3D printing of interdigital sensor based conductive ABS for salt and sucrose concentration sensing

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Abstract. This paper reports the application of three-dimensional (3D) printing to the fabrication of an interdigital sensor based conductive acrylonitrile butadiene styrene (ABS) for salt and sucrose concentration sensing. The substrate and interdigital sensor are fabricated by 3D printing based ABS and conductive ABS filament, respectively. The interaction between the samples and interdigital sensor was analyzed based on a direct current circuit. The proposed sensor was tested for the electrical current response to salt and sucrose at various concentrations ranging from 0 to 10 % (W/V) with steps of 2 % (W/V). The experimental results confirmed that the electrical currents were linearly changed when the concentration of salt and sucrose was changed. Moreover, it has a wide dynamic range and offers rapid lower-cost measurement. The proposed technique offers an opportunity for the development of salt and sucrose meter systems.

1. Introduction

3D printing is a technology applied for the rapid prototyping or rapid manufacturing of 3D objects with unique structure and diverse properties directly from digital computer aided design (CAD) files [1]. Nowadays, various techniques are used such as fused deposition modelling (FDM), stereo lithography apparatus (SLA), continuous liquid interface production (CLIP), digital light processing (DLP) and selective laser sintering (SLS) [2]. 3D printing has received a lot of attention because it has many unique characteristics such as a high degree of design customization can be achieved in relatively short turnaround time [3]. Many applications of 3D printing have been proposed such as electronic ears [4] antennae [5, 6] light emitting diodes [7] and sensors [8–11]. In a number of these works, then focus of attention for electrically conductive materials used with 3D printing is conductive acrylonitrile butadiene styrene (ABS) materials. However, there are no reports about 3D printing of sensor based conductive ABS for salt and sucrose concentration sensing. This work reports the feasibility of using conductive ABS material for the fabrication of 3D structures with the emphasis on the electrical properties and sensor structure. An interdigital sensor structure has been fabricated based on these materials and investigated for salt and sucrose concentration sensing.
2. Material and method

2.1. Interdigital conductive ABS sensor
The interdigital sensor configuration is shown in figure 1. The sensor layout is shown in figure 1 (a). The top view and back view of fabricated sensors are shown in figure 1 (b) and figure 1 (c), respectively. The sensors were fabricated based on conductive ABS material.

![Figure 1](image)

Figure 1. Interdigital conductive ABS sensor (a) structural layout (b) front view of fabricated sensor (c) back view of fabricated sensor (W = 4 mm, L1 = 65 mm, L2 = 70 mm and g = 2 mm).

2.2. 3D printing
Esan3D creator FDM printers were used for the 3D printing reported here, using the same nozzle diameter of 0.4 mm. 3D printing was performed on a heated platform (60 °C) covered with glass as substrate, and the nozzle temperature was set to 260 °C. For the 3D interdigital sensor, the structural architecture was first designed in CAD, exported as stereolithography (STL) files, and uploaded onto and digitally aligned in the Repitier - Host. Once the objects were aligned in the Repitier-Host, the software converted the imported digital objects into a series of g-codes that instructed the printer to print out the desired geometry layer by layer.

2.3. Material preparation and experiment setup

2.3.1. Material preparation. The copper with a diameter of 1.5 mm, conductive ABS filament with a diameter of 1.75 mm and conductive ABS was injected by 3D printing with the area of the cross-section with 9 mm² were prepared with the length of 20 mm, 40 mm, 60 mm, 80 mm and 100 mm, as shown in the figure 2 (a). The salt (NaCl) and sucrose were prepared in deionized water concentrations from 0 – 10 % (W/V) with steps of 2 % (W/V). Then, 100 ml of the different salt and sucrose concentrations were placed into the beaker to measure with the proposed sensor device, as shown in the figure 2 (b).

2.3.2. Experiment setup. The resistance, reactance and impedance as a function of frequency in the range of 1 kHz – 2 MHz were measured and recorded by the precision LCR meter, as shown in the figure 2 (a). The proposed sensor detected the different salt and sucrose concentration placed in the beaker. The voltage across the resistance (R) was measured and recorded from the circuit, as shown in figure 2 (b). The voltage data were converted to current for analysis.
3. Results and discussion

3.1. Electrical property of conductive ABS filament

Figure 3 (a) shows the impedance as a function of the frequency of copper, conductive ABS filament and conductive ABS s injected by 3D printing with the length of 80 mm. The result shows that the impedance of conductive ABS filament and conductive ABS s injected by 3D printing decreased when increased frequency. At frequency, the impedance of conductive ABS injected by 3D printing is more than conductive ABS filament. At high frequency, the impedance of conductive ABS filament is more than conductive ABS injected by 3D printing while the impedance of copper increased when the increased frequency. Figure 3 (b) shows that the conductive ABS filament and conductive ABS without inductance in the range of 1 kHz – 2 MHz, while the inductance of copper was in the range of 170 – 210 nH.

3.2. Length of conductive materials

Figure 4 (a) and figure 4 (b) show the Nyquist plot for conductive ABS filament and conductive ABS filament injected by 3D printing, respectively. It is clear from these figures that the impedance spectra were semi-circular in shape. A semi-circular shape generated from the capacitance of the conductive ABS filament and conductive ABS filament was injected by 3D printing. Figure 4 (c) shows the relationship between impedance and the length of the material under test (MUT). It is clear that the impedance of conductive ABS filament and conductive ABS filament injected by 3D printing increased with increased length of MUT. While, the impedance of the all length of copper was 0.154 Ω.
3.3. Salt and sucrose concentration

The electrical current shifted as a function of the salt and sucrose in the deionized water concentration as illustrated in figure 5. The slope of the regression and coefficient of determination ($R^2$) values was calculated as shown inserted figure 5 (a) and figure 5 (b). The slope of the regression value for the salt in deionized water was 0.0433 and the $R^2$ value was 0.9750. For the sucrose in in deionized water, it was -0.0033 and the $R^2$ value was 0.9594.

![Figure 5](image-url)

**Figure 5.** Percentage of solution versus electrical current (a) salt and (b) sucrose.

4. Conclusion

In this paper, we report the feasibility of using conductive ABS material for the fabricated 3D MUT and the electrical properties. An interdigital sensor structure has been fabricated based on these materials and investigated for salt and sucrose concentration sensing. We showed that the 3D interdigital sensor based conductive ABS can be used to determine the concentration of salt and sucrose. The electrical current were observed and analyzed when there were changes in the concentrations of salt and sucrose in deionized water. The proposed technique has many advantages, such as wide dynamic range, high linearity, rapid measurement and lower-cost.

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