Wireless ECG Circuit on Flexible Material: A Preliminary Study

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***Abstract*—Flexible printed circuit is rapidly developing in the electronics industry. However, the circuit substrate of flexible materials limited due to its temperature limitation characteristics. In this study, two flexible materials were tested: a silicon rubber and a thermoplastic polyurethane (TPU). The effectiveness of the fabrication process on both materials was compared using a vinyl cutter. Results showed that the TPU material is better for the fabrication process due to the roughness of its surface which is higher than silicon rubber that makes the adhesion of the copper tape stronger on the surface.**

***Index Terms*—Flexible Circuit; Silicon Rubber; Thermoplastic Polyurethane; Vinyl Cutter; Wireless ECG System.**

I. Introduction

The statistic shows that 300,000 to 400,000 sudden cardiac death cases happened in the United States per year [1]. Sudden deaths due to heart problem are less among young athletes [2], but the number is still worrying. Although research shows lower chances of youth to have sudden cardiac deaths [1], it is still a major concern especially among athletes as sudden cardiac death normally happens to them during and after exercise.

For prevention of sudden cardiac death among athletes, pre-participation cardiovascular screenings of competitive athletes were implemented in United State and Italy two decades ago. In Italy, they used 12 leads ECG to screen athlete's heart condition [3]. This traditional method is time-consuming and inconvenient for the athletes. Additionally, this screening can be done only during their rest time. It is very difficult to monitor the heart condition during exercise.

In order to fulfill athletes' demand for heart rate monitoring, many company and researcher developed a portable heart rate monitoring system. Recently, a flexible printed circuit (FPC) is emerging in the electronics industry because it can reduce the device size, weight and improve durability due to the flexible property of FPC. Smaller and lighter device can be convenient to the user.

There is a need to develop flexible ECG monitoring system even though there are challenges in fabricating it. Some of the flexible plastic material used for FPC is polyethylene terephthalate (PET) and Kapton. These two materials were chosen because it can withstand high temperature and has a high barrier against oxygen and water. High technology is needed in order to generate conductors on FPC and to assemble surface mount device (SMD) on PET or Kapton materials. However, the flexibility of these two materials is at a medium level based on folding experiment to test the endurance level which was done by the previous researcher. It Is proven that thermoplastic polyurethane (TPU) has highest folding cycles [4]. On top of that, TPU also has the highest stretchable level among others substrates [5].

In this study, we performed a study on the fabrication of wireless ECG circuit on a flexible material. Two types of flexible material (silicon rubber and TPU) are used to compare the effectiveness of the fabrication process using a vinyl cutter. These two materials were chosen because of the tensile strength property. High tensile strength in the substrate of the circuit can increase flexibility and provide more convenience to the user.

II. Circuit Design And Methodology

In this preliminary study, a simple circuit was designed as the first milestone in developing flexible wireless ECG circuit. Figure 1 shows the steps to develop the ECG circuit in this study.

According to Figure 1, the first step is to choose suitable components for wireless ECG circuit setup. As an early stage, three components are chosen, which are ECG module, microcontroller and a wireless communication module (Bluetooth). These components are SparkFun AD8232 board, Arduino Nano board and HC-05 module, respectively. AD8232 is a module designed to extract, amplify and filter signals of ±300 mV input. A two-pole high-pass filter is integrated into the board to restrain residual baseline drift. In addition, a three-pole low pass filter is used for eliminating muscle noise. The input port for the AD8232 board is a single lead ECG which supports two to three electrodes configuration. An Arduino NANO was chosen because it is small size, which is (18x45) mm.

In this study, size of the developed ECG circuit, for all components used, need to be considered as we aimed to develop a heart rate monitor with a smaller size. Hence it can be easily carried by users while performing any daily activities. The microcontroller is used to control the ECG module automatically and the wireless module to perform as a wireless ECG module. In order to develop a wireless ECG circuit, this study decided to use a Bluetooth module, HC-05 module, for wireless connection setup. The HC-05 module has a sensitivity of -80 dBm and up to +4 dBm RF transmit power which is considered for this study development. On top of that, it can operate with low operation power of 1.8V to 3.6V.

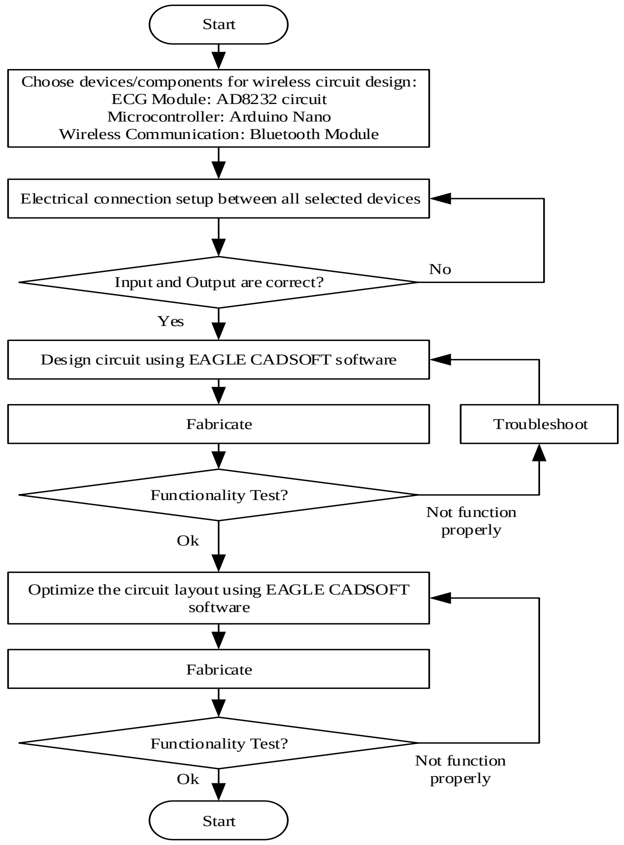

Figure 1: Steps to develop wireless ECG circuit

The devices are connected manually (soldering) to test the function. The input and output for the connected devices are observed and monitored.

Next is to design a connection between the three selected devices on a printed circuit board (PCB). EAGLE CADSOFT software is used for designing the single layout electrical connections between the selected devices. Figure 2 shows the layout design.

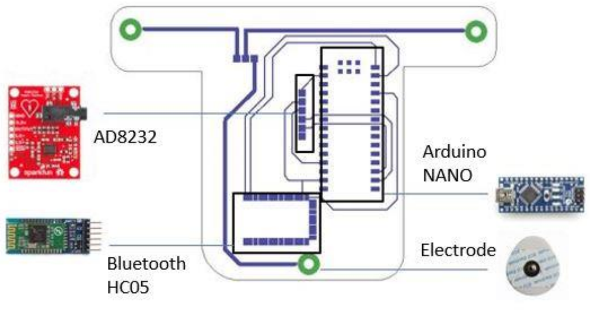

Figure 2: Board Design of ECG circuit and component use on it

The ECG circuit layout included AD8232 Heart Rate Monitor from Sparkfun, HC-05 Bluetooth and Arduino Nano microcontroller.

Figure 3 shows the fabricated ECG circuit layout on PCB assembled with the devices by using solder paste. We fabricated the circuit on standard PCB and used one layer only.

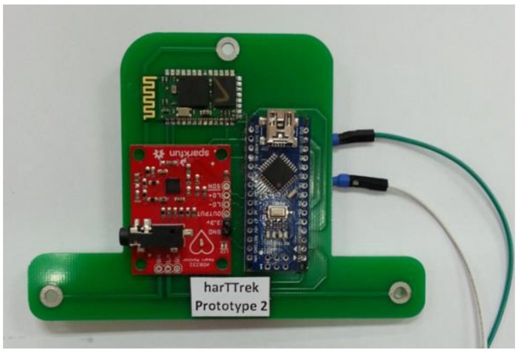

Figure 3: A fabricated wireless ECG circuit on a PCB

Figure 4 shows a user wearing the wireless ECG circuit develop in the study. For current ECG circuit (Figure 4), we used three electrodes (one lead ECG signal) for bio-signal detection. The position of the electrodes followed single lead electrodes position [6], which are placed on right arm (RA), left arm (LA) and ground (G). G is placed in the middle of the chest. The electrodes detected user heartbeat and AD8232 would process the data. Algorithms are included in the microcontroller, such as to display the data on the mobile phone. The algorithm was installed in the microcontroller to read the value from the sensor then send the data through Bluetooth. The ECG signal can be seen as in Figure 5.

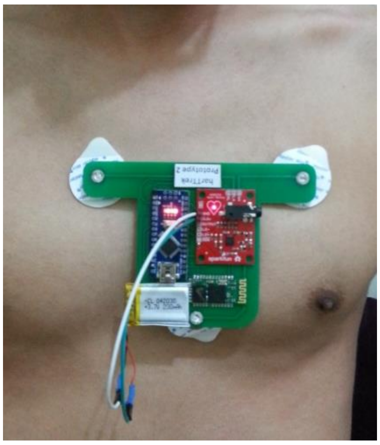

Figure 4: User wearing wireless ECG system

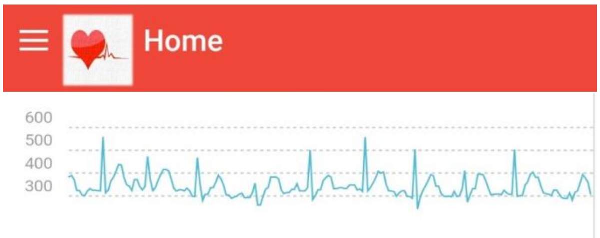

Figure 5: ECG signal display on a mobile phone

Figure 5 shows the display of the signals acquired from the ECG device in a mobile phone. The signals are electrocardiogram acquired from the developed ECG device. The code for reading the input and displaying the output such as Figure 5 is shown in Figure 6.

```
// Functions
// Read sensor and send data through Bluetooth.
void readSensor(uint32_t time) {
  packet.time = time;
  packet.checksum = (time >> 16) + (time & 0xffff);
  for (int c = 0; c < NUM_CHANNELS; c++) {
    // analogRead completes in about 0.0001s
    // and it map input voltages between 0 and 5 volts into
    // integer values between 0 and 1023.
    word adc_value = analogRead(c);
    packet.data[c] = adc_value;
    packet.checksum += adc_value;
  }
  packet.checksum = -packet.checksum;
  btSerial.write((uint8_t*)&packet, sizeof(packet));
}
```

Figure 6: Arduino codes for reading input

The fabrication of a new wireless ECG circuit is a success. Therefore, the layout is intended to be developed on a flexible material to replace the PCB. This study has compared two types of material for further development.

In the process of circuit fabrication on the flexible material, a simple LED circuit was printed on the material. This is to ensure the electrical connections for all components are properly connected.

First, the copper tape was transferred on to the chosen flexible material. In this study, silicon rubber and thermoplastic polyurethane (TPU) were used as the flexible substrate. Figure 7 shows the substrate materials.

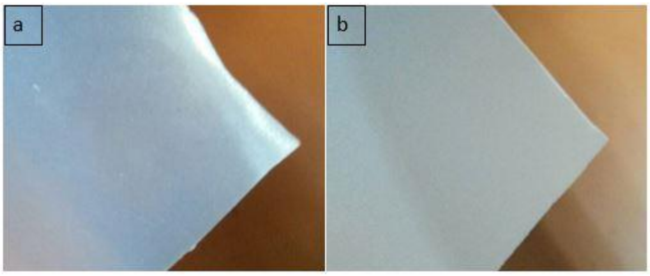

Figure 7: Shows the material: (a) silicon rubber, (b) TPU.

Once the copper tape was ready on the substrate, it was inserted into the vinyl cutter of SUMMACUT D60R. Then, the LED circuit was cut on it. Figure 8 shows the cutting process of the circuit using the vinyl cutter. Lastly, the excessive copper tape is removed to get LED circuit design.

To complete the LED circuit, SMD LED was soldered on the flexible substrate. Solder paste CHIP QUIK SMDLTLFP SOLDER PASTE, SN, BI, AG, 138DEG C, and 15G from ELEMENT14 was used and is soldered on the substrate using ATTEN 858D hot air gun at 240°C. Figure 9 shows LED circuit after SMD LED being soldered on (TPU).

Figure 8: Process of circuit cutting using a vinyl cutter (Summacut D60R)

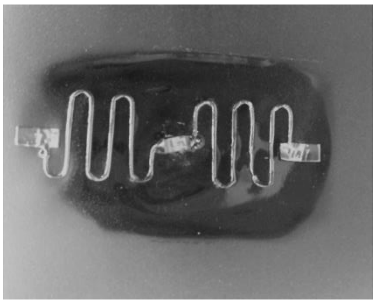

Figure 9: LED circuit on TPU material after soldering SMD LED component

III. Results And Discussion

From the results of the LED circuit fabrication, we found that it is not suitable to use silicon rubber as the substrate flexible material. The vinyl cutter is not able to cut the desired circuit design on the material due to the less adhesive properties of the copper tape on the silicon rubber. Peel force displacement of each substrate material differs on each surface roughness. The surface which is rougher has high peel force displacement [7]. Fabrication of silicon rubber substrate results from the vinyl cutter is shown in Figure 10.

Circuit fabrication using vinyl cutter on TPU substrate is completed successfully. The adhesive of the copper tape is strong on TPU material. However, the texture of the TPU material is changed during soldering process of SMD component. This is due to the high temperature (240°C) used during the soldering process. Yet, the circuit still functions well as the LED can light up as seen in Figure 11.

One of the recommendation to improve the assembling process of the component on TPU substrate is to use conductive epoxy [8]. Conductive epoxy only needs low temperature and this may not change the texture of the substrate material.

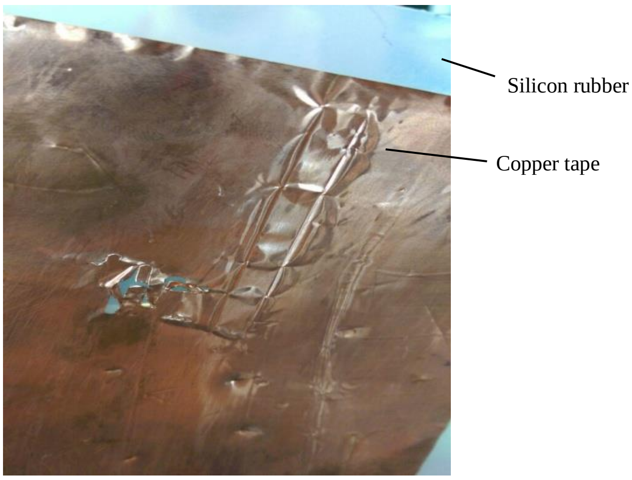

Figure 10: Fabrication of LED circuit on silicon rubber substrate (copper tape dislodged)

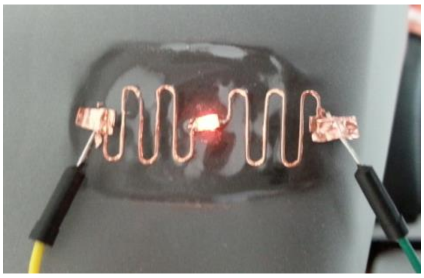

Figure 11: Function LED circuit

IV. Conclusion

The development of portable heart rate monitoring system is crucial since there is an increasing demand from sports users. It remains a challenging task to develop the device as a flexible device. In choosing the flexible substrate material, we need to consider the surface roughness as it will determine the strength of the copper tape adhesive. In this study, we found that TPU material has a strong adhesive with the copper tape. Despite that TPU can only withstand low temperature, we can use conductive epoxy as the alternative to assemble the SMD component.

Acknowledgment

The authors would like to thank the Ministry of Higher Education Malaysia and Universiti Teknologi Malaysia for supporting and funding this study under grant no. Q. J130000.2501.11H29 and Collaborative Research in Engineering, Science & Technology Center (CREST) for their continuous support for this research.

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