Optimisation of a Novel Direct-Write Dispenser Printing Technique for Improving Printed Smart Fabric Device Performance

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Summary

This paper reports for the first time, an optimisation process for a dispenser printable ink on 65% polyester 35% cotton blend woven fabric for printed smart fabric applications. In this work, the ink is an interface layer material, (Fabinks-IF-UV-1004) which is printed directly on the untreated fabric to provide a smooth homogenous platform allowing the printing of subsequently printed electronic layers. Dispenser printing, a direct-write method, is a process where an electrically functional ink is directly deposited on areas of a substrate defined by computer; it is an additive manufacturing process. It is a novel state of the art process which has been developed for use in printed smart fabrics by the University of Southampton. It offers features of: custom digital patterning, the ability to print multi-layered and multi-material structures and is a rapid prototyping process. Dispenser printing provides greater design freedom compared to screen-printing and inkjet printing because it can print a broader range of ink rheologies and produce thicker layers compared to inkjet printing whilst remaining a digital printing process and therefore avoiding the need for additional screens as required with screen and gravure printing. In addition, the digital additive manufacturing process means that there is less material wastage as material is only deposited where required. Polyester cotton was chosen because it is a common fabric in many clothing and home furnishing applications. It also provides a challenging surface for printing because it has a loose woven structure, high porosity and a relatively rough and uneven surface compared to typical printed electronics substrates such as Kapton or FR4. Optimisation of an interface layer on polyester cotton can be replicated on most types of fabrics.

1 Introduction

Smart fabrics incorporate sensors, actuators, communication, power transmission, information processing and interconnection technology [1]. They can be realised by integrating functional active materials (such as conductive, piezoelectric and electroluminescent) with fabrics. These materials can be integrated with fabrics via printing. Printing is widely used in the fabric industry as a method of adding colours and patterns to fabrics. Conductive tracks are fundamental to any electronic functionality on a fabric. They can be printed directly on to fabric using conductive paste [2]. However, printing on fabrics is challenging compared to traditional printed electronics substrates such as Kapton and FR4 which present a smooth, low porosity surface where an ink can be uniformly deposited. Fabrics generally have significantly rougher surfaces which result in non-uniform printing which may not be immediately obvious to the eye but which for printed conductive tracks adversely affects their electrical properties and durability making them more susceptible to cracking and breakages [2]. Breathable fabrics such as polyester/cotton have a loose structure and high porosity which causes conductive ink deposits to absorb into the fabric structure and form inconsistent structures. Printing multiple layers can improve the consistency of the printed tracks but increases the amount of expensive conductive paste used.

2 Background

Previously, lamination [3] and screen-printing of a polyurethane based paste [2] on the fabric surface have been used to create a smooth interface layer between the rough fabric and the subsequent printed electronics layers. However, lamination covers the whole fabric surface which reduces the breathability and flexibility of the fabric and it adds to the number of fabrication processes. Individual pieces can be cut and laminated but this method does not lend itself to mass production and is difficult to align. Screen-printing offers limited design freedom as a specific designs require specific screens. Previous work at the University of Southampton has developed a screen printable interface paste (Fabink-IF-UV-1004 [4]) which reduces this problem by only being printed where required, thus maintaining the fundamental properties of the underlying fabric [5]. Figure 1 shows the SEM image of the polyester cotton surface without and with the interface layer printed on it. The interface paste provides protection underneath the conductive tracks, improves the reproducibility of the tracks and allows uniform deposition of conductive tracks using a single printed layer.

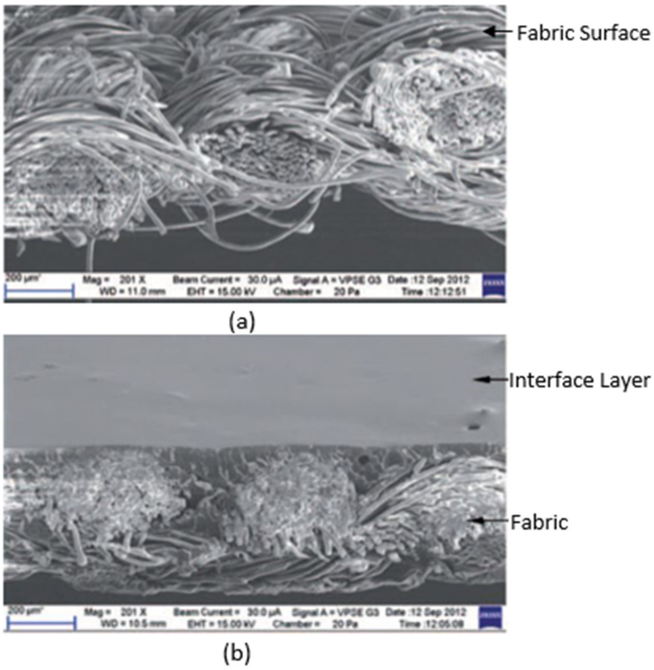


Figure 1: Scanning electron microscope image of (a) fabric surface before printing (b) Isometric view of the fabric surface with two printed interface layers [5]

The procedures reported in this paper determined an optimum set of dispenser printer settings and number of layers which produced an interface layer print with minimum bleeding and a smooth surface suitable for subsequent printed layers to produce an all digitally printed smart fabric obviating the need for the screens required for each new design in the previously reported screen-printing work.

3 Fabrication Technology

Dispenser technology uses pressure to dispense a specific quantity of material on a substrate. Pressure used in dispensers can be mechanical, where positive displacement of mechanical parts such as rotor or a plunger creates pressure, or pneumatic, where compressed air/gas creates pressure. This work has focused on a pneumatic dispenser which connects to a syringe containing the ink, and linear XYZ movement stages all connected to a PC to control the position, speed, applied pressure and dispense time. Figure 2 shows the dispenser printer setup used for this work.

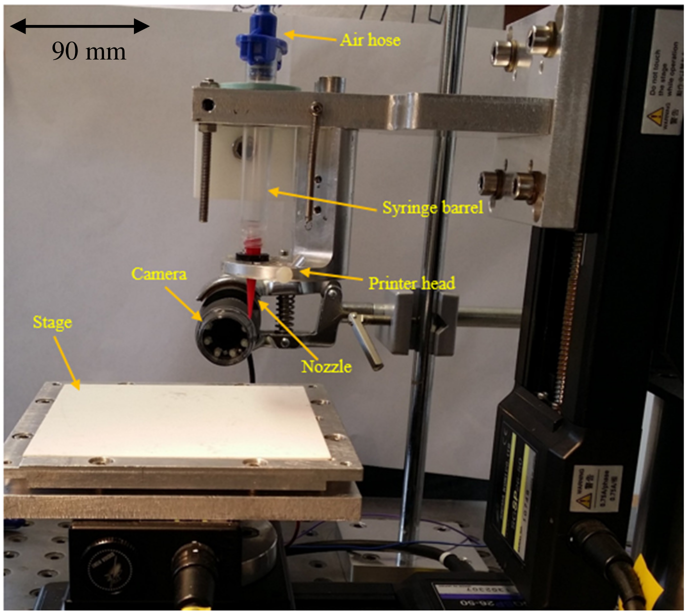


Figure 2: Dispenser printer setup used for this work.

The dispenser printing setup is governed by the following parameters:

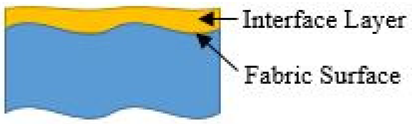
- Resolution: the gap between consecutive dots in the x and y axis.
- Nozzle height: the gap between the substrate and the printing nozzle.
- Pressure: air pressure applied to the syringe to expel the ink.
- Vacuum: providing a back pressure on the ink to avoid dripping when not dispensing.
- Dispensing time: duration for which the pressure is applied on the ink to dispense it.
- Dispensing speed: the stage movement speed.

4 Experimental Procedure

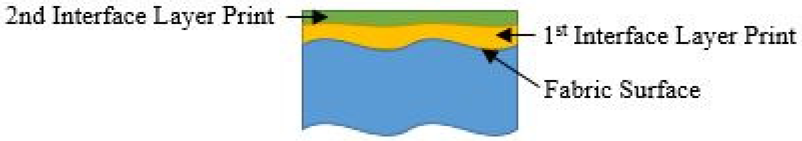
The optimisation interface paste printing was performed in three steps. First the effect of each parameter on the interface and the printer settings for an optimum single interface layer were examined. A series of single interface layers were printed; varying each individual parameter over a range while keeping other parameters constant. Secondly, several two layered prints were printed, the first layer was cured before printing a second on top. Finally, the two layer settings were further optimised to reduce the thickness of the printed layers to maximise the final flexibility.

It was observed the interface paste in the first prints would be partially absorbed by the fabric structure. The first layer settings were therefore optimised to allow sufficient absorption by the fabric to block the gaps in the weave. The second layer was optimised to produce a smooth and even print on top of the cured first layer. The dispenser settings for the two layers of interface were defined as the optimum interface paste printing settings.

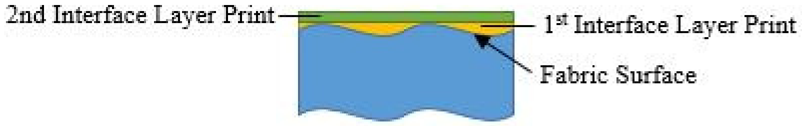
The three optimisation steps are represented in figure 3.



Experimental Procedure Step 1 - Optimisation of single layered print



Experimental Procedure Step 2 – Printing of two layered interface prints



Experimental Procedure Step 3 – Optimisation of two layered interface print to reduce thickness of the interface layers

Figure 3: Diagrammatical representation of the experimental procedure for optimising the interface layer.

5 Results and Discussion

Initial experiments produced an optimum single layered print which was significantly smoother than the fabric surface as shown using the KLA Tecnor P-11 surface profiler results in figure 4 below.

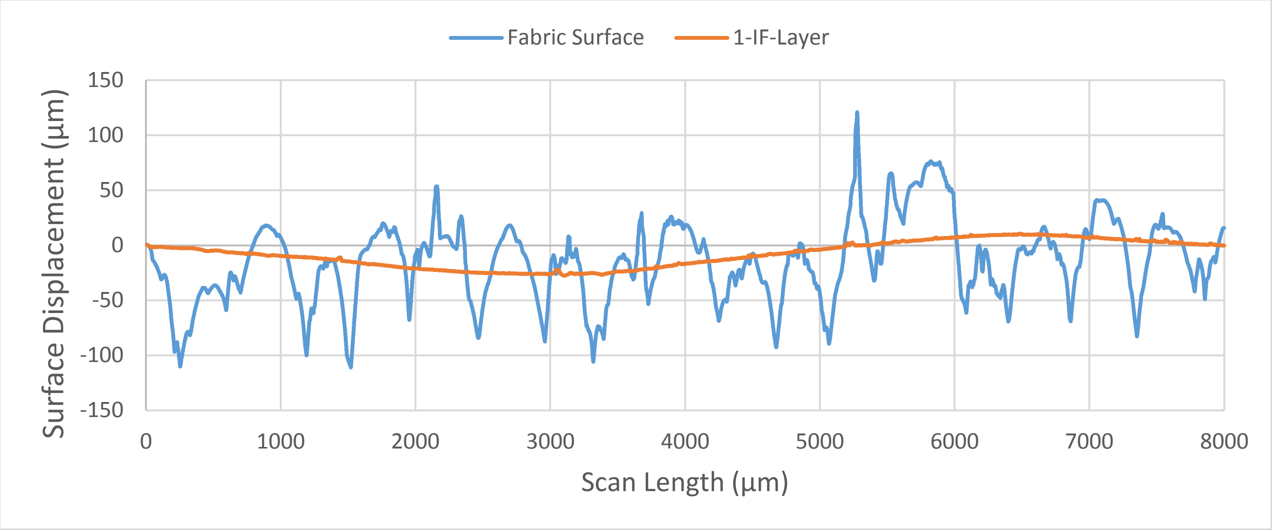


Figure 4: 2-D surface profiles of fabric surface and the optimum single layered interface print

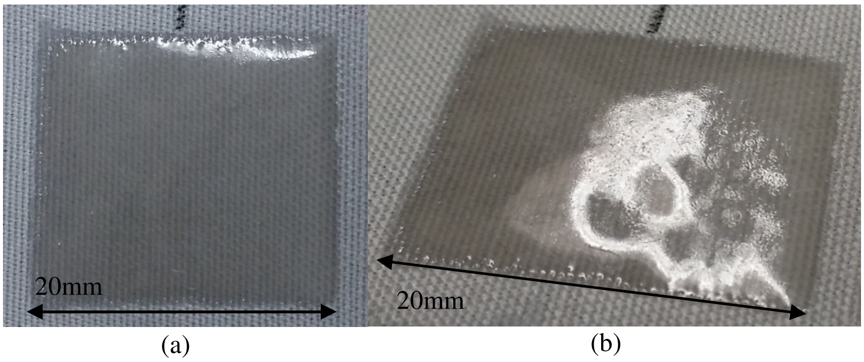
It also revealed:

- Pressure and resolution controlled the volume of paste deposited per unit area in interface prints which can be calculated by thickness and area of the prints. High pressure and higher resolution resulted in thicker prints. Pressure was varied from 20 kPa to 50 kPa and resolutions of 0.2 µm, 0.22 µm, 0.3 µm, 0.4 µm and 0.6 µm were tried.
- Nozzle heights higher than 300 µm reduced surface homogeneity of the interface prints.
- Vacuum settings between 0.4 kPa and 1.2 kPa had no significant impact on the print quality.
- The printer is programmed to print at a constant stage speed and therefore has no effect on the print.
- The interface was printed continuously whilst the stages traced the path of the design; hence, the dispensing time parameter has no effect on the prints.

The optimized interface dispenser printer settings presented in table 1 produced prints of an average thickness of 274 µm, shown in figure 5.

Y-resolution	0.22 µm
Nozzle Height	200 µm
Pressure	40 kPa
Vacuum	0.4 kPa
Speed	5 mm/s

Table 1: Dispenser printer settings for optimized single layered print.



(a) (b)

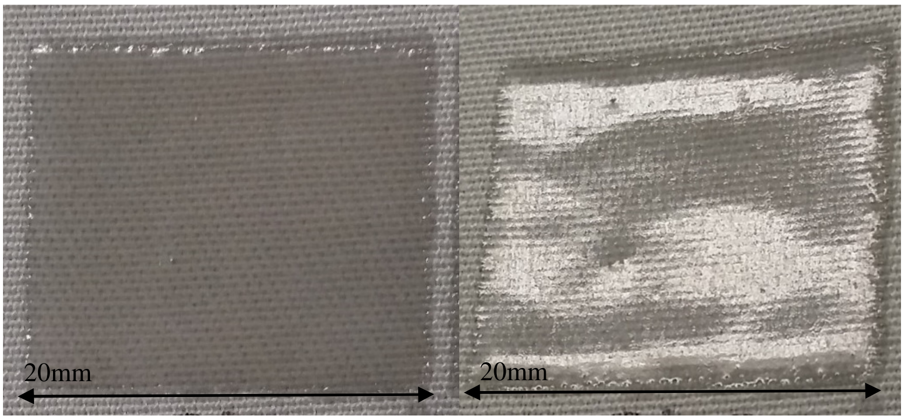
Figure 5: Optimized single layered print (a) top view (b) angled view

The second experiments showed that two layers of the interface paste improved the smoothness of the print producing a 280 µm thick print. This is thick enough to reduce the flexibility of the fabric slightly and therefore the third step produced the final optimized print which is thin and homogenous. The print parameters are presented in table 2.

Parameters	**1st Layer**	**2nd Layer**
Y-resolution	0.4 µm	0.25 µm
Nozzle Height	200 µm	200 µm
Pressure	17.5 kPa	15 kPa
Vacuum	0.4 kPa	0.4 kPa
Speed	5 mm/s	5 mm/s

Table 2: Dispenser printer settings for optimized two layered final print.

The optimized settings produced prints with an average thickness of 156 µm with comparable surface quality to step 2.



(a) (b)

Figure 6: Optimized double layered print (a) top view (b) angled view

Figure 7 compares the surface quality of bare fabric and the three interface layer optimisations.

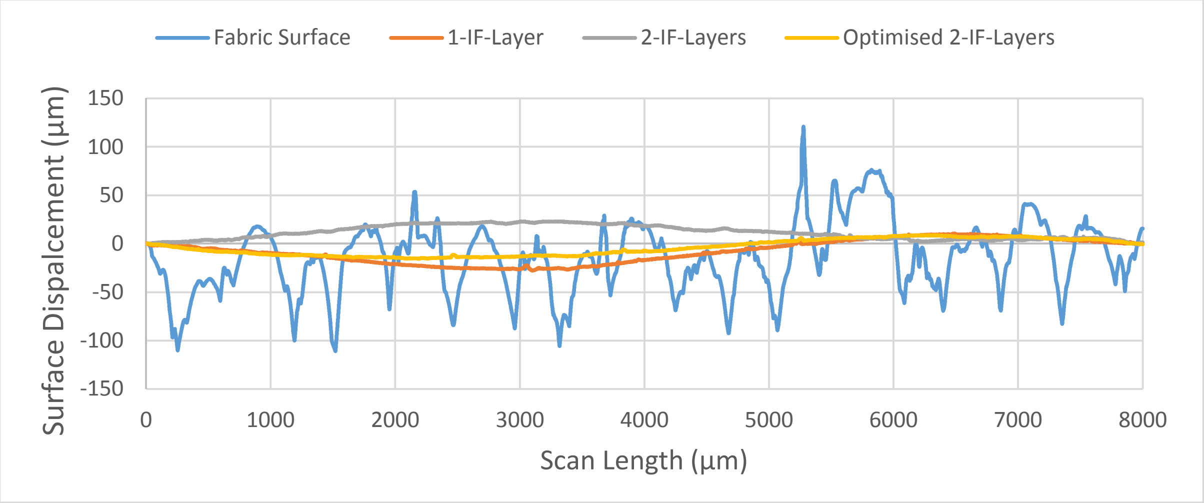


Figure 7: 2-D surface profiles of fabric and interface layers.

5 Conclusions

The results show the capabilities of dispenser printer technology and defines the best settings for the interface paste which provides a platform for subsequent printed layers used to create a range of smart fabric devices. The results have shown that, whilst a sufficiently smooth interface layer can be printed in a single pass, the layer is thick and will affect flexibility of the fabric. Further optimization showed that it is possible to achieve a smooth homogenous layer of ~160 microns with just two layers. This compares favourably with the screen-printing equivalent process which produces a smooth surface using 4 layers and an overall print thickness of 150-180 microns [5]. The results also show that the optimized interface print reduces the surface roughness average (S_a) of the fabric surface by ~74%. Further data will be published in the paper.

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Biography

Zeeshan Ahmed received a BEng degree in electrical and electronic engineering from Queen Mary University of London, UK in 2012. He is currently pursuing a PhD at Univeristy of Southampton UK. His research focus is colour changing dispenser printed interactive fabrics.