Investigation of printing and curing micro-conductive ink tracks using syringe-based deposition system and oven on fabric

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Abstract. Miniaturization of electronic structure for smart textile application has been seen dominated in recent years due to its low cost and light but it requires flexibility to resist stresses. Printing using conductive inks provides the flexibility but it remains a challenge since current printing techniques suffered from ink incompatibility especially on conformal substrates due to its rigidity and low flexibility. An alternative printing technique via syringe-based deposition system is proposed since it capable of printing various materials with different viscosity level. An investigation is required to evaluate its feasibility in printing micro-conductive ink tracks on fabric. The effect of printing and curing parameters including printing speed, deposition height, curing time and temperature to the morphology of the ink tracks and conductivity were investigated. Electrical tests were performed to determine the resistance level. It was found that 0.50 mm width of designated ink track was successfully printed and printing with higher speed reduced the track width while deposition heights affected the thickness of the ink track. Printing speed of 7.00 mm/s with deposition height of 0.59 mm were concluded as the optimum printing parameters. A longer curing time and higher temperature used resulted in lower resistance as expected. The lowest resistance achieved was 1.70 Ω cured at 160°C for 45 minutes. It was proven that a syringe-based deposition system able to print micro-conductive ink track and oven is suitable to cure the ink properly on fabric.

1. Introduction
Radio frequency identification (RFID) technology uses radiated and reflected radio frequency (RF) power to identify and track a variety of objects. A typical RFID system consists of a reader and transponder. A RFID reader contains RF transmitter, one or more antennas and RF receiver [1]. RFID tag antennas have been seen in miniature size due its low cost and light but to realize this remains a challenge especially on manufacturing side as the designated ink track size itself is in micro-scale and requires flexibility to resist stresses when printed on fabric for smart textile application. Conventionally, a wearable fabric that has an antenna printed is consist of industrial and conventional fabric. They are made from fibers that can act as substrate material such as by waving or knitting, therefore by depositing a conductive layer onto a fabric it can act as a radiation substance and ground plane. Generally, printed RFID tag uses thin strips of metallic film such as metalized adhesive tape or metal plating or metalized adhesive tape [2] deposited on a non-conductive substrate material including plastics, silicon or fabrics which is called carrier. It has no flexibility and they are incompatible with non-planar substrates [3]. Printing this antenna require a set of parameters consideration to ensure sufficient morphology could be produced. Conductive ink is used as an alternative due to conductive ink has been proven suitable to
give some elastic character (stretchable) [4, 5]. The ink has been used on some electronics applications such as remote sensing and wireless communication. The printing process via inkjet [6], flexography, aerosol and gravure printing were mostly employed but all of this printing techniques only capable of printing on planar substrates [7]. Syringe-based deposition systems capable of printing wide variety of materials with different viscosity level as well as provide larger building volume, flexible and user friendly [8, 9]. However, the potential of syringe-based deposition system has not been explored thoroughly especially on printing of micro-conductive ink tracks that makes up the electronic structure on non-planar substrates (fabric). Thus, an investigation is performed to investigate the feasibility of syringe-based deposition system on printing micro-conductive RFID antenna tag’s on fabric. The effect of printing and curing parameters to the morphology of the ink tracks and conductivity is also evaluated accordingly. By realizing this, it will open up a new scale of target market especially in the field of wearable electronics application (smart textiles) as miniaturization of electronic structure for smart textile application has been seen dominated in recent years due to its low cost and light.

2. Methodology

2.1 Pattern design
A type of Smartrac Web RFID tag antenna was first identified and selected to be printed and its detail dimension and shape were modeled using computer-aided design (CAD) software. Figure 1 shows the design of the antenna with its detail dimension respectively. The total length of the antenna designed is 58.23 mm long with a 0.50 mm width of the track.

![Figure 1. RFID antenna tag design with its detail dimension (units in mm) ](image)

2.2 Printing and curing
An automatic syringe-based deposition system (Model: FISNAR 3-axis, F4200N.1) equipped with a teach pendant and industry’s leading dispensing software is used to deposit the ink on polyester substrate as shown in Figure 2. The system has been widely used in electronic industries especially in solder paste machine and surface mount technology. A series of pilot tests were conducted to identify and determine the range of suitable printing parameters and these exercises were also performed to obtain the desired dimension set previously. The dimensions are measured by taking an average from several points on the sample. The range of printing parameter used is illustrated in Table 1 which the printing speed was varied between 3.00 to 7.00 mm/s while deposition height was varied from 0.58 mm to 0.62 mm. The other two parameters including pressure and nozzle diameter were set to be constant. A curing process was then employed using an oven to reduce the percentage of unwanted material in conductive ink since
conductive ink; either oil-based or contain water or solvents is normally comes in liquid and needs to be
cured usually by heating process to expose its metallic contents [10]. The curing process played an
important role to provide a good conductivity of the ink tracks. Oven is used as a curing process since
it provides a consistent and stable temperature and the samples could be cured at a higher temperature
if needed. In addition, oven is easy to set up by simply adjust the timer and the temperature gauge.
Several pilot tests were previously performed to determine the optimum curing parameters that result in
the lowest resistance. The optimum curing parameter selected is depicted in Table 1. A total of 25
samples were printed from the simplification method made using Taguchi method. Figure 3 shows the
RFID antenna tag that had been successfully printed using syringe-based deposition system on polyester
and cured with oven.

| Table 1. Selection of printing and curing parameters. |
|------------------------------------------------------|
|                Printing Parameter                  |
| Pressure (kPa) | Speed (mm/s) | Height Deposition (mm) | Nozzle Diameter (mm) | Viscosity of ink (cP) |
| 200            | 3.00 – 7.00 | 0.58 – 0.62            | 0.33                 | 3654.31               |
| Curing Parameter |       |                       |                     |                     |
| Temperature (°C) |       |                       |                     |                     |
| 160            | 45     |                       |                     |                     |

2.3 Material and substrate
A conductive ink used throughout the whole study is silver epoxy-based ink material (Model : AG806)
as shown in Figure 4 and direct usage of the ink is not possible due to high solid fraction thus an
adjustment of viscosity via dilution with Toluene solvent is necessary. The substrate used is made from
polyester fabric material and since the aim is to embed antenna on a life jacket, polyester material is
much suitable because it mimics the actual fabric made for life jackets.

2.4 Measurement
Analysis of the antenna printed is consisted of the measurement of width and thickness of the ink track
as shown in Figure 5 using an optical microscope and its electrical properties via digital multimeter. A
cross-sectional area of the ink track and its total length were determined to calculate the resistivity using
the following equation (1) [4]:

$$\rho = \frac{RA}{l}$$  (1)
where $\rho = \text{the resistivity in } \Omega \cdot m$, $R = \text{resistance in } \Omega$, $A = \text{area of the ink track in mm}^2$ and $l = \text{length in meter}$ while conductivity is calculated using equation (2) [4] shown below:

$$\sigma = \frac{1}{\rho}$$

where $\sigma = \text{conductivity in } \Omega^{-1}m^{-1}$.

3. Result and discussion

3.1 Morphology analysis

A tabulated results of the morphological and electrical analysis are shown in Table 2. Each of the results had to be calculated first using equation (3) to evaluate its percentage of dimensional error to the designated width of the ink track (0.50 mm). Printing speed and deposition height were set to be at five different levels and Figure 6 shows the result of percentage of dimensional error for all five variations of printing speed and deposition height. It was observed that printing speed at 7.00 mm/s has the lowest error while printing speed of 4.00 mm/s resulted the most error for all deposition heights. An error percentage ranging from 30%-50% was observed at deposition height of 0.61 mm and 0.62 mm. This is due to the printing speed was too fast with a big gap between the tip and the substrate result in discontinuous ink track. However choosing the deposition height of 0.59 mm is the best distance as it gave an output of minimal errors throughout the study. The best parameter obtained was printing with a speed of 7.00 mm/s and the deposition height of 0.59 mm.

$$\text{Dimensional error, } \% = \frac{\text{sample result} - \text{expected result}}{\text{expected result}} \times 100\%$$

(a) Figure 6. Percentage of dimensional accuracy error on the results of track width

(b) Figure 7. (a) Changes of track width with respect to variation of printing speed for five different deposition heights

Table 2. Results of morphological and electrical properties (N/A means not available)
flows thus resulted in decreasing the volume of the ink dispensed on the substrate. In the mean time, the nozzle tip is too slow which eventually swept some of the ink track during printing. In addition, the printed RFID antenna tag’s size is strongly affected by the variation of printing parameters as shown in Figure 7 (a) and (b). Figure 7 (a) shows the relationship between printing speed parameters with the track width for different ink deposition height. It was observed that all results show a constant decrease in track width as the printing speed increased. This is due to the increase in printing speed lowered the volume of the ink dispensed and shortened the time of the ink to disperse on the substrate. A deposition height of 0.58 mm mostly gave the largest track width due to the nozzle tip was too near to the substrate thus forcing the ink to disperse more to the side by the nozzle tip as illustrated in Figure 8 (a).

Figure 7 (b) shows the effect of printing speed to the track thickness in which most of the lines show a trend of decreasing track thickness when increasing the printing speed. The thinnest track obtained was 0.20 mm for a deposition height of 0.61 mm with a printing speed of 7.00 mm/s while the thicker track produced was 0.37 mm at deposition height of 0.59 mm and printing speed of 4.00 mm/s (figure 8 (b)). It was also observed that both deposition heights of 0.58 mm 0.59 mm resulted in a small track thickness with a printing speed of 3.00 mm/s. It is due to the fact that the nozzle tip is too close to the substrate and the speed is too slow which the tip eventually swept some of the ink track during printing and when the speed is higher, the printing is fast enough to prevent the tip from sweeping the ink track. When compared between the five lines, the track width itself showed a constant decrease when the deposition height increased. Bigger ink deposition height is actually disrupted the continuity of the ink’s flows thus resulted in decreasing the volume of the ink dispensed on the substrate. In the mean time, the

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Sample & Printing speed (mm/s) & Deposition height (mm) & Width (mm) & Dimensional error of width (%) & Thickness (mm) & Resistance (Ω) \\
\hline
1 & 3 & 0.58 & 0.69 & 38 & 0.23 & 2.20 \\
2 & 3 & 0.59 & 0.67 & 34 & 0.29 & 2.60 \\
3 & 3 & 0.60 & N/A & N/A & N/A & N/A \\
4 & 3 & 0.61 & 0.45 & 10 & 0.35 & 2.40 \\
5 & 3 & 0.62 & N/A & N/A & N/A & N/A \\
6 & 4 & 0.58 & 0.75 & 50 & 0.3 & 3.90 \\
7 & 4 & 0.59 & 0.66 & 32 & 0.37 & 1.80 \\
8 & 4 & 0.60 & 0.65 & 30 & 0.31 & 2.40 \\
9 & 4 & 0.61 & N/A & N/A & N/A & N/A \\
10 & 4 & 0.62 & N/A & N/A & N/A & N/A \\
11 & 5 & 0.58 & 0.69 & 38 & 0.38 & 2.50 \\
12 & 5 & 0.59 & 0.58 & 16 & 0.32 & 2.40 \\
13 & 5 & 0.60 & N/A & N/A & N/A & N/A \\
14 & 5 & 0.61 & N/A & N/A & N/A & N/A \\
15 & 5 & 0.62 & N/A & N/A & N/A & N/A \\
16 & 6 & 0.58 & N/A & N/A & N/A & N/A \\
17 & 6 & 0.59 & 0.56 & 12 & 0.28 & 1.90 \\
18 & 6 & 0.60 & N/A & N/A & N/A & N/A \\
19 & 6 & 0.61 & N/A & N/A & N/A & N/A \\
20 & 6 & 0.62 & N/A & N/A & N/A & N/A \\
21 & 7 & 0.58 & 0.70 & 40 & 0.16 & 1.90 \\
22 & 7 & 0.59 & 0.52 & 4 & 0.22 & 1.70 \\
23 & 7 & 0.60 & N/A & N/A & N/A & N/A \\
24 & 7 & 0.61 & N/A & N/A & N/A & N/A \\
25 & 7 & 0.62 & N/A & N/A & N/A & N/A \\
\hline
\end{tabular}
\end{table}

3.2 Effect of printing speed and deposition height

The purpose of morphological analysis is to identify the relationship between variation of printing parameters with the printed RFID antenna tag’s size. Cross-sectional area and the total length of the antenna tag were then used to calculate the resistivity. It was found that the ink track size is strongly influenced by the variation of printing parameters as shown in Figure 7 (a) and (b).
track thickness for the five different deposition heights showed only a slight decrease as the printing speed increased. It concludes that the track thickness is not heavily affected by the ink deposition height and it only plays a small role in determining the thickness of the ink track.

![Graph](image1)

**Figure 7.** (b) Change of track thickness with respect to variation of speed for five different deposition heights

**Figure 8.** (a) Larger track width (b) Thicker ink track

3.3 *Effect of curing parameters*

It was also discovered that the electrical properties of the ink track is mainly depended on curing parameters used. Since the curing process removed the unwanted material mainly solvent and binder by mostly evaporation process, the used of longer and higher curing temperature had resulted in better electrical properties of the ink track. From equation (1) shown previously, a relationship between the resistance and the cross-sectional area of the ink track was determined easily in which the resistance is inversely proportional to the cross-sectional area of the ink track. Thus, the resistance results were rearranged according to the increasing cross-sectional area of the ink track. It is done to evaluate the relationship between the cross-sectional area of the ink track to resistance when cured with an optimum curing parameters. It was noted that larger cross-sectional area of the ink track resulted in lower in resistance value as shown in Figure 9. It shows a decreasing trend of resistance while the cross-sectional area of the conductive ink track increased. It can be concluded that a larger cross-sectional area of the ink track provides greater volume for more electrons to flow result in lower resistance.

![Graph](image2)

**Figure 9.** Relationship between resistance and cross-sectional area of the ink track

4. **Conclusion**
Several conclusions could be made especially on the feasibility of the syringe-based deposition system to print micro-conductive ink. It was proven that the syringe-based deposition system is capable of printing micro-conductive ink on fabric substrate by properly controlled its printing parameters. The optimum printing speed obtained was printing at a speed of 7.00 mm/s with a deposition height of 0.59 mm from the surface of the substrate. By realizing this actually had fulfilled the objective of the study set up. The study also shows that variation of printing speeds have a significant influence on the morphology of the ink track while variation of the ink deposition height only plays a small role to the morphology of the ink track. Oven has also been seen capable of properly cured the ink track without damaging the fabric substrate. The electrical properties of the ink track have been recognized to be influenced greatly by the curing parameters used which lower resistance of the ink track is always desirable. A relationship between the resistance and the cross-sectional area of the ink track is also established experimentally where a larger cross-sectional area of the ink track provides greater volume for more electrons to flow result in lower resistance of the ink track.

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