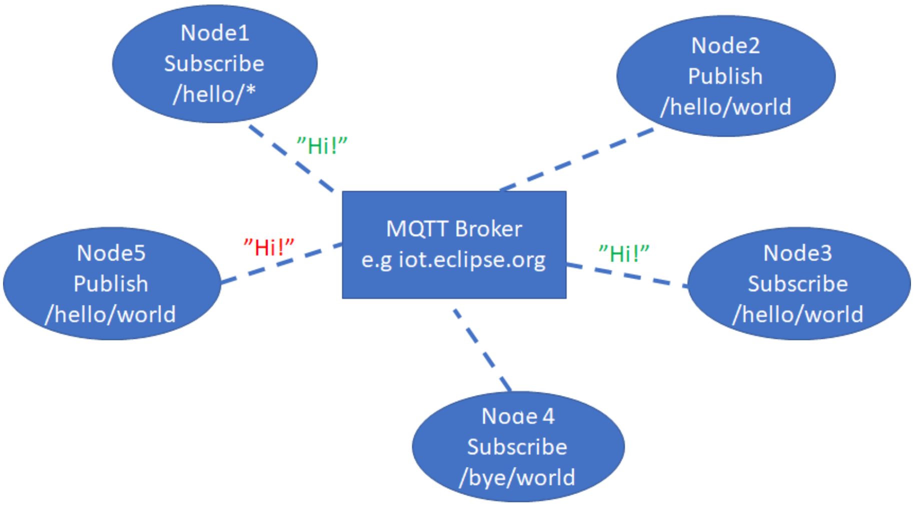

Figure 5.2: MQTT publish and subscribe architecture [17].

The Arduino board was coded and configured to send data to the public MQTT server "iot.eclipse.org", under two topics, namely "sg/force" and "sg/angle". The topic "sg/force" was used for force values and "sg/angle" for the wrist angle values. In order to analyse these values, an MQTT client is required. The configuration was first tested with several client softwares which are free viz. MQTT.fx, mqtt-spy. Then Python MQTT client was used in order to plot real-time graph and store the data. Fig. 5.3 depicts the data retrieval block diagram.

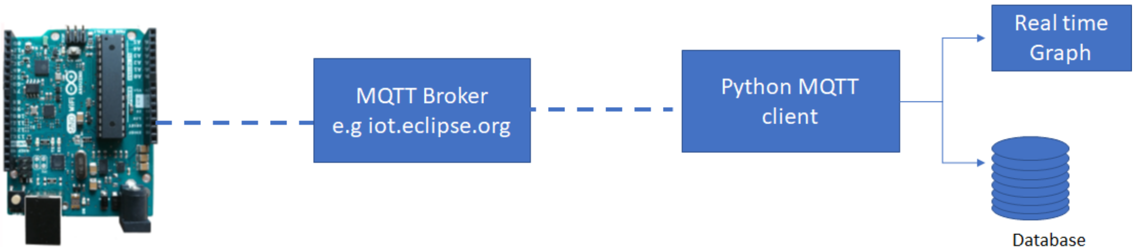

Figure 5.3: Data retrieval block diagram

5.2 Data retrieval using Python

Python is a high-level, object-oriented programming language. In order to generate graph of live data and store the data values in a database python scripts are used.

5.2.1 Python MQTT client

The python client for the MQTT server was implemented using Paho API client library. By using this library, the python client can publish or subscribe a topic. In this thesis work, the python client was implemented in subscriber mode, connected to "iot.eclipse.org" and subscribing topics "sg/force" and "sg/angle". The Python script was successfully reading the data from MQTT server. Authentication of the MQTT protocol is done by username and password at the application level.

5.2.2 Real time graph and data storage

The wrist angle and force values can be read at the same time using python MQTT client. By using the libraries matplotlib.pyplot and numpy the real time plot of the data was done. Fig. 5.4 represents the real time graph thus obtained.

5.2.3 Data storage

The data is further stored in an SQL database using sqlite3 library [23]. A python code first initializes the database. Then the python MQTT client receives data and pass it to the python code which manages the database.

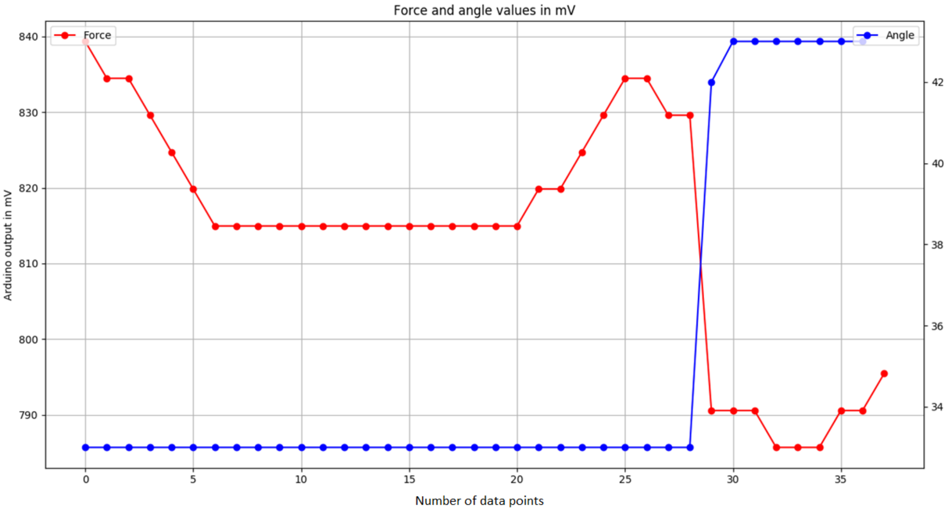

Figure 5.4: Real time graph generated using Python

6

Results and Analysis

This chapter summarizes the results. It also critically analyzes the results and the research approach.

6.1 Bekinox 50/2 in knitted structure for force detection

From the force sensor characterization the following observations were made:

6.1.1 Stable structure

By comparing the three conditions in force measurements, the the standard deviation was very high (1613 +/- 66) for the third condition causing a low repeatability, where the compressed yarns are relaxed between the readings. In first two conditions, where yarns were in compressed state, the standard deviation was low (1642 +/- 24) showing a high repeatability. Therefore, compressed yarns are more preferable for good repeatability. The current glove has force sensor part covered around the thumb, which causes a deviation in output for a small movement. Therefore, compressed yarn structure under the finger is desirable.

6.1.2 Measurement range

It was observed that the sensor can produce statistically different output values for different force inputs, with an increasing slope till around 12N and a maximum output variation around 50 N ("saturation value"). The measurement range could possibly be improved by adding more number of sensor layers.

From these observations a compressed yarn structure under the finger with more number of layers is preferred for force measurement. It will be suitable for low force measurements, with sensor having hysteresis and drift.

6.2 Bekinox 50/2 in knitted structure for angle detection

From the angle sensor characterization following observations were made:

6.2.1 Sensitive to sideways movement

Even though the wrist angle sensor is suitable for flexion angle sensing, it is sensitive to sideways movement of the wrist. Therefore other sensors should be incorporated to detect sideways motion of the wrist.

6.2.2 Calibrating the sensor for each wearing

Repeatabilty tests show that slight differences in values can occur for different wearings. Also, the wrist angle sensor does not behave in the predicted nature for the sideways movement. These observations substantiate the requirement calibration in each wearing.

From these observations, it is clear that by adding more sensors to detect sideways movement, the sensor can be used to detect flexion motion from 0° to 90°. To detect extension of the wrist, the same sensor can be given on the opposite side of the wrist.

6.3 Data retrieval

The data retrieval was implemented with the lightweight MQTT protocol. Python scripts were used for data storage and real time plot of the graph. The real-time plot and data storage were successfully implemented.

6.4 Analysis

One of the specific aims of this thesis work was to characterize the newly developed textile sensor in order to examine if it can reproduce accurate sensor output values with minimum number of recalibrations.

For the force sensor characterization, along with providing stable measurement condition, we made sure that it replicates the actual physical condition by providing a foam, which resembles finger tissue as the contact surface on textile sensor for applying weights. The stable measuring condition was ensured by applying a constant weight for longer time and accurately measuring the applied weight. In order to study the accuracy and recalibration requirements, the repeatability of the sensor output values were observed for many number of iterations. Along with that other sensor characteristics such as hysteresis, drift which should be considered for calibration were also studied. From these studies, it is observed that a stable sensor structure will only provide minimum recalibration requirement with good accuracy. Even though the measurement range can possibly be increased by adding several layers of textile sensor, the measurement range of the current sensor was found to be 50N, which is very less when compared to the smart-glove requirements given in Table 2.2.

For the angle sensor characterization, the measurement was carried out using the human hand therefore the actual physical condition was studied compromising the stable condition. To study the accuracy and recalibration requirements, the repeatability of the sensor output values were observed for many number of iterations and wearings. From the repeatability test, it was clear that slight variations in values can occur in different wearings. Also, the sensitivity of the sensor for sideways movement in an unpredictable manner was observed. These observations establish the requirement of calibration in each wearing. The hysteresis should also be considered for the calibration. By adding sensors to detect upward movement, to differentiate sideways movement along with the sensor in the current glove can be used for smart-glove application based on the conditions given in Table 2.1.

The other specific aim of the thesis was to retrieve the data through the internet and display it in graphical form. As the smart-glove is supposed to operate using battery, we chose the MQTT protocol for communication, which is established as the best IOT protocol for battery operated devices [21]. Real-time plot is implemented using Python. Also, we have gone a step further in aim and implemented data storage using Python.

7

Conclusion and Future work

The overall aim the project is to improve the ergonomic condition for assembly-line workers. With the use of textile sensors, more comfortability can be provided for the user. By characterizing the textile sensors knitted using Bekinox 50/2 and suggesting an efficient data retrieval method, this thesis work complements the overall aim. The results show that Bekinox 50/2 in knitted structure, in the current glove can only be used only for low-force measurement and it does not satisfy smart-glove force measurement requirements. By adding several sensor layers the measurement limits can possibly be increased. The textile force sensor's recalibration requirement can be minimized by providing a stable structure. For the wrist angle sensor, a structure with sensor less sensitive to sideways direction or incorporating additional sensors to identify sideways movement is preferred. The data retrieval is successfully implemented through MQTT protocol and Python scripts.

As future work, there is more scope to continue the work in order to produce the final smart-glove with high reliability in measurement and lower power consumption. It will be interesting to study the sensor after making the suggested structural changes. The structural change preferred for the force sensor is a stable structure with a support material. For the angle sensor, the structural change should ensure less sensitivity in sideways direction or should incorporate more sensors to differentiate sideways movement. Further, it will be necessary to study the sensor characteristics for wear, sweating and for different temperature conditions. The data security of MQTT protocol was only ensured by password protection. But it is necessary to improve the security conditions in future works. The MQTT performance deteriorates for higher sampling rates. Therefore, it will be good to study its performance with additional sensors in the glove.

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