MODELLING AND CHARACTERIZATION OF NOVEL FLEX SENSOR

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this Report titled **“MODELLING AND CHARACTERIZATION OF NOVEL FLEX SENSOR”** is the bonafide work of **ADITHYA HARI (191002005), ASHWIN PRABHU (191002024)** who carried out the work under my supervision. Certified further that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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We are grateful to our Principal **Dr. V. E. Annamalai for** providing us a constructive environment for carrying out our project.

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ABSTRACT

A sensor is a device that measures physical input from its surroundings and converts it into data that can be analysed by humans or machines. The majority of sensors are electronic (the data is transformed to electronic data), although some are simpler, such as a glass thermometer that displays visual data. Sensors are used to monitor temperature, measure distance, detect smoke, regulate pressure, and for a variety of other purposes. Resistive flex sensors are rapidly being used in a variety of applications due to its unique ability to change resistance when bent. They can be used in systems that require a joint rotation to be measured, such as biomedical systems, to measure human joint static and dynamic postures. However, the production of sensors necessitates the use of a variety of materials and chemicals, such as rare earth metals, which can have negative environmental consequences. These materials' mining and processing can lead to habitat damage, soil and water contamination, and increased greenhouse gas emissions. Furthermore, if sensors are not properly disposed of after their useful life, they can generate electronic waste and toxic pollution. As a result, it is critical for manufacturers to follow sustainable practises and examine the environmental impact of sensor production over the product's full lifecycle.A Flex sensor is created that is constructed of an ecologically friendly material, has great flexibility and linearity features, and has a lower bending strength. The same is contrasted with market sensors using mathematical modelling, with the possibility of incorporating the same in a glove for Parkinson's patients in the future.

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LIST OF SYMBOLS, ABBREVIATIONS

RPM	**Rotations Per Minute**
IoT	Internet of Things
GO	Graphene Oxide
STFS	Self-Powered Triboelectric Flex Sensor
PVC	Polyvinyl Chloride
KOH	Potassium Hydroxide
HNO_3	Nitric Acid
V	Volts
A	Ampere
kJ	kilo Joules

CHAPTER – 1

INTRODUCTION

A sensor is a device that measures physical input from its environment and converts it into data that can be interpreted by either a human or a machine. Most sensors are electronic (the data is converted into electronic data), but some are simpler, such as a glass thermometer, which presents visual data. People use sensors to measure temperature, gauge distance, detect smoke, regulate pressure, and various other uses.
Sensors play a pivotal role in the internet of things (IoT). They make it possible to create an ecosystem for collecting and processing data about a specific environment so it can be monitored, managed and controlled more easily and efficiently. IoT sensors are used in homes, out in the field, in automobiles, on airplanes, in industrial settings and in other environments. Sensors bridge the gap between the physical world and logical world, acting as the eyes and ears for a computing infrastructure that analyzes and acts upon the data collected from the sensors.

1.1 Type of Sensors

Sensors are used in a wide variety of applications. The dependence on sensors in almost every field has reached high depths. Sensors can be categorized in multiple ways: Such as Active, Passive, Analog , Digital.
An active sensor is one that requires an external power source to be able to respond to environmental input and generate output. For example, sensors used in weather satellites often require some source of energy to provide meteorological data about the Earth's atmosphere.

A passive sensor, on the other hand, doesn't require an external power source to detect environmental input. It relies on the environment itself for its power, using sources such as light or thermal energy. A good example is the mercury-based glass thermometer. The mercury expands and contracts in response to fluctuating temperatures, causing the level to be hapazhard.

Another way in which sensors can be classified is by whether they're analog or digital, based on the type of output the sensors produce. Analog sensors convert the environmental input into output analog signals, which are continuous and varying. In contrast to analog sensors, digital sensors convert the environmental input into discrete digital signals that are transmitted in a binary format.

1.2. Flex Sensor

Flex sensor is a type of variable resistor . The resistance of the flex sensor increases as the body of the component bends.

A flex sensor consists of a phenolic resin substrate with conductive ink deposited. A segmented conductor is placed on top to form a flexible potentiometer in which resistance changes upon bending. The conductive ink on the sensor acts as a resistor. When this is straight,resistance is 25 kΩ and while bent to 90° ,the value shown is 100 kΩ. The sensor comes in varies lengths.

As mentioned earlier, **Flex Sensor** is basically a **Variable resistor** whose terminal resistance increases when the sensor is bent. So this sensor resistance increases depending on surface linearity. So it is usually used to sense the changes in linearity.

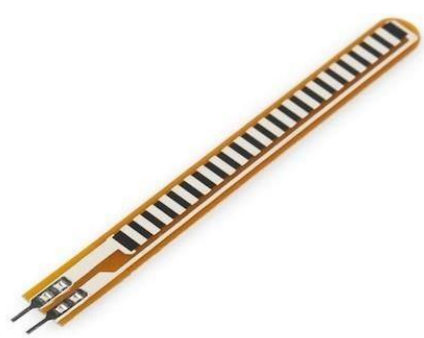

Fig 1 Commercial Flex Sensor

There are multiple types of flex sensors such as Optical fiber sensor,velostat flex sensor and capacitive flex sensor.

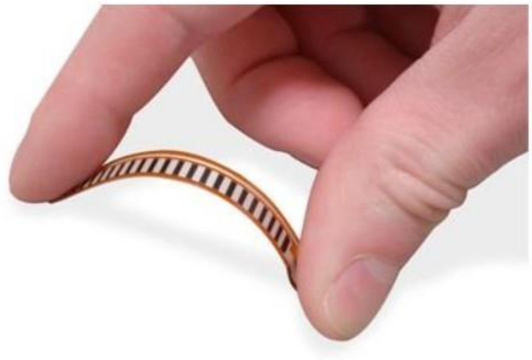

Fig 2. Bending of Flex sensor

1.3. Characteristics

Flex sensors portray certain characteristics, such as linearity and sharp resistance. The radius of curvature defines the resistance produced by bending the epoxy resin.

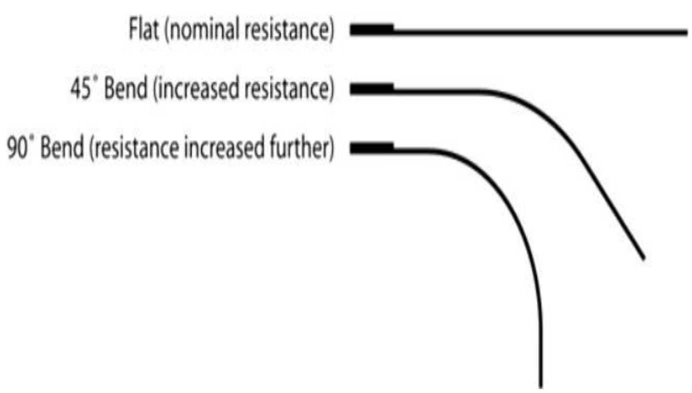

Fig 3. Change in resistance wrt bending angle

1.4. Applications

Flex sensors have a wide application. And they work effectively in areas that require the measurement of a device's angle or accurate motion. It is used in fitness devices, Robots, and the Medical Industry.

The sensors have the potential to detect the presence of tremors in patients recovering from Parkinson's.

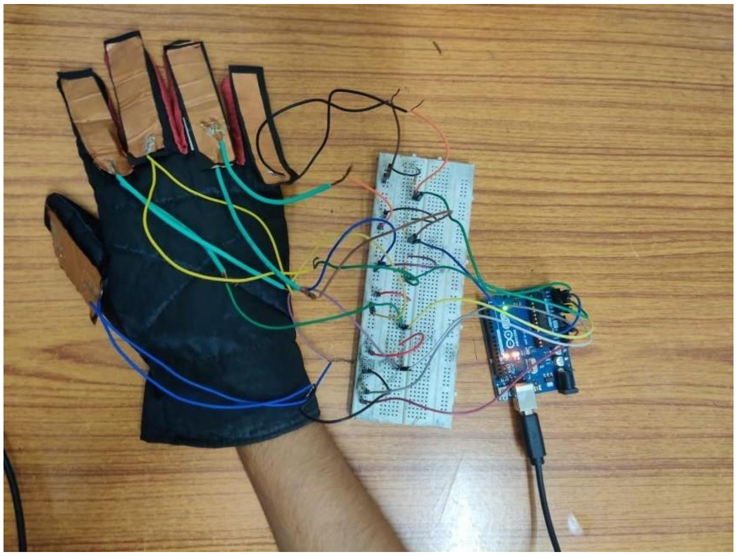

Fig 4. Glove with Velostat-based flex sensors

1.5. Bio-char

Biochar is a carbonaceous material obtained from the thermochemical decomposition (pyrolysis) of naturally abundant raw materials (biomasses) and has attracted strong interest owing to the combination of fascinating physicochemical properties, sustainability and low-cost.

The possibility to tune its properties, in terms of surface area, porosity, surface charge and elemental content is perhaps the most striking advantage of biochar and its outstandingly good performances in diverse research fields, ranging from energy materials to environmental remediation, are a direct consequence of its tailoring opportunities

Different types of biochar-modified electrochemical sensors can be identified depending on an adopted experimental approach.
Voltametric (measurement of the current as a function of a potential sweep) and amperometric (measurement of the current at constant potential) measurements represent the whole panorama of biochar-based electrochemical devices applications.

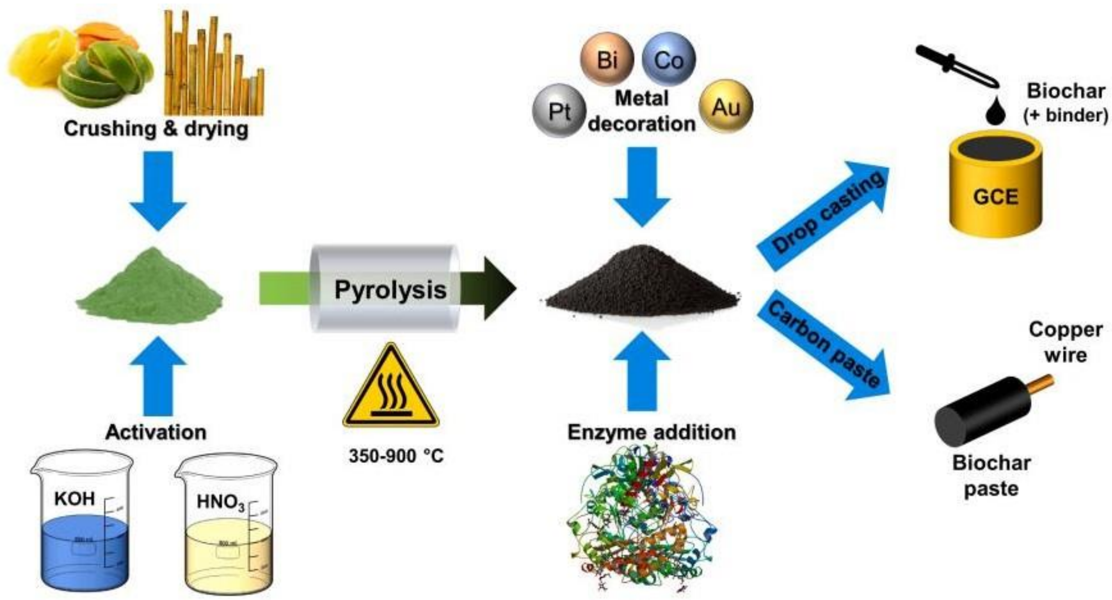

Fig 5. Biochar processing steps

1.6. Motivation

Resistive flex sensors have been increasingly used in different areas for their interesting property to change their resistance when bent. They can be employed in those systems where a joint rotation has to be measured, in particular biomedical systems, to measure human joint static and dynamic postures. In spite of their interesting properties, such as robustness, low price and long life, to date commercial flex sensors have been only characterized against the variation of the bend angle with small fixed curvature radius mostly around the device center, so limiting the application to the measure of human joints

Proposed sensor must be:

- Excellent flexibility and linearity properties
- Eco-friendly
- Lower bending strength
- High Flexibility

CHAPTER-2

2. Literature Survey

2.1. JOURNALS REVIEWED

1. Flexible graphene oxide sensor for electrochemical monitoring

International journal of pure and applied chemistry, Year: 2020

- In this study, the detection of lactate in appropriate ranges of perspired human sweat was established at low volume using a crossing membrane metal electrode sensor system.
- The sensing ability was done by measuring impedance changes associated with lactate binding to the lactate oxidase at the GO nanosheet interface using electrochemical impedance spectroscopy
- A specificity study conducted using cortisol expressed in sweat revealed a negative response to the lactate oxidase.
- Continuous lactate sensing studies were performed during which the sensor was responsive to concentrations of lactate upto 138mM

2. Self –healing hydrogel-based sensor based on polyvinyl alcohol and sodium tetraborate for human monitoring

International Journal of Biological Macromolecules, Year: 2022

- This study is about sensor made out of hydrogel which has high stretchability.
- They are used to detect human motion.
- However, most hydrogel-based sensors are processed by template method, which is unable to fabricate complex three-dimensional (3D) structures, and limits the development of hydrogel-based sensor devices.

- The SPB hydrogel rapidly healed at room temperature, while its mechanical properties and conductivity also recovered quickly after healing.

- It is also used as wearable strain sensors which have moderate stretchability and large stretch deformation not detecting tiny changes in pressure.

-

3. Highly stable flex sensors fabricated through mass production roll-to-roll micro-gravure printing system

Sensors and Actuators A: Physical- Elsevier , Year: 2018

- In this paper, a novel mass production roll-to-roll micro-gravure printing system has been used to fabricate bend sensors

- Composite of activated carbon and Polyvinylidene flouride used as binding agent has been used to fabricate the active layer of the sensors

- Polyvinyl acetate has been used to fabricate the protective coating on top of the active layer

- The sensors show stable and accurate response in terms of change in resistance upon wide bending angles.

- Increasing the sensor width decreases the resistance and so does reducing the length

4. Flex sensor characterization against shape and curvature changes

Sensors and Actuators -Elsevier , Year: 2018

- This paper provides an investigation to improve flex sensors linearity and sensitivity to measure body joint angles

- To this aim, an empirical model of the sheet (or surface) resistance of the active layer, to simulate its behavior against the layer shape and size as well as the bending angle was provided, to investigate whether changes of the standard rectangular shape can improve sensitivity and linearity.

- In addition, to date commercial flex sensors have been characterized only against the bending angle with a radius of curvature smaller than the device length, so limiting the application to small joints such as finger or knee

- In order to extend the flex sensor applications, for instance, to measure the trunk posture in back disease and rehabilitation monitoring, the sensor response against a radius of curvature greater than the sensor length was analyzed.

- Finally, a new modeling technique, based on the inverse model of the sensor characteristic, to enable fast measurements of the bending angle or the radius of curvature from sensor response also in real time, and fast calibration procedures, fitting the same model to measurements with different joint size and even device, were developed.

5. A human skin-inspired self-powered flex sensor with thermally embossed microstructured triboelectric layers for sign language interpretation

Nano Energy conference, Year: 2020

- In this work, a highly sensitive and facile fabricated self-powered triboelectric flex sensor (STFS) is presented which can efficiently detect the finger bending motion and monitor the hand gestures.

- Flex sensors are essential for the mechano-sensation of human gesture monitoring, electronic skin development, and human-machine interfaces, but require a power supply for their operation.

- Drawn inspiration from the highly sensitive human skin dermis-epidermis interlocked haptic performance, the fabricated STFS consists of randomly distributed micro-structured triboelectric layers imprinted from an emery paper through thermal embossing technology

- Under the bending of a finger, the STFS realizes the contact and separation to convert the finger motion stimuli into an electrical signal.

6. Curvature characterization for human posture detection

Universal Journal of Biomedical Engineering, Year: 2017

- This paper talks about the basic characterization of commercial flex sensors that have been tried to incorporate into human posture detection.

- Resistive flex sensors have been increasingly used in different areas for their interesting property to change their resistance when bent.

- They can be employed in those systems where a joint rotation has to be measured, in particular biomedical systems, to measure human joint static and dynamic postures

- In spite of their interesting properties, such as robustness, low price, and long life, to date commercial flex sensors have been only characterized against the variation of the bend angle with a small fixed curvature radius mostly around the device center, so limiting the application to the measure of human joints

- Commercial bend sensor devices consist of a single, thin (less than 0.005”) flexible plastic material that is coated with a resistive film, a proprietary carbon/polymer ink, which can be applied on virtually any custom shape and size.

7. Resistive and capacitive strain sensors based on customized compliant electrode

Sensors and actuators A: physical, Year: 2020

- In this study, simultaneous preparation of two high-performance types of stretchable strain sensors (resistive and capacitive sensors) based on customized compliant electrode

- The electrode was developed by embedding multi-walled carbon nanotubes (MCNTs) into plasticized polyvinyl chloride (PVC) using the solvent casting method

- The resistive strain sensor was fabricated by the compliant electrode and tapes in a sandwich structure.

- The capacitive sensor was obtained after simple stacking steps based on the preparation of resistive sensor

8. **Biochar as an alternative sustainable platform for sensing applications**

   Microchemical Journal, Year: 2020

- The contents reported in this review show the extreme versatility of biochar for the fabrication of different kind of sensing materials

- This material represents a valid low-cost and sustainable alternative to traditional carbon-based materials, presenting at the same time comparable analytical performances. i) porous carbonaceous materials, beneficial for electrochemical sensors by enhancing electronic and adsorption properties and ii) carbon dots, valuable materials for both electrochemical and optical sensing applications are used.

- The typical self-doping and surface functionalization of biochar further contribute to enhance the sensing properties of this material, irrespectively from the principle of operation of the sensor.

9. **Structurally hierarchical flex-sensor of MWCNTs/TPU composite via mesh mould-based selective laser sintering (SLS) and ultrasonic cavitation-enabled treatment (UCT)**

   Elsevier, Year: 2022

- In this study, a multi-walled carbon nanotubes (MWCNTs)/thermoplastic polyurethane (TPU) CPC structurally hierarchical flexible strain sensor was created using a simple hybrid fabrication path that included selective laser sintering (SLS) 3D printing, inverted-mould grooving, and ultrasonic cavitation-enabled treatment (UCT).

- On the sensor properties, the effects of SLS process parameters, mesh-molded groove geometry, and material ratio were investigated. The mechanisms of sensing were discussed. There were some application demonstrations of the prepared sensors on display. The hierarchically structured design and fabrication path makes it easier to create more versatile flex-sensors.

10. Piezoelectric $BaTiO_3$/alginate spherical composite beads for energy harvesting and self-powered wearable flexion sensor.

Composites Science and Technology , Year: 2017

- In this study,the ionotropic gelation (IG) method was used to create spherical composite (BaTiO3 nanoparticle/Ca-alginate) beads on a large scale.
- The energy harvesting performance of a composite bead-based nanogenerator (CBNG) was investigated using different device areas, mechanical pressures, bending angles, rapid hand force, capacitive loadings, and electrical poling.
- With a simple low mechanical pressure of 1.70 kPa, a high output (82 V, 227 A) was generated, which is sufficient to drive low power electronic devices.

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13. A flexible and highly sensitive nonenzymatic glucose sensor based on DVD-laser scribed graphene substrate.

Biosensors and Bioelectronic, Year: 2018

- In this study they have fabricated a flexible and highly sensitive nonenzymatic glucose by using DVD-laser scribed graphene (LSG) as a flexible conductively substrate.
- Copper nanoparticles (Cu-NPs) are electrodeposited as the catalyst.
- The LSG/Cu-NPs sensor demonstrates excellent catalytic activity toward glucose oxidation and exhibits a linear glucose detection range from 1 μM to 4.54 mM with high sensitivity (1.518 mA mM^{-1} cm^{-2}) andlow limit of detection (0.35 μM).
- Moreover, the LSG/Cu-NPs sensor shows excellent reproducibility and long-term stability.

14. ZnO nanorods/carbon black-based flexible strain sensor for detecting human motions.

Journal of Alloys and Compounds, Year : 2018

- In this study, simple, effective, low-cost, and convenient strategy was used to create a flexible strain sensor using hexagonal ZnO nanorods (NRs) and carbon black as sensing elements, polydimethylsiloxane (PDMS) as the matrix, and latex film as the substrate.
- The benefits of as-assembled strain sensors include high flexibility, high sensitivity, a wide workable strain range, good linearity, and ideal stability.
- The ZnO/carbon black-based sensor outperforms the carbon black-based sensor in terms of tensile stress sensitivity.
- The ZnO/carbon black-based sensor is also capable of detecting and distinguishing various degrees of human motions such as wrist rotation, knee flexion, and finger tapping.

15. Development of conductive inks for electrochemical sensors and biosensors

Microchemical Journal, Year: 2021

- Monitoring of species of medicinal, environmental, and industrial relevance is critically needed. Several times, the need for precise and speedy quantification at the point of care and/or point of use has been highlighted, and wearable and flexible disposable electrochemical sensors and biosensors have proven to be excellent options.
- A quick summary of the main advancements in the fabrication and development of conductive inks for the creation of tiny and disposable electrochemical devices is offered in this context.

- Electrochemical devices made from conductive inks are a novel technology that provides electrode design freedom.

- The expanding number of studies on the development of inks is driven by the desire for simplicity, cheap cost, minimal waste generation, mass productio

2.2. SUMMARY OF LITERATURE SURVEY

1. From the above literature surveys, it is evident that flex sensors are used in different types of Industries and experimentation.

2. The implementation and usage of flex sensors are majorly used in the healthcare industry due to their wide variety of applications in joint degree motions.

3. Experimentation of commercial flex sensors shows its limited use in an application-oriented scenario

4. Production of currently produced flex sensors as a substitute to epoxy-based market sensors require more capital to produce that its actual product value.

5. Bio-char has been used for different applications, but has not yet been experimented in the making of flex sensors.

6. From this survey, we have come to a conclusion that a flex sensor can be made of eco-friendly biochar made flex sensor with high flexibility

2.3. GAP IN LITERATURE

1. According to the preceding literature review, flex sensors are manufactured using numerous processes in various types of manufacturing setups.

2. Most flex sensors exhibit non-linear characteristics due to the usage of epoxy resin, which lowers the sensor's flexibility.

3. The most prevalent issues with conventional flex sensors include low accuracy, non-linearity, and a limited radius of curvature.

4. The usage of hazardous chemicals in the manufacturing process of flex sensors makes them less sustainable and damaging to the environment.

5. The studies of many have been done in scales that are not commercially achievable and are only limited for research purposes.

CHAPTER-3

OBJECTIVE

1. To develop a novel flex sensor on a textile substrate made of bio-char which is environmentally friendly.

2. To characterize the sensor for a small radius of curvature in order to detect minute changes in resistance when the sensor is being handled by the user.

3. To characterize the sensor for a large radius of curvature for healthcare applications used majorly for longer joints in the human body.

4. The goal is to make a mathematical model to accumulate the dynamicbehavior of the flex sensor so that in the future it can be used in a commercialspace with high efficiency and efficacy.

5. To create an analytical comparison between the novel flex sensor made and the commercial flex sensor available in the market.

CHAPTER-4

METHODOLOGY

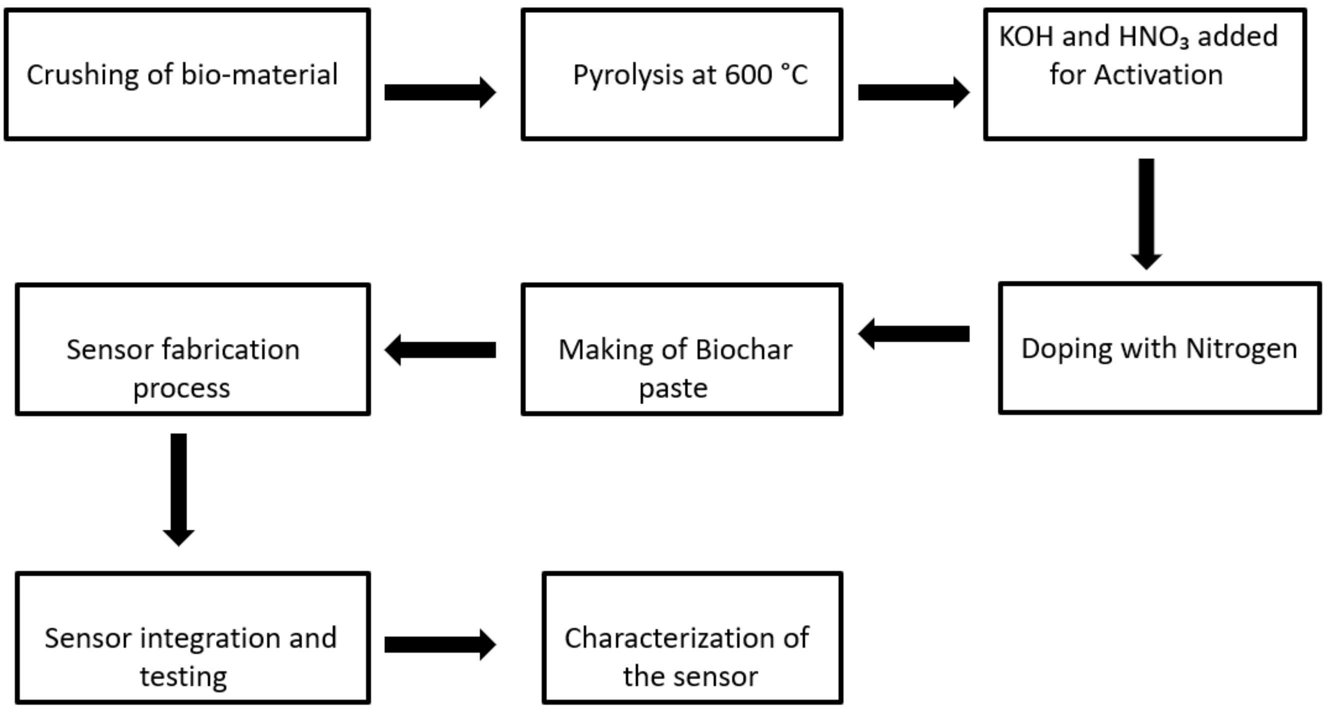


Fig 6. Flowchart

4.1. Bio-Material

- The first step of the project was to identify a material that would be best suitable for the grinding process.
- After a lot of scrutiny and errors, rice was chosen as the foundation material.
- For smooth operation the rice husk was put in a grinder and made into a powder form.
- After this it was sent to the lab for the pyrolysis process.

4.2. What is Pyrolysis?

- Pyrolysis is a thermal decomposition process that involves the breakdown of organic materials at high temperatures in the absence of oxygen.

- The process converts the organic materials into a range of valuable products, including biofuels, chemicals, and biochar.

- During the pyrolysis process, organic materials are heated to temperatures of between 400 and 800°C in an oxygen-free environment.

- The high temperatures cause the materials to break down into smaller molecules, which can then be collected and refined into a range of useful products.

4.2.1. Types of Pyrolysis

- There are several different types of pyrolysis, including slow, fast, and flash pyrolysis.

- Slow pyrolysis involves heating organic materials at a low temperature over a long period of time, while fast and flash pyrolysis involve higher temperatures and shorter processing times.

4.2.2. Applications of Pyrolysis

- Pyrolysis has a wide range of applications, including the production of biofuels, chemicals, and biochar.

- The process is also used in waste management, where it can be used to convert waste materials into useful products while reducing the volume of waste that needs to be disposed of.

4.3. Pyrolysis process

- The apparatus for the experiment consists of a reactor, furnace, collector, copper wires etc.

- The ground rice husk is kept in storage to avoid getting affected by the moisture present in the air.

Fig 7. Pyrolysis apparatus

- The reactor is made of propane material and a metal covering is provided on the outside in order to increase the convectional effect inside the reactor.

- The reactor base is surrounded by nichrome wire which acts as the heating element.

- To avoid short-circuiting the base of the material is made up of clay for insulation.

- The end of the reactor has 2 copper wires connected to the nichrome wire for the intake of power supply around 120 V.

- The top of the reactor is plated with hard Teflon to make it airtight. Any leakages can be avoided which will cause a pressure drop.

- The current passing through the circuit is approximately 12 Amps.

Fig8. Powdered Rice husk

4.3.1 Four Stages of Pyrolysis:

1. **Moisture evaporation process**

   - The high temperature of the upper part of the reactor makes the ground rice husk lose its excess moisture content.

   - This lets the upcoming processes to happen smoothly.

2. **De-gasification process**

   - The biomass is heated between the temperatures of 400 °C- 600°C.

   - This helps in removing all the volatile substances from the mixture.

   - KOH is added to remove the presence of CO_2. The presence of CO_2 will lead to incomplete combustion of the mixture.

   - This will lead to the formation of char instead of ash which is required.

3. Carbonization process

- In the process of carbonization, high temperatures cause the formation of carbon and remove the fiber’s elemental structure.

- HNO_3 helps in the process of carbonization.

- Depending on the inside temperature of the reactor, the calorific value of the material is between 25- 29 kJ/kg

4. Cooling Process

- The hot carbon extract material is cooled down with the help of cross flow water coolant tubes.

- These tubes are made up of copper material as well for better thermal absorption properties.

- After this we store the final cooled-down ash in an air-tight bag for later use.

- The excess gas let out, is used for reheating and doing the process again.

5. Doping

- The activated carbon is doped with nitrogen and copper enzymes were added which acted as a catalyst to the process.

- Now this material is ready for the fabrication process of the sensor

4.4. Fabrication

Now that we have done the carbonization of the given powder form we have to fabricate it into a sensor. The sensor has to be made into sheet form or strip.

This can be seen in the following steps to come on how the sensor has to be fabricated.

4.4.1. Magnetic stirring

Fig 9. Magnetic Stirrer

A magnetic stirrer is a laboratory device used to mix liquids or solutions by using a rotating magnetic field. It consists of a small magnetic bar (or stir bar) that is placed in the solution to be stirred, and a magnetic stir plate which contains a rotating magnet.

When the magnetic stir plate is turned on, the magnetic bar rotates with it, creating a vortex in the solution and effectively mixing it.

Magnetic stirrers are commonly used in chemistry, biology, and medical laboratories to mix solutions that are too viscous or delicate to be stirred by hand.

They are also useful for maintaining a consistent temperature throughout the solution as the heat generated by the rotating magnetic bar can evenly distribute throughout the liquid.

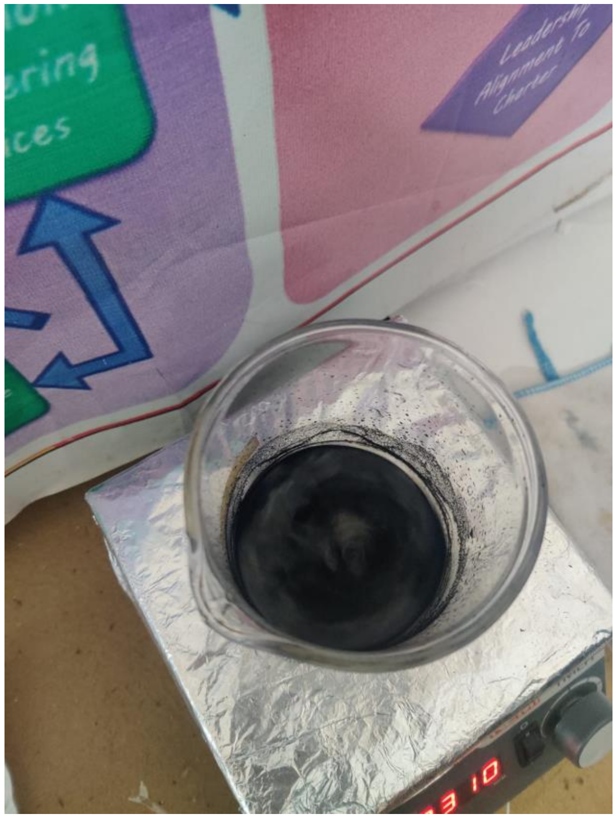


Fig10. Low RPM rotate

Powder is measured on a measuring scale and taken in small quantities according To the amount of distilled water taken. We have considered a quantity of 50 ml of distilled water and accordingly taken 10 percent of the powder which comes down 50 g.

Distilled water is a type of purified water that has gone through a process of distillation to remove impurities and minerals. The process involves boiling water and then collecting the steam, which is then condensed back into liquid form. This method of purification removes not only visible contaminants but also dissolved minerals and ions, resulting in water that is highly pure and free of any taste or odor.

The distilled water is added to a beaker and placed on top of the magnetic stirrer.

The beaker is placed on the apparatus and when switched on the magnetic stirrer Starts to rotate, thus also making the water mix. The RPM of the magnetic stirrer has to be gradually increased.

Around the same time, we will also be adding the powder slowly into the water evenly mixing it around.

The problem with setting a fast RPM from the beginning will make the powder form residue all over the beaker. This will lead to the wastage of the material.

The material is set to rotate for 3 hours and should be undisturbed.

4.4.2. Textile substrate

A textile substrate is a type of material that is commonly used as a base or foundation for the production of various textile products. It is a flexible, woven or knitted fabric that serves as a starting point for the application of various treatments, coatings, and finishes that improve the properties of the final product. Textile substrates come in a wide range of materials, including cotton, polyester, nylon, rayon, and silk, and can vary in texture, weight, and thickness.

One of the most common uses of textile substrates is in the production of apparel and clothing. Clothing manufacturers use textile substrates as a base for various coatings, finishes, and treatments that improve the properties of the fabric, such as durability, water resistance, and wrinkle resistance. For example, textile substrates can be treated with chemical finishes to improve the stain resistance of a fabric, or coated with polyurethane to make it water-resistant.

Another common application of textile substrates is in the production of home furnishings and upholstery. Textile substrates can be used as a base for various coatings and treatments that improve the durability and stain resistance of the fabric, making it ideal for use in furniture upholstery and other home furnishings.

Textile substrates are also widely used in the production of technical textiles, such as geotextiles and medical textiles. In geotextiles, textile substrates are used as a base for various coatings and treatments that make them ideal for use in soil stabilization, erosion control, and filtration. In medical textiles, textile substrates are used as a base for various treatments and coatings that improve the properties of the fabric, such as antimicrobial properties, blood resistance, and moisture management.

In conclusion, textile substrates are a versatile and essential component in the production of a wide range of textile products. They serve as a base for the application of various coatings, treatments, and finishes that improve the properties of the fabric and make it suitable for a variety of applications, including apparel, home furnishings, and technical textiles.

Two substrates were chosen to conduct the experiment. The materials chosen were wool and cotton.

Fig11. Dipping wool substrate

In the picture, the wool and cotton substrate was dipped into the biochar mixture. It was constantly dipped 5 times in intervals of 30 secs. Only after these many dips the material fully absorb the nanoparticles.

This dipped substrate was left out to dry for 1 day and 1 night. The next day the dried-up substrate was extracted. The Nanoparticles of the biochar mixture had occupied the empty spaces

Fig12. Dipping cotton substrate

A difference in colour could be seen between the wool and cotton substrate. The wool substrate had better texture and colour compared to the cotton substrate. This proved the fact that the thicker material absorbed more nanomaterials compared to the lighter and thinner cotton.

A copper strip was pasted on either side of the substrates. The wires were soldered to the substrate ends. The excess dried-up biochar mixture was made into a paste and wound over a thin coil. It was made into wire form and and both end of the coil we soldered with a wire.

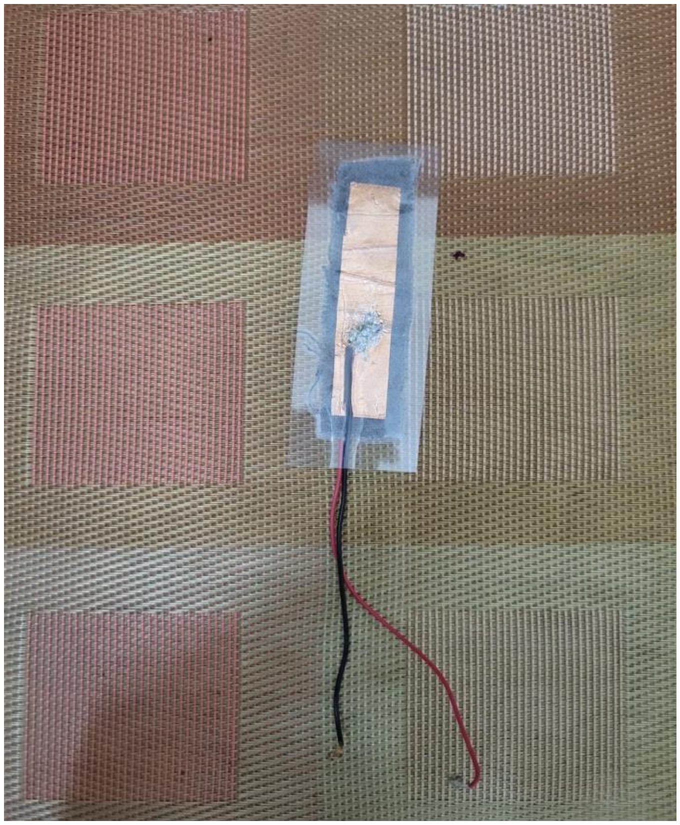


Fig13. Wool substrate sensor

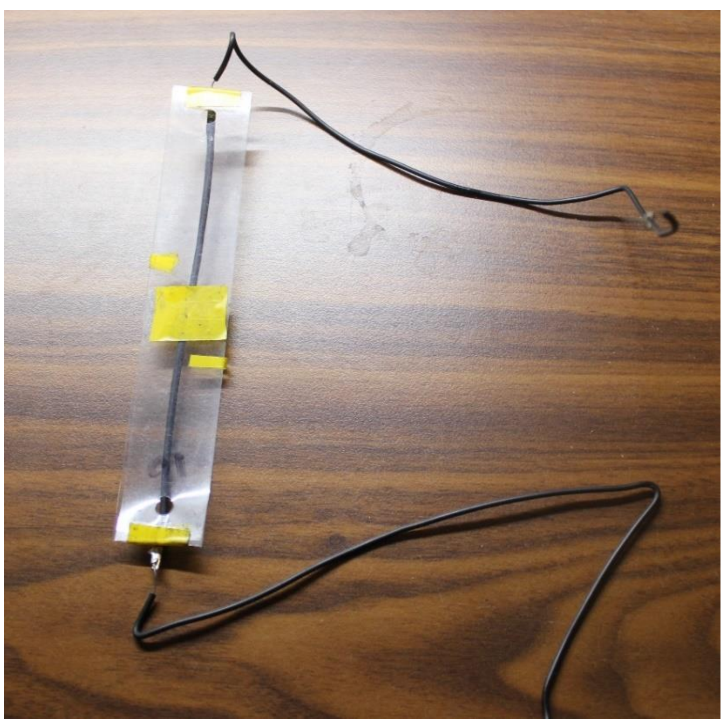


Fig14. Coil flex sensor

CHAPTER-5

EXPERIMENTATION

Now after the fabrication of the sensors, we have to check for resistance The nanoparticles harden up which creates a major resistance. A setup was created in order to test the conditions of resistance.

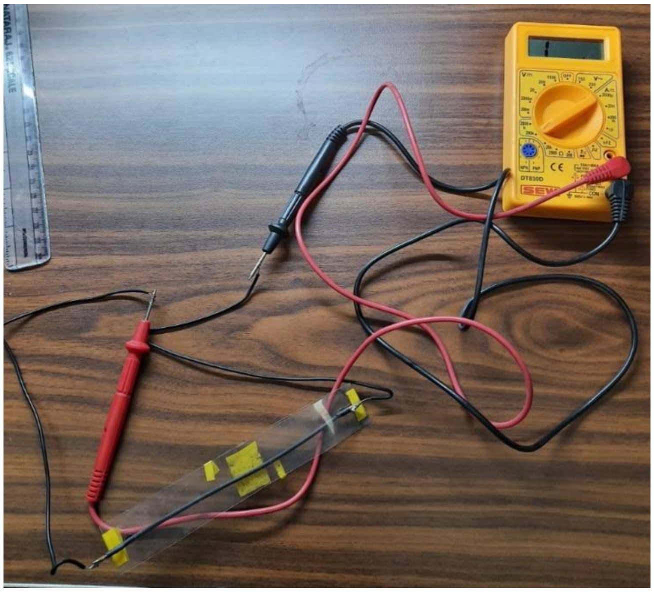


Fig 15a: Threshold resistance - Before

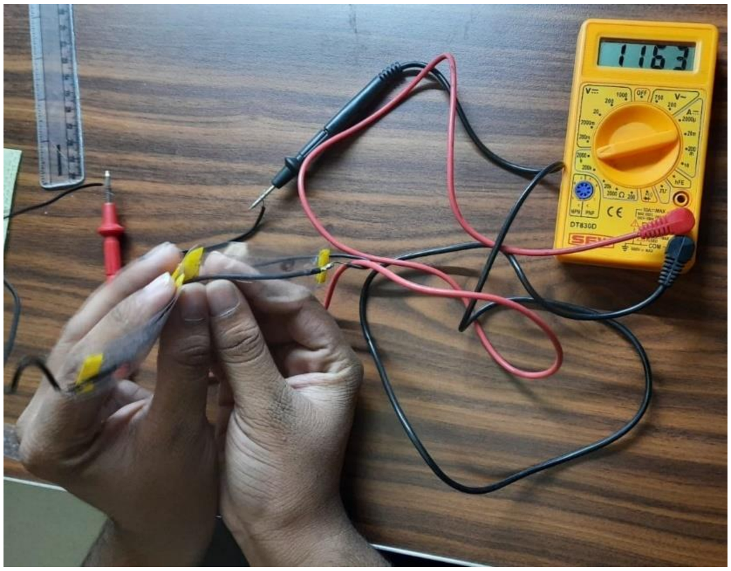


Fig 15b: Threshold resistance - After

The setup consisted of an Arduino Uno, Arduino Nano, 9 V battery, Stepper motor, motor driver and capacitor.

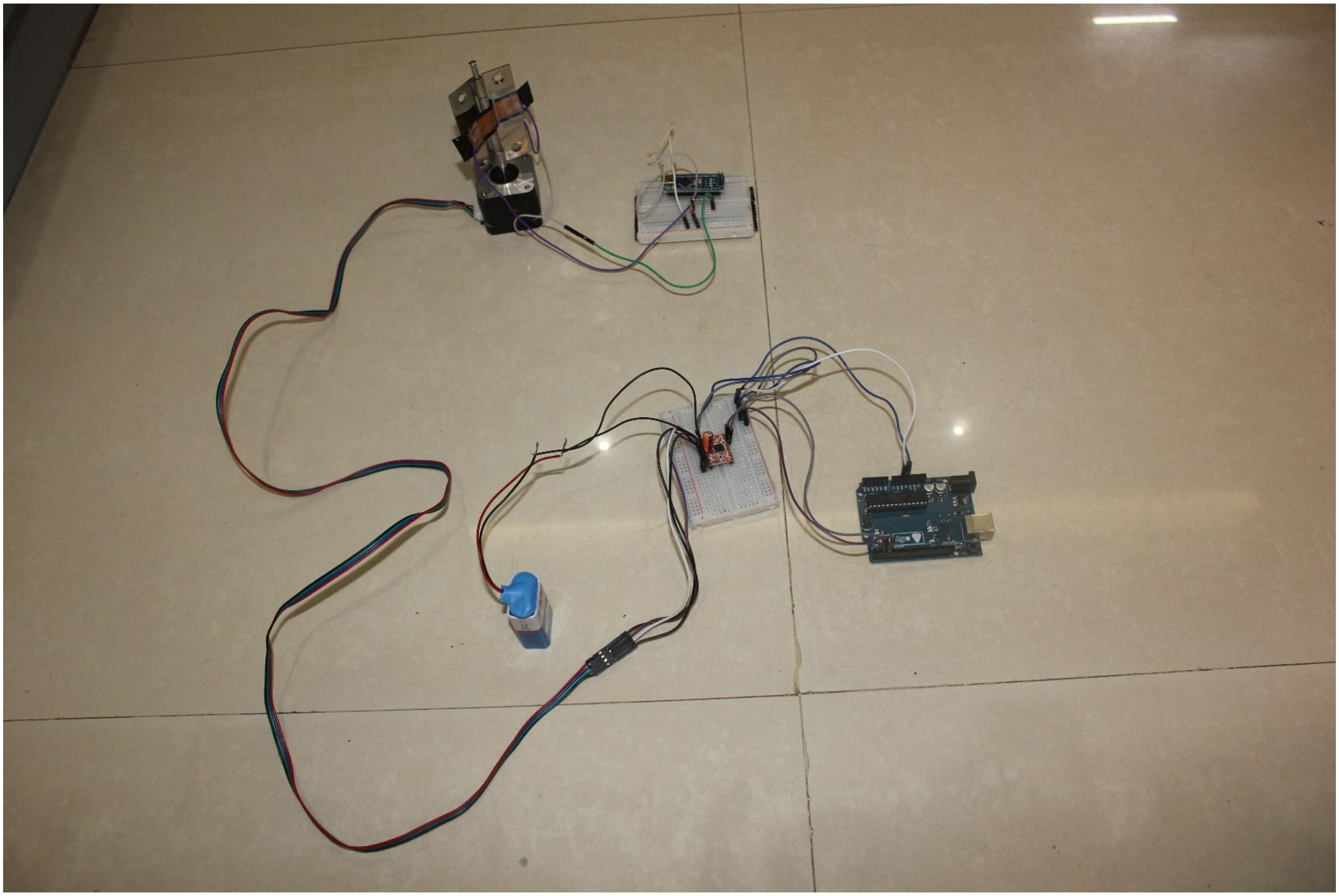


Fig16. Experimental Setup

The stepper motor have Green, Black, Red, Blue wires. The black and green are connected to one side and red and blue are connected to other side.

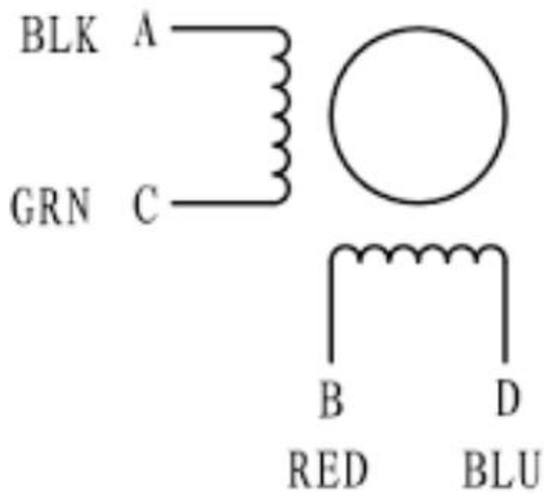


Fig17. Stepper motor wiring

It is connected in this format so that the north and south will alternately move

Fig18. Stepper motor and latch

A latch was placed on top of the stepper motor. Upon programming it the latch will open and close in intervals of 20°. In this setup, the motor driver used is A4988 and 100 microfarad capacitor was used to store and deli

The A4988 is a popular motor driver integrated circuit (IC) designed for driving bipolar stepper motors. It is widely used in 3D printers, CNC machines, and other projects where precise control of stepper motors is required.

The A4988 motor driver is capable of driving a bipolar stepper motor with up to 2A of current per coil. It uses a pulse width modulation (PWM) technique to control the current to the motor coils, allowing for smooth and precise motor movement. The driver also has a built-in micro-stepping feature, which enables the motor to be moved in very small increments, resulting in smoother and quieter motor operation.

The A4988 motor driver is compatible with a wide range of microcontrollers can be controlled using simple step and direction signals. It also includes a thermal shutdown circuit that protects the IC from overheating.

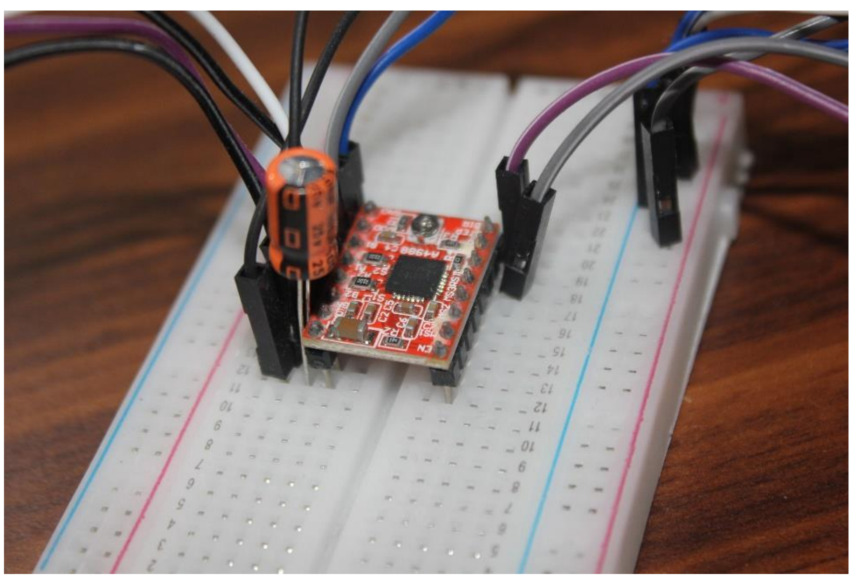


Fig19. A4988 Motor driver

To determine how much voltage was being outputted, the nominal value of the flex sensor could be computed using the formula. When the flex sensor was flat, the output voltage Vout was 2.5V when Vin = 5V, R0 = Rflat= R

- Formula used:
  1. Stepper Motor current limit = 1.7 A
  2. Vref of A4988 Driver = (current limit/2.5)

$$= 1.7/2.5$$

$$= 0.68 \text{ V}$$

5.1 ARDUINO CODE

```
// Define pin connections & motor's steps per revolution
const int dirPin = 2;
const int stepPin = 3;
const int stepsPerRevolution = 200;

void setup()
{
  // Declare pins as Outputs
  pinMode(stepPin, OUTPUT);
  pinMode(dirPin, OUTPUT);
}
```

Fig20. Arduino setup

Before starting the code, it is essential that we initialize a few variables to the This helps the Arduino to identify the proper connections made by the user.

As we can see in the above code we have initialized a variable called stepsPerRevolution to a value of 200. This is because the total angle achieved by the stepper motor is 360°. The given resolution of the stepper motor is 1.8°. Hence 360/1.8 = 200. This is considered universally for the NEMA 17 stepper motor used. In the void setup () we set the stepPin and dirPin to OUTPUT mode as we want the number of steps and direction to change according to the coded program in the next set of code.

```
void loop()
{
  // Set motor direction clockwise
  digitalWrite(dirPin, HIGH);

  // Spin motor slowly
  for(int x = 0; x < stepsPerRevolution; x++)
  {
    digitalWrite(stepPin, HIGH);
    delayMicroseconds(2000);
    digitalWrite(stepPin, LOW);
    delayMicroseconds(2000);
  }
  delay(1000); // Wait a second

  // Set motor direction counterclockwise
  digitalWrite(dirPin, LOW);

  // Spin motor quickly
  for(int x = 0; x < stepsPerRevolution; x++)
  {
    digitalWrite(stepPin, HIGH);
    delayMicroseconds(1000);
    digitalWrite(stepPin, LOW);
    delayMicroseconds(1000);
  }
  delay(1000); // Wait a second
}
```

Fig21. Arduino loop

The void loop () holds the set of lines of the program that have the commands that execute the code. As we have to make the stepper motor spin clockwise and anti-clockwise, we set the dirPin values to HIGH and LOW.

StepPin was set to HIGH to make it move and the LOW mode was set to stop the rotation. The code can be adjusted according to user requirements.

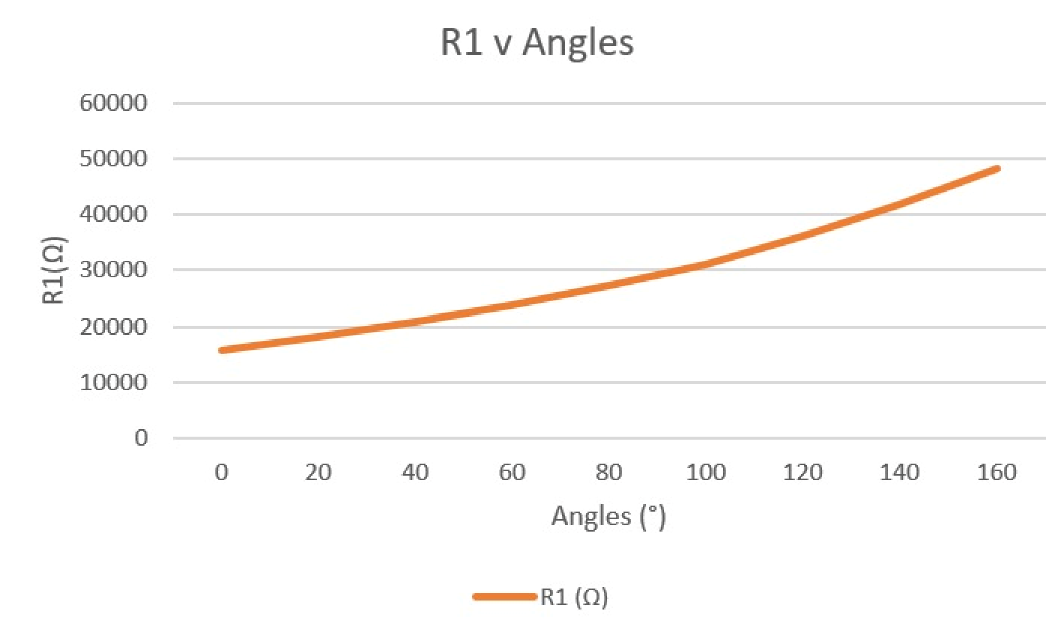
CHAPTER-6

RESULTS

After execution of the following codes we were able to get concise details of the Values of resistance offered by these sensors. Graphs are plotted for each of the following sensors with respect to the angle and a comparative analysis graph is shown at the end .

6.1. COMMERCIAL FLEX SENSOR

The first sensor to be tested is the commercial flex sensor used in the market.



Graph 1: R1 vs Angle

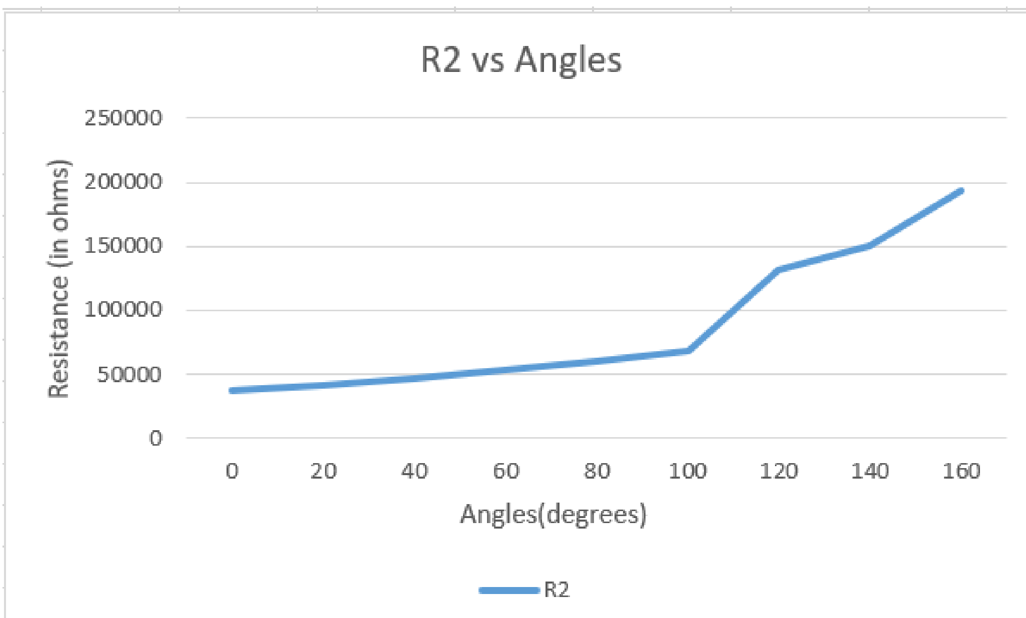
Table: 1 - Commercial Flex Sensor

Angle (°)	0	20	40	60	80	100	120	140	160	180
R1 (Ω)	13567	15666	18096	20919	23783.1	27367.1	31073	36038	41679.24	48141.47

INFERENCE: The commercial flex sensor shows a very gradual increase in the resistance and even over a large course of angles. Hence it isn't very efficient for practical use. The radius of curvature to resistance ratio is very less. So it is not advisable to be used in medical devices for Parkinson's disease.

6.2. WIRE-FORM FLEX SENSOR

The values shown below are the values taken on the experimental setup for the wire form sensor.



Graph 2: R2 vs Angle

Table:2 – Wire Form Flex Sensor

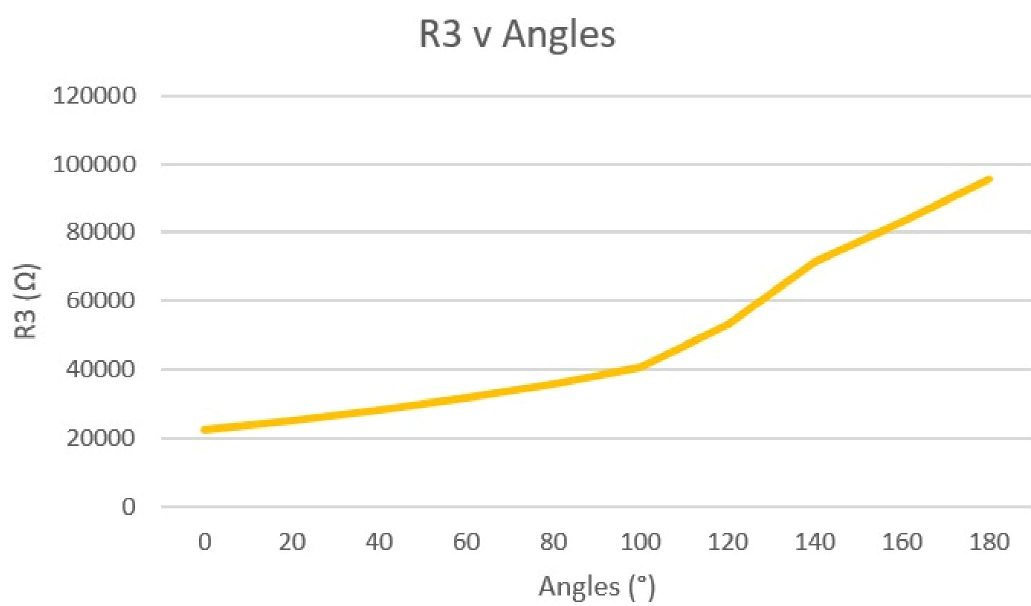
Angle (°)	0	20	40	60	80	100	120	140	160	180
R2 (Ω)	33756.01	37532.37	42015.15	47377.51	53000	60305.93	68196.07	131030.3	150400	192795.9

INFERENCE: In the above graph the values of the flex sensor have a sharp increase in the resistance values after a certain 100°. Hence we can conclude the threshold resistance is after 100°.

This can be used in medical devices for gait analysis due to its moderate threshold values.

6.3. WOOL SUBSTRATE FLEX SENSOR

The graph below indicates the values of resistance taken on the wool substrate



Graph 3: R3 vs Angle

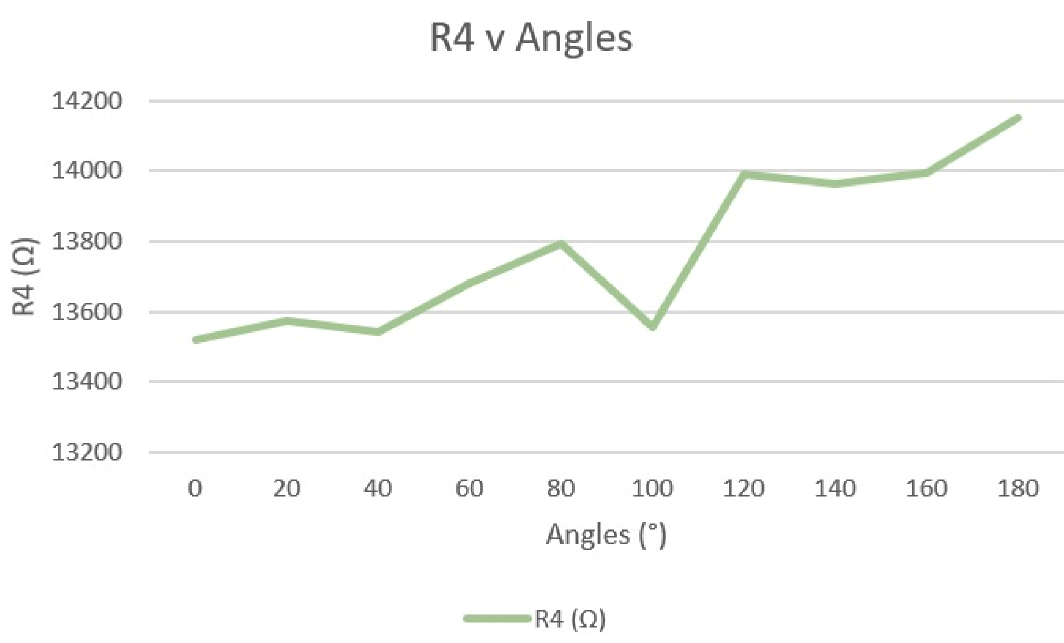
Table: 3 – Wool Substrate

Angle (°)	0	20	40	60	80	100	120	140	160	180
R3 (Ω)	22219.44	24975.5	28200	31859.06	35892.41	40686.56	53000	71387.9	83193.9	95424.24

INFERENCE: Compared to the wire form flex sensor, we can say that this sensor is not as reactive or flexible, but it has greater resistance properties compared to the commercial flex sensor.

6.4. COTTON SUBSTRATE FLEX SENSOR

The below graph indicates the resistance values of the cotton substrate flex sensor



Graph 4: R4 vs Angle

Table: 4 – Cotton Substrate

Angle (°)	0	20	40	60	80	100	120	140	160	180
R4 (Ω)	13520	13573	13542	13682.3	13793.6	13555	13990	13964	13994	14150

INFERENCE: Compared to the other sensor the value of this sensor is very less with values of resistance being very unstable and not in linear pattern.

CHAPTER-7

CONCLUSION

From the above experimentation and results we have come to the conclusion that the different sensors have different forms of resistance according to their properties and fabrication process.

Graph5: Cumulative resistances

It can be observed that R1 has the best change in resistance. This makes us conclude that the torsional twist created by the wire offers better resistance when compared to bending on the material longitudinally compared to others.

Wool substrate offers better resistance when compared to commercial flex sensor. Thus achieving the objective to get better resistance for small and large radius of curvature.

A bio-friendly material made flex sensor was also successfully fabricated.

CHAPTER-8

SCOPE FOR THE FUTURE

The use of eco-friendly materials in flex sensors is a growing trend in the sensor industry. Eco-friendly materials, such as biodegradable plastics and natural fibers, have several advantages over traditional materials. They are sustainable, renewable, and have a lower environmental impact compared to traditional materials.

The future scope of eco-friendly flex sensors is promising. With the increasing focus on sustainability and environmental conservation, the demand for eco-friendly products is on the rise. The use of eco-friendly materials in flex sensors can help reduce the carbon footprint of the sensor industry and contribute to a more sustainable future.

One of the major advantages of eco-friendly flex sensors is that they can be easily recycled or biodegraded at the end of their lifecycle. This can help reduce the amount of waste generated by the sensor industry and promote a circular economy.

In addition, eco-friendly flex sensors can also offer improved performance compared to traditional sensors. For example, natural fibers such as bamboo and cotton have been found to have excellent mechanical properties, such as high strength and flexibility. These properties make them ideal materials for flex sensors, which require high durability and flexibility.

Furthermore, the use of eco-friendly materials in flex sensors can also lead to cost savings. Many eco-friendly materials, such as biodegradable plastics, are cost-effective compared to traditional materials. This can help reduce the overall cost of producing flex sensors and make them more accessible to a wider range of applications.

CHAPTER-9

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