Developing Sensors With Paper and Graphite Along With Implementation Into Human Health Tracking and Environment Tracking

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ABSTRACT – **Most modern electronics choose to miniaturize, which means that the sensors or other components are smaller than their typically large bulky size. Utilizing flexible electronics is one way to choose miniaturization. In this study, we explain the creation of several paper-based sensors, including strain sensors and capacitive touch sensors, which were mostly made of graphite. These sensors were created by applying graphite in certain patterns on paper, and an ESP32 was used to program them. Certain recommendations are made for enhancing the sensors, and some sensors—like the switch and touch sensor—were utilized to create a health tracker to alert users to potential health risks and assist them in avoiding them.**

Keywords—graphite, paper-based electronics, flexible sensors, strain sensor, capacitive touch sensor.

I. INTRODUCTION

Due to the excellent electrical and heat conductor properties, graphite materials have recently gained popularity in a wide range of applications. Paper is a versatile, flexible, absorbent, and environmentally friendly substrate that is used in the creation of inexpensive devices and biosensors for the quick detection of important samples. Paper-based sensors offer inexpensive platforms for pathogen detection, food quality monitoring, environmental and sun exposure monitoring, and simple, accurate, quick illness diagnosis. In resource-constrained contexts, such as in poor nations or harsh regions, when fully equipped facilities and highly skilled medical professionals are missing, paper-based devices offer an affordable technology for manufacture of basic and portable diagnostic equipment. Although paper-based sensors and devices have many potential uses, there are certain drawbacks in terms of sensitivity, accuracy, and simultaneous detection of numerous samples. In order to overcome these limitations, patterning has recently been used to manufacture paper-based sensors. [1] Using only paper and graphite and avoiding elaborate and expensive production processes, we present many forms of inexpensive sensors in this study.

II. THEORY

A. Conductivity of Graphite

Due to its own structure and bonding, graphite exhibits conductive properties. Carbon atoms make up graphite, and each one contains four valence electrons. There is a spare electron since the nearby carbon atoms only establish 3 covalent bonds when joining together. These layers of hexagonally linked carbon atoms are what make up graphite. The spare electrons are given the opportunity to travel freely and become delocalized as the layers glide past one another, which enables them to conduct electricity.

III. METHODOLOGY

In this mini-project, inexpensive paper-based sensors were constructed using the concepts of graphite conductivity and utilized to produce a modular health tracker that shields users from health dangers.

Graphite pencils are used to make geometrical sketches on the papers, which are equivalent to graphite films on paper. Since the papers are flexible whole sensor is flexible allowing to make flexible sensor systems.

The ESP32 was combined with other appropriate circuits to create the several sensors and ultimately interfaced together to make a health and environmental tracker for athletes.

A. Grove – Temperature & Humidity Sensor

This sensor is based on DHT1 sensor, and it can measure relative humidity through a capacitive sensor element. Also, it can measure temperature using a negative temperature coefficient (NTC). Even though this sensor is old and slow when taking measurement, it is reliable and accurate. And this can be used in many everyday automation projects which requires humidity and temperature readings. However, in this project, function of this sensor is to provide the user with useful information such as humidity, temperature and heat index which are useful when working out.

Materials used to develop the sensor are,

- Grove – Temperature & Humidity Sensor
- ESP32 microcontroller
- Male-male jumper cables

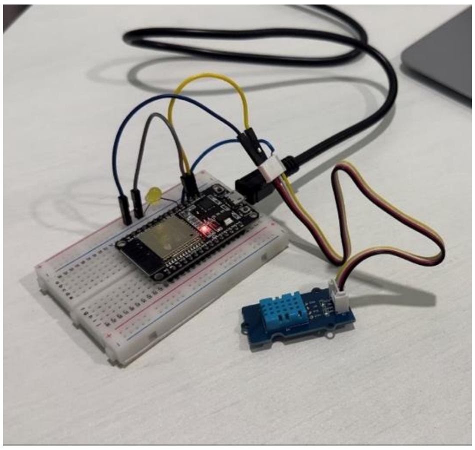


Figure 1 - Wiring diagram of Grove Temperature & Humidity Sensor

```
#include "DHT.h"

#define DHTPIN 2     // Digital pin connected to the DHT sensor

#define DHTTYPE DHT11   // DHT 11
#define LED 4

DHT dht(DHTPIN, DHTTYPE);

void setup() {
  Serial.begin(115200);
  Serial.println(F("DHT11 test!"));
  pinMode(LED, OUTPUT);
  dht.begin();
}

void loop() {
  // Wait a few seconds between measurements.
  delay(2000);

  // Reading temperature or humidity takes about 250 milliseconds!
  // Sensor readings may also be up to 2 seconds 'old' (its a very slow sensor)
  float h = dht.readHumidity();
  // Read temperature as Celsius (the default)
  float t = dht.readTemperature();
  // Read temperature as Fahrenheit (isFahrenheit = true)
  float f = dht.readTemperature(true);

  // Check if any reads failed and exit early (to try again).
  if (isnan(h) || isnan(t) || isnan(f)) {
    Serial.println(F("Failed to read from DHT sensor!"));
    return;
  }

  // Compute heat index in Fahrenheit (the default)
  float hif = dht.computeHeatIndex(f, h);
  // Compute heat index in Celsius (isFahreheit = false)
  float hic = dht.computeHeatIndex(t, h, false);
  if(t>50){
    digitalWrite(LED,HIGH);
  }
  else{
    digitalWrite(LED, LOW);
  }

  Serial.print(F("Humidity: "));
  Serial.print(h);
  Serial.print(F("%  Temperature: "));
  Serial.print(t);
  Serial.print(F("°C "));
  //Serial.print(f);
  Serial.print(F("  Heat index: "));
  Serial.print(hic);
  Serial.println(F("°C "));
  //Serial.print(hif);
  //Serial.println(F("°F"));
}
```

Figure 2 - Code to measure temperature and humidity through Grove sensor

B. *Strain Sensor*

Strain sensor, which is also known as the strain gauge. In a strain sensor, its resistance changes with the applied force. It converts force into an electrical resistance where change in resistance can then be measured to determine the applied force. In a strain sensor, when it is under tension, resistance increases while when under compression, resistance decreases. However lateral forces do not apply to strain sensors.

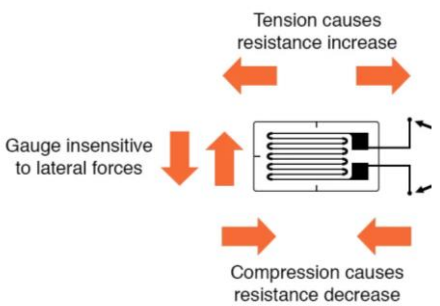


Figure 3 - Working principle of a strain gauge

In this project hand drawn strain gauge is used to detect the heart rate by measuring the movement of chest muscles.

Materials used to develop the strain sensor are,

- A4 paper
- 4B graphite pencil
- ESP32
- Resistor
- Male-male jumper cables
- Breadboard
- Paper clips

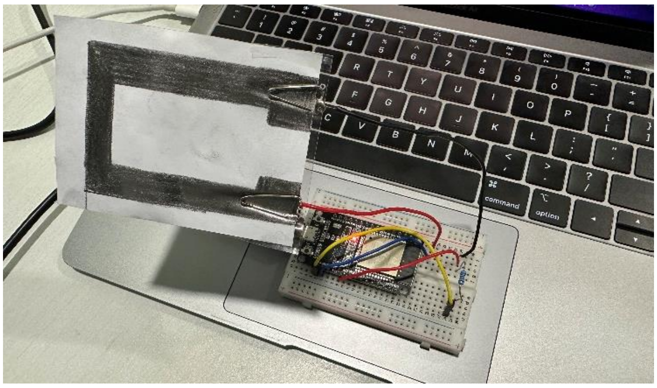


Figure 4 – Experimental setup of Strain Sensor (Hand drawn on paper)

When this sensor is bended, it applied a tension. Then it is much harder for the electrons to travel on a surface with more tension, hence the electrical resistance has increased. Internal LED on the ESP32 board will light up as the strain sensor is bent to indicate the threshold has been reached. When sensing the heart rate or the breathing pattern, this theory can be applied to count the movement of the chest muscles within a specific period of time.

```
const int SensorPin = 4;
#define ONBOARD_LED 2
//pin A0 as Sensor Input
int value; //sensor value
void setup() {
pinMode(ONBOARD_LED,OUTPUT);
Serial.begin (9600); //start serial port
}
void loop() {

value = analogRead(SensorPin);
//value = map (value, 0, 1023, 0, 255);
if(value < 2000){
  digitalWrite(ONBOARD_LED,HIGH);
}
else {
  digitalWrite(ONBOARD_LED,LOW);
}
Serial.println (value);

delay(200);
}
```

Figure 5 - Code used to display values from the strain sensor

C. *Capacitive Proximity Sensor*

The shape of the conductors and the surrounding dielectric material both affect capacitance. The capacitance can alter if the geometric properties change. The concept-based sensors revolve around changing geometric features. We made the decision to create a capacitive-based proximity sensor [2]. This sensor has a flexible feature because it is built on a paper-based concept. Additionally, it weighs less than the conventional sensor. Any wearable may quickly and easily be added to this without adding any additional weight. Since this sensor is constructed on paper, developed sensor also have the advantage of being less brittle.

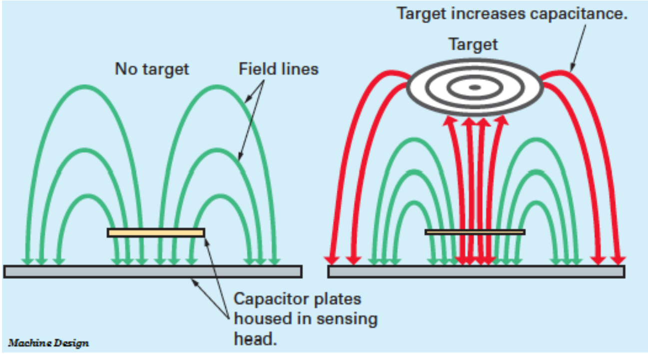


Figure 6 - Working principle of a capacitive proximity sensor

As shown in figure 6, when the target (finger) enters the range and interferes with the field lines, it induces capacitance into the sensor. Hence, this sensor functions by detecting changes in capacitance between the sensor and the target. Therefore, factors such as distance and size of the target will affect the amount of induced capacitance[3], [4].

Materials used to develop the proximity sensor,

- A4 paper
- 4B pencil
- ESP32 microcontroller
- Resistor
- Male-male jumper cables
- Breadboard
- Paper clip

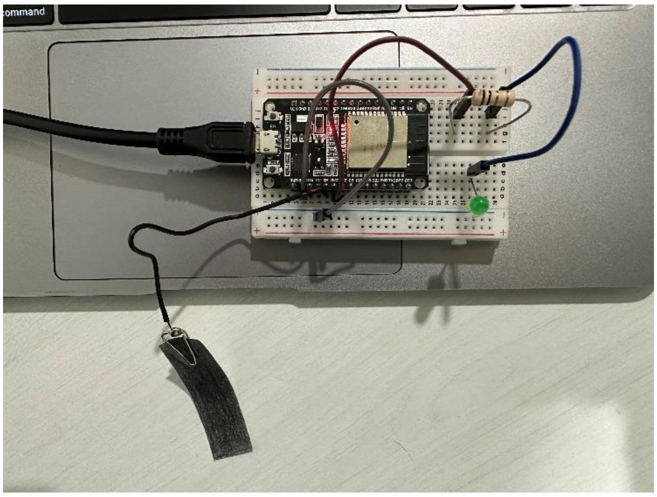


Figure 7 - Capacitive Proximity Sensor Setup

This capacitive proximity sensor works even after covering the graphite surface with an insulating material such as transparent tape. This is because of the working principle which was explained earlier [5].

```
// set pin numbers
const int touchPin = 4;

// variable for storing the touch pin value
int touchValue;

void setup(){
  Serial.begin(115200);
  delay(1000); // give me time to bring up serial monitor

}

void loop(){
  // read the state of the pushbutton value:
  touchValue = touchRead(touchPin);
  Serial.println(touchValue);
  delay(500);
}
```

Figure 8 - Code to display the functionality of the capacitive proximity sensor

D. Resistive Switch (Multi-stage)

A resistive switch with multiple levels is used in this project to select different modes in the final build. This sensor works according to the theory of voltage divider. This can be interfaced into the system as a multi-stage toggle switch which can be used to switch between different functions.

Materials used to develop the proximity sensor,

- A4 paper
- 4B pencil
- ESP32 microcontroller
- Resistor
- Male-male jumper cables
- Breadboard
- Paper clips

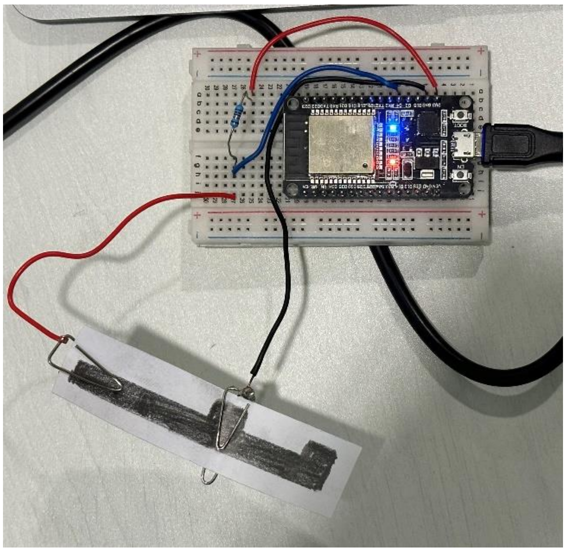


Figure 9 - Setup of the Resistive Multi-stage Switch

This switch can be used to toggle between two stages, in the project demonstration it is used to toggle the internal LED of the ESP32 board on and off.

```
const int SensorPin = 4;
#define ONBOARD_LED 2
//pin A0 as Sensor Input
int value; //sensor value
void setup() {
pinMode(ONBOARD_LED,OUTPUT);
Serial.begin (9600); //start serial port
}
void loop() {

value = analogRead(SensorPin);
//value = map (value, 0, 1023, 0, 255);
if(value < 2600){
  digitalWrite(ONBOARD_LED,HIGH);
}
else {
  digitalWrite(ONBOARD_LED,LOW);
}
Serial.println (value);

delay(200);
}
```

Figure 10 - Code to read the switch position and toggle the LED

IV. Results and Discussion

Several tests were carried out on the sensors used in this project, and the obtained results are presented and discussed in this section.

A. Resistors

An Arduino based on ohmmeter was created as an alternative to a multimeter to calculate the resistance.

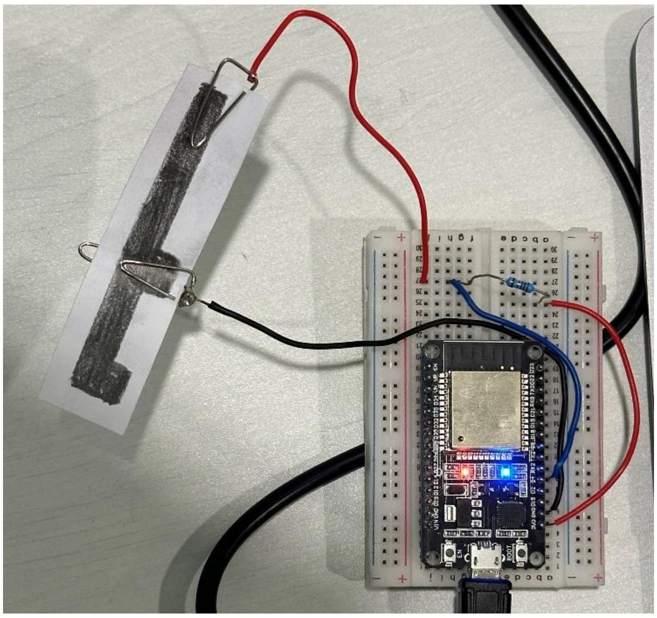


Figure 11 - Wiring Diagram for Arduino based Ohmmeter

Theory of voltage divider is used to measure the unknown resistance of the sketched resistor on paper.

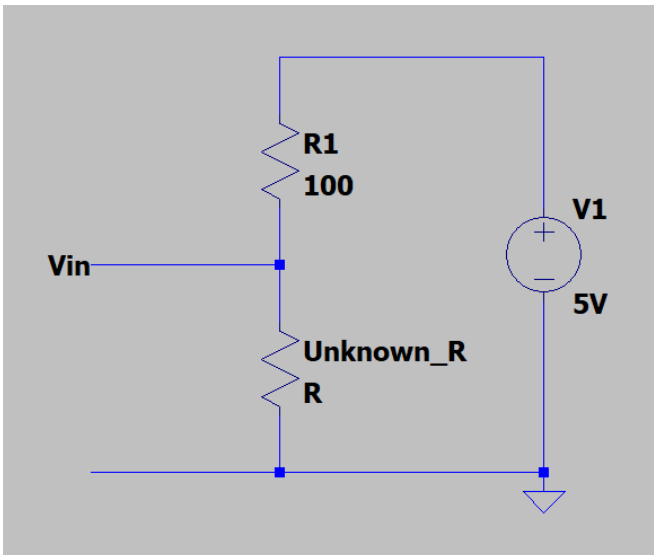


Figure 12 - Voltage divider circuit to measure the unknown resistance of the sketch

Arduino code was used to read the unknown resistance of the sketch.

```
int analogPin = 4;
int raw = 0;
int Vin = 5;
float Vout;
float R1 = 100;
float R2 = ;
float buffer = 0;

void setup() {
  Serial.begin(9600);

}

void loop() {
  raw = analogRead(analogPin);
  if(raw){
    buffer = raw*Vin;
    Vout = (buffer)/1024;
    buffer = (Vin/Vout) - 1;
    R2 = R1 * buffer;

    Serial.print("R2:  ");
    Serial.println(R2);
    delay(5000);
  }

}
```

Figure 13 - Arduino code to measure unknow resistance of the sketch

Materials used to develop the Arduino based ohmmeter are,

- A4 paper
- 4B pencil
- ESP32 microcontroller
- 100-ohm Resistor
- Male-male jumper cables
- Breadboard
- Paper clip
- Multimeter

Resistance of hand drawn resistors were measured using a multimeter to observe how resistance varies with length and surface area.

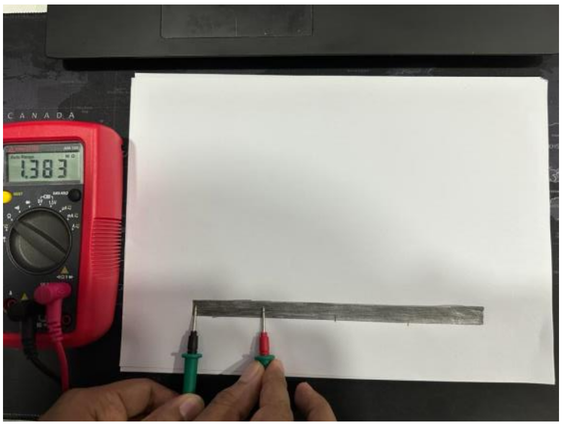


Figure 14 - Resistance of sketch length 5cm

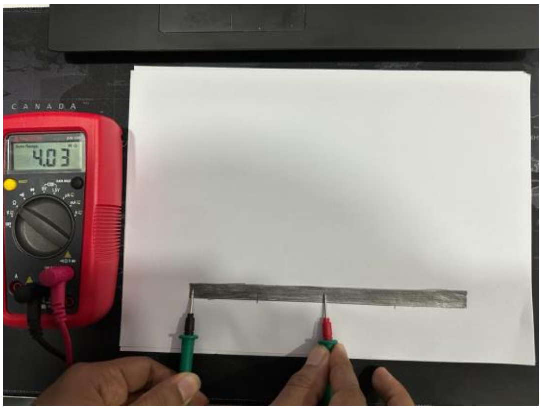


Figure 15 - Resistance of sketch length 10cm

Figure 16 - Resistance of sketch length 15cm

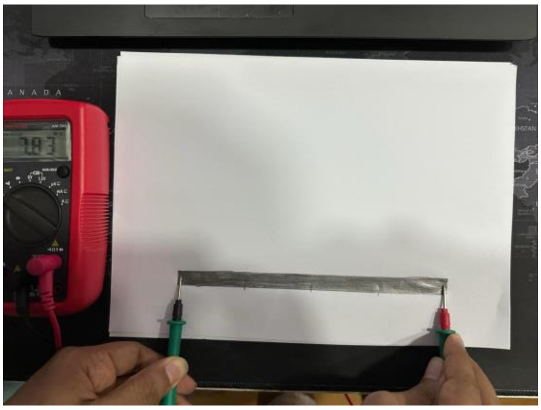


Figure 17 - Resistance of sketch length 20cm

Recorded data were tabulated and graph was plotted as follows.

Table 1.1 - Recorded data for length and corresponding resistance

Length (cm)	Resistance (Mohm)
5	1.383
10	4.03
15	6.16
20	7.83

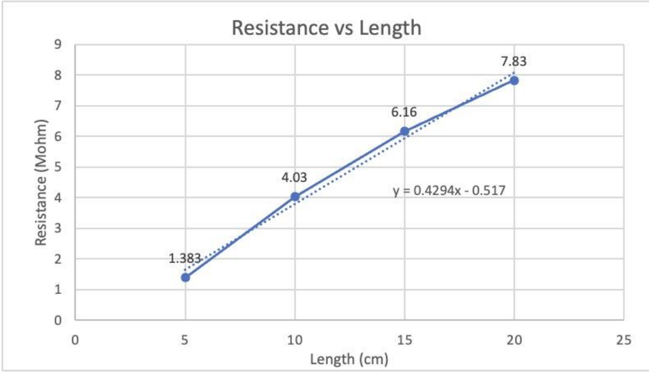


Figure 18 - Resistance vs Length Plot

Also, resistance vs surface area was measured simultaneously. Recorded data is presented as follows,

Table 1.2 - Recorded data for surface area and corresponding resistance

Surface Area (cm^2)	Resistance (Mohm)
6	0.241
13.5	0.191
24	0.163
35	0.137

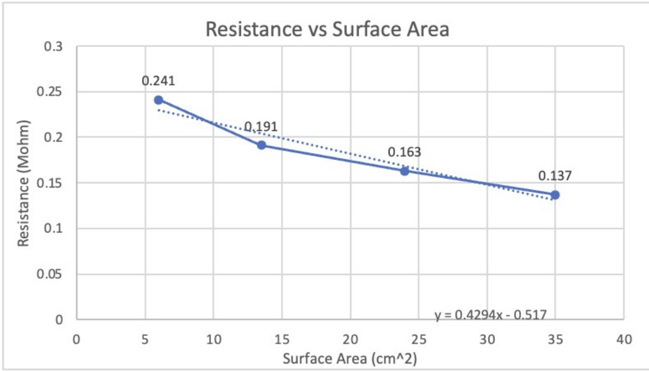
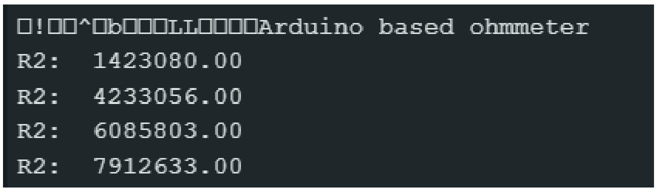


Figure 19 - Resistance vs Surface Area Plot

Afterwards, Arduino based ohmmeter was used to take the measurements of the sketch to test the accuracy. Recorded data were tabulated as follows,



```
□!□□^□b□□□LL□□□□Arduino based ohmmeter
R2:   1423080.00
R2:   4233056.00
R2:   6085803.00
R2:   7912633.00
```

Figure 20 - Arduino resistance readings

Table 1.3 - Recorded data (Multimeter and Arduino) for length and corresponding resistance

Length (cm)	Multimeter Resistance (Mohm)	Arduino Resistance (Mohm)
5	1.383	1.42308
10	4.06	4.233056
15	6.16	6.085803
20	7.83	7.912633

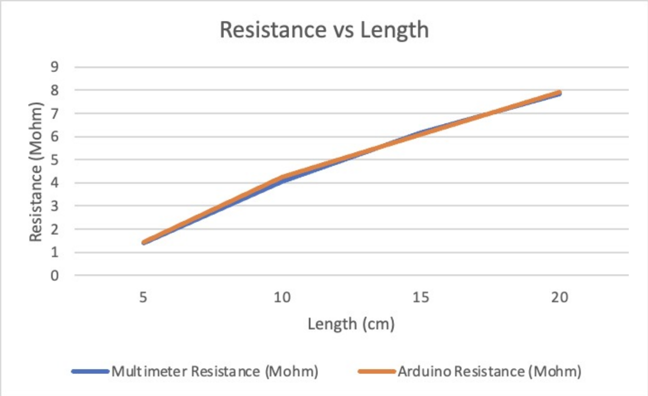


Figure 21 - Resistance vs Length Plot (Multimeter and Arduino based Ohmmeter)

B. *Capacitive Proximity Sensor*

Capacitive proximity sensor was tested with several designs with increasing surface area and observed that as the surface area increases, range of proximity sensing increased. Also, as the target size increases, the range of detection increases.

The current capacitive proximity sensor was chosen because of its small size. Due to the small size, it is much easier to be placed in a wearable device. Even though it is small in size; it can detect a hand which is 2cm above it.

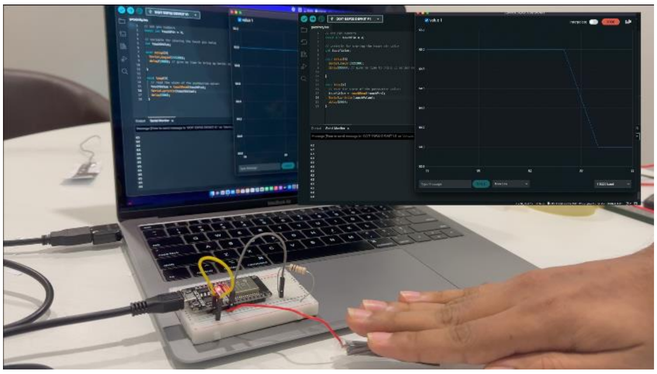


Figure 22 - Hand 3cm above the proximity sensor

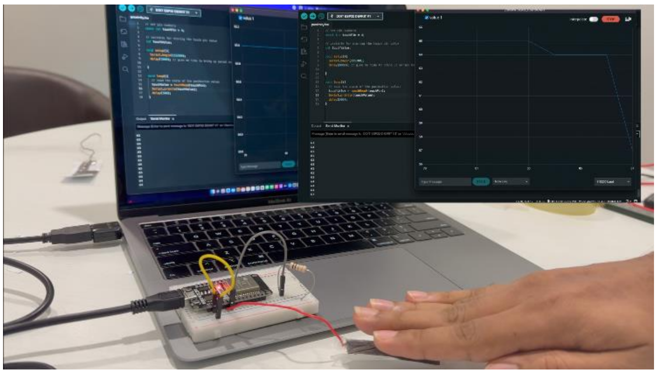


Figure 23 - Hand 1cm above the proximity sensor

As shown in the above figures, when idle proximity sensor gives a reading of 65. And when the hand is held 3cm above the proximity sensor gives a reading of 64. And when the hand is held 1cm above the sensor, Arduino reads 57.
Using a threshold variable, this sensor can be used to do many things.
When working out people sweat, in that scenario proximity sensor can be used to operate the wearable sensor system.

C. *Strain Sensor*

The function of the strain sensor is comparable to that of the earlier-discussed Ohmmeter. This section demonstrates an advanced use of an Ohmmeter built on an Arduino platform. Below, you can see how the strain sensor functions.

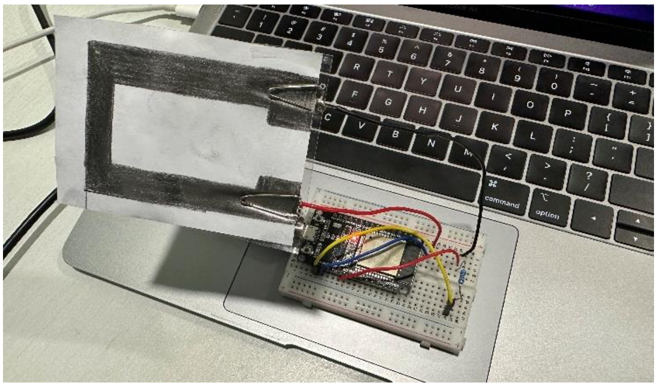


Figure 24 – Setup of the strain sensor

The strain sensor can be tested by bending it to different levels. The difference in readings according to the bend of the sensor was recorded.

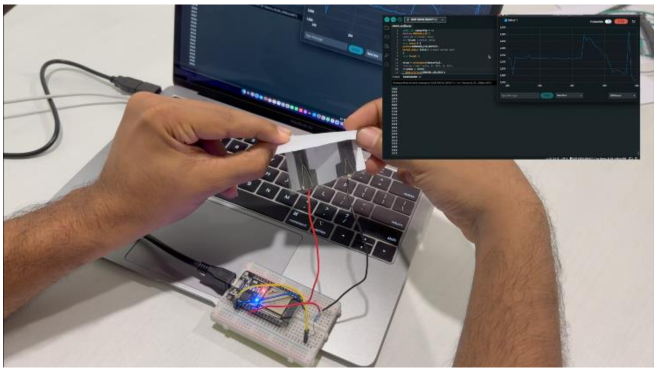


Figure 25 - Bending the strain sensor

As shown in figure 25, as the strain sensor is bend resistance values changes. By conditional formatting using two threshold values, to define inhaling and exhaling, this strain sensor can be used to count the number of inhales and exhales within a specific time period. Which can be used to determine the breathing rate and heart rate.

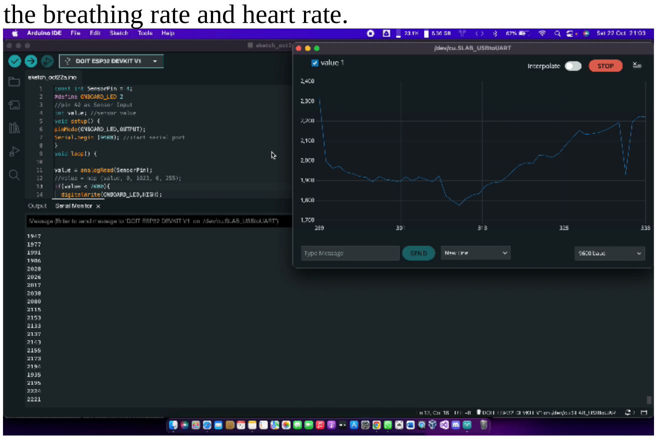


Figure 26 - Resistance change as the sensor is being bent and un-bent

D. Grove – Temperature and Humidity Sensor

Functionality of the Grove – Temperature and Humidity Sensor can be observed below.

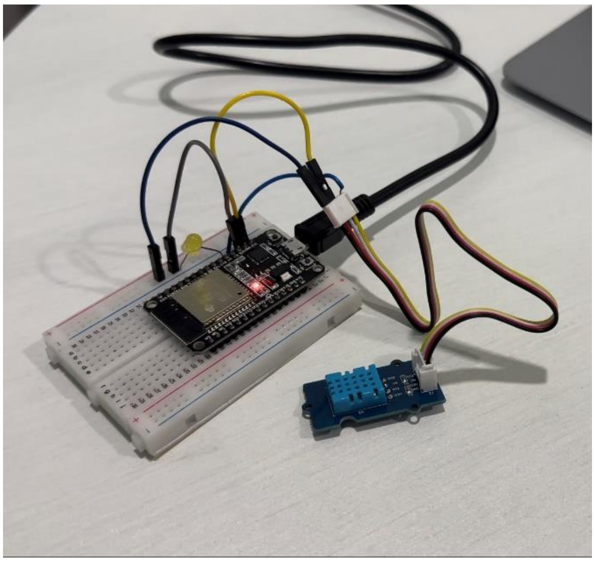


Figure 27 - Experimental setup of Grove Temperature & Humidity Sensor

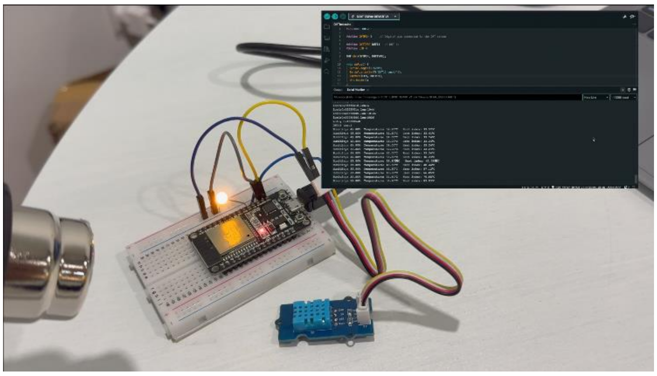


Figure 28 - Functional Grove - Temperature & Humidity Sensor

As observed in figure 27, Even though in room conditions humidity and temperature values stay constant at 68% and 28-degree Celsius respectively, when heated with a heat gun temperature reading rapidly increases and as the threshold value is set to 50-degree Celsius, yellow LED turns on to indicate that the temperature has increased above 50 degrees Celsius.

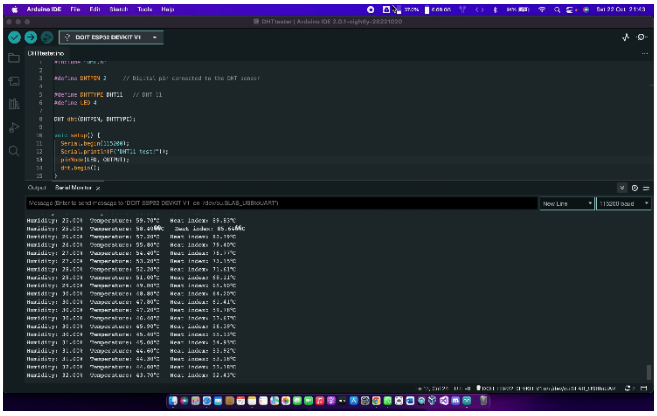


Figure 29 - Rapid change in temperature and humidity

The sensor's sensitivity to the temperature and humidity of the environment is one of its drawbacks. The humidity and temperature values slightly rise when the sensor is gently touched. If used with a tiny wearable device, this could result in inaccurate data. By positioning the sensor as far away from the skin's surface as feasible, this is prevented.

However, this limitation could be used as a feature. By attaching the sensor in a way that it always touches the skin, the body temperature of the user can be measured accurately.

V. Wearable Health and Environmental Tracker

Selectively developed sensors were interfaced together to make wearable band, which can be worn around the chest to measure useful parameters such as breathing rate, body temperature, ambient temperature, and humidity.

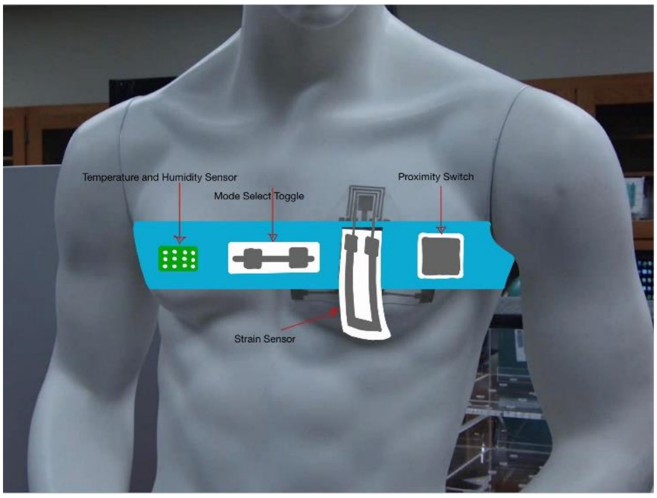


Figure 30 - Wearable Health and Environment Tracker

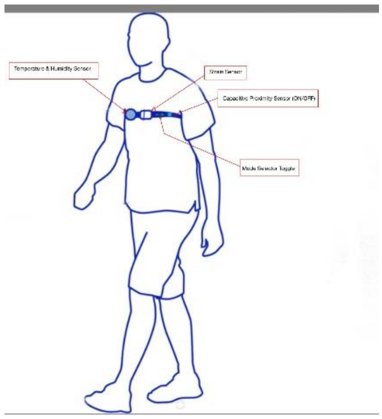


Figure 31 - Wearable Health Tracker Illustration

With the help of capacitive proximity sensor, user can switch on the system without touching the sensor band. Even if workout clothes are worn over the band, proximity sensor can detect the hand through the workout clothes.

Variable resistor switches are used to toggle between different modes in the system, such as breath rate monitor, body temperature monitor, and humidity readings.

All the recorded data is uploaded to the TheThingsNetwork server in real-time. User can use any mobile device with network access to read or view real-time sensor data.

VI. CONCLUSION

In conclusion, numerous paper-based sensors, including capacitive switches, capacitive touch sensors, proximity switches, and strain sensors, were created by covering a flexible substrate, such as paper, with a conductive layer, such as graphite. The human chest region was merged with flexible strain sensor and groove-temperature and humidity sensor, capacitive touch sensor, capacitive proximity sensor and flexible variable resistor which may act as a very helpful tracker against human health. Grove - Temperature and Humidity Sensor collects temperature and humidity information that may be utilized to analyze the surroundings. The Strain Sensor, which is fastened to the left side of the chest muscle, can measure the user's heart rate by obtaining the appropriate readings during each inhalation and exhalation. The entire system can be turned on or off using the capacitive touch sensor and capacitive proximity sensor. Different modes that can be added later can be chosen using a variable resistor. But for the time being, it will be utilized to alternate between the strain sensor and the grove sensor.

A few suggestions for improving the idea include using thicker paper at the back of the sensor to get around the touch sensor's limitations (or sticking many papers together to enhance the thickness). This is due to the absence of graphite on the sensor's back. As a result, the sensor won't pick up anything if the rear portion is now contacted with the thicker paper. Change the touched Cutoff value to run more tests to determine at what value the sensor's rear portion stops signaling that a touch has been detected. The proximity sensor's second restriction was that it could only detect movements within a 6cm range. Therefore, to extend this range, better-quality graphite might be used to test whether the capacitance measurement shown on the Arduino's serial monitor is sufficient to detect objects at distances greater than 6cm. More investigation might be done to find a different material to use to construct the sensor, such as applying conductive ink, or a conductive paper called Velostat to create a sensor with more capacitance. To choose a sufficient detection range for the proximity sensor, which is around 1 to 20 cm, tests must be performed on the sensors that are created.

The electrical circuit connected to the sensors could be made smaller to improve some aspects of the innovation in the future. This is proposed because using conductive materials, such as graphite, would make the circuits more portable and flexible, allowing for simpler health trackers. The sensor would need to be powered by a tiny power source, and the microcontroller that would be utilized would be much smaller, more like a little chip. Making a flexible paper-based temperature sensor is the final step, as opposed to the present groove temperature sensor.

VII. REFERENCES

[1] A. T. Singh, D. Lantigua, A. Meka, S. Taing, M. Pandher, and G. Camci-Unal, “Paper-based sensors: Emerging themes and applications,” Sensors (Basel), vol. 18, no. 9, p. 2838, 2018.

[2] A. Chatham, “Turn a Pencil Drawing Into a Capacitive Sensor for Arduino,” Instructables, 26-May-2012. [Online]. Available: https://www.instructables.com/Turn-a-pencil-drawing-into-a-capacitive-sensor-for/. [Accessed: 22-Oct-2022].

[3] J. Moermond, “Does target size affect the sensing performance of an inductive proximity sensor?” AUTOMATION INSIGHTS, 15-Jun-2010. [Online]. Available: https://automation-insights.blog/2010/06/15/does-target-size-affect-the-sensing-performance-of-an-inductive-proximity-sensor/. [Accessed: 22-Oct-2022].

[4] Eaton.com. [Online]. Available: https://www.eaton.com/us/en-us/products/controls-drives-automation-sensors/sensors---limit-switches/capacitive-proximity-sensor/how-to-select-a-capacitive-proximity-sensor.html. [Accessed: 22-Oct-2022].

[5] “Capacitive Instrument (using the Principle of the Distance Sensor),” Instructables, 19-Dec-2016. [Online]. Available: https://www.instructables.com/Capacitive-Instrument-using-the-Principle-of-the-D/. [Accessed: 22-Oct-2022].