Investigation of the Effects of Ink Pigmentation on Substrate Profiling for E-Textile Dispenser Printing

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Abstract—Dispenser printing is a useful technique in the development of e-textile devices. However it is limited by the requirement to maintain a gap of less than 200 µm below the printer's nozzle, making it impractical on uneven substrates. Using a laser displacement meter to record and compensate for changes in substrate height can overcome this problem. However, the binders and inks used in e-textile primer layers are typically translucent or arbitrarily pigmented. This work investigates adding specific pigments to interface paste and shows that it can improve the laser measurements' accuracy and reduce the percentage of printing errors by 80%.

I. Introduction

Dispenser printing is a digital printing technique that uses a robotic actuator to precisely deposit inks in a manner similar to a 3D printer. These inks can be cured to create printed electronics. Because it is a drop on demand technique, it is versatile and changing the printed design is simple. This, plus the ability to use a wide variety of pastes and substrates, makes it attractive for producing prototype or bespoke e-textiles [?], [?], [?], [?], [?].

To print reliably, it is necessary to accurately control the distance between the printer's nozzle and the substrate. The exact range available depends on the paste as well as parameters like nozzle size, but previous work showed the margin of error can be as low as 150 µm [?], [?].

On flat substrates, this is not an issue: the nozzle can be positioned the required distance above any point on the surface and printing can begin. However, few of the substrates used in e-textiles provide a flat enough surface for this technique to work reliably. Even relatively even textiles will often have too much height variation introduced once an interface layer, used to add strength and waterproofing and to reduce small scale surface roughness [?], [?], [?], has been added on top of them.

Because of this, it is necessary to have the nozzle track the height of the substrate. Dispenser printers are capable of this; their heads can be moved vertically just as easily as horizontally, however the topography of the surface needs to be measured in order to compensate for its changes.

It is possible to do this manually, by positioning the nozzle above enough points in the design, moving it slowly down until it makes contact with the substrate surface and recording the position. While this method works, it is slow and susceptible to human error.

An alternative is to use a laser displacement meter, attached to the print head, to measure the distance down to the surface. This allows the height to be measured quickly and automatically at a number of points relevant to the design, creating a detailed toolpath.

Laser displacement meters work by projecting a laser dot onto an object and calculating its distance from the path along which the light returns. In order to work effectively, the laser light needs to reflect off the surface and disperse such that enough light reaches the detector for it to make a measurement. This can be an issue when working with e-textiles as the translucent primer layer allows the laser's light to penetrate some distance beyond the surface before bouncing back.

This work investigates the effects of adding pigment to a typical primer layer as a means of improving the accuracy of these laser measurements and observing the effect that has on the resulting prints.

II. Method

The techniques in this investigation were tested by printing traces of Smart Fabric Inks Ltd.'s Fabinks-TC-C4007 silver polymer paste on Fabinks-UV-IF1004 interface. The base textiles were the A1656, 165µm thick, plain weave polyester - cotton fabric from Whaley's Ltd. of Bradford and Mölnlycke Mepore wound dressings which provided an example of a less even substrate. The pigments investigated were 1391C yellow, 2629C-A red and 5249P blue from DCC Colourants' Dynaco range. These were chosen for their good opacity and their ability to be mixed into the interface paste.

The three pigments were added to the interface at concentrations of 2.5% and 5% by mass. With the addition of uncoloured interface, this made a total of seven colours. The tests were conducted on two layers of interface where one layer was printed and cured, then another layer printed on top of it as recommended by [?].

The printer used was a Fisnar F7300NV along with a Keyence LC-2540 laser for the height measurements.

The primary method of determining the accuracy of the laser measurements was by comparing them to measurements taken by manually lowering the printer nozzle to the substrate's surface. Therefore, identifying the amount of error typical in these manual measurements was a necessity. This was achieved by taking five measurements at each of five different points on each surface. The standard deviation of each point's measurements was calculated and then averaged with the other points on that surface to get a value for the typical error.

The laser's error was then calculated by measuring another five points on each surface, first manually with the nozzle, then with the laser. Because the laser can only give relative measurements, and needs to be calibrated manually against the length of the nozzle during normal use, the important result was not the difference in the measured values themselves, but how much those differences vary between points on a given surface.

To determine whether using laser profiling affected the success rate of prints done with the dispenser, custom software was written to measure a number of points along a given print path and the print the design using those height offsets. The design chosen was a third order Hilbert curve occupying an area just under one square centimetre. This gave a relatively long line, 7.65 cm, that remained in a small area thus any irregularities in the surface would only affect one print and could be identified as anomalies. The software was setup to measure one point per millimetre, rounded up to a whole number of points per straight line segment. The generated toolpath moved the nozzle linearly between these 3d coordinates.

The test prints were done with a single pass, using a 30 gauge (0.16 mm inner diameter) nozzle, 35 kPa of pressure and a print speed of 3.5 mm/s. Using these values makes printing less reliable because only a small amount of paste is deposited, but doing so meant that any small change in the height control would have a noticeable effect on the resulting print.

III. Results

The viscosity of the coloured interface pastes were measured using a Brookfield CAP 1000+ viscometer and were found to within the viscometer's margin of error of uncoloured interface. There was however a significant effect on the interface's curing process. Fabinks-UV-IF1004 is cured by exposing it to a 365 nm UV light. The effect of adding red or yellow pigment is mild, compensated for by curing the print for slightly longer, usually two and a half to three minutes rather than the two minutes needed to cure a clear layer. However, blue pigment severely hampered curing, preventing the UV light from curing more than a thin layer at the top, producing a skinning effect. The uncured paste left underneath would then soak out into surrounding fabric causing the cured paste to wrinkle as shown in figure 2 (left).

In an attempt to quantify this effect, the laser was used to measure a detailed profile of 2.5 cm of each surface, the results of which are shown in figure 3.

Although the accuracy of the laser's measurements on these surfaces had not been established at this point, it was clear that blue interface presents a much less even surface than red or yellow. It is also worth noting that the oscillations in the clear measurements match the spacing between the fibres of the polyester-cotton base fabric. This shows that the laser's light was travelling all the way thought the interface layer instead of measuring the distance to the surface, a fact that would be backed up by later tests.

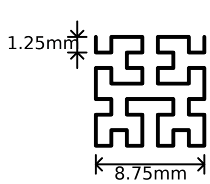

Fig. 1. Design used to test the printing system. This shape, a third order Hilbert curve, creates a line 7.65 cm long in an area less than 1 cm².

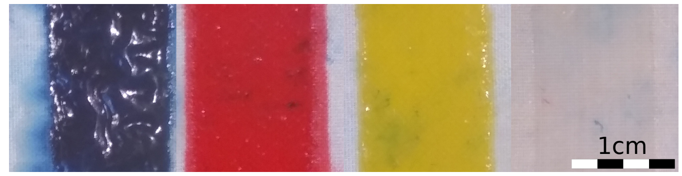

Fig. 2. Four areas of interface coloured, from left to right, blue, red, yellow and clear. The blue area is much less even than the others. Uncured blue interface has bled out into the surrounding fabric.

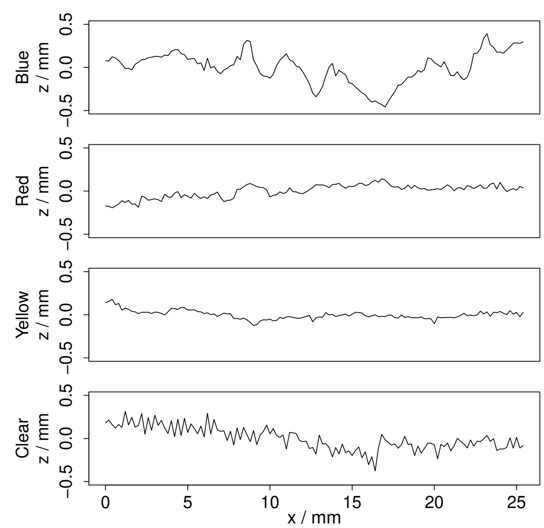

Fig. 3. Height change across a 2.5 cm of interface of each colour. The height of the blue interface is much more variable than red or yellow. The clear interface's height is fairly consistent over the space of a few centimetres, but has high frequency oscillation with a period 0.6 mm superimposed on top of it.

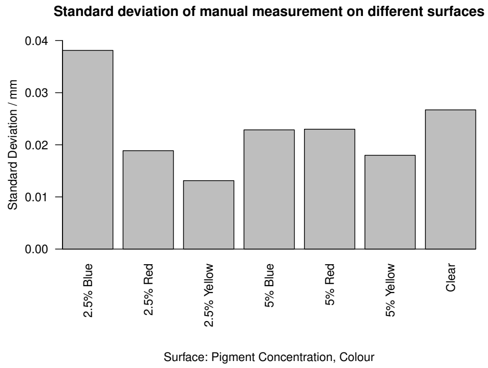

Fig. 4. Graph of the standard deviation of manual height measurements on each surface, i.e. the y value is the amount of error that can be expected from a manual measurement on that surface.

Figure ?? shows the variation in manually conducted measurements. The graph plots the standard deviations of the measurements conducted at five different points on each surface. All of the surfaces have errors below 40 µm, this not insignificant but is considerably smaller than the 150 µm range available for successful prints as well as the errors that were later seen in laser measurements.

Figure ?? shows the variation in the difference between manual and laser measurements on each surface. As expected, clear interface gives a very wide variation as a result of the laser penetrating into the material instead of reflecting off the surface. The blue surfaces also introduce a large error in the laser's measurements. This is likely because the blue surface absorbed large amounts of the red laser light, leaving little to be reflected and picked up by the detector. This was corroborated by the laser receiving unit's received intensity readout which showed a value approximately ten times lower than it did when profiling the other colours.

The smallest variations are shown by the red and yellow surfaces which manage to be sufficiently opaque and reflective enough to produce an accurate measurement.

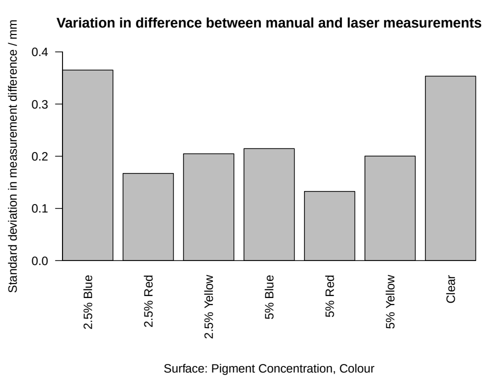

Fig. 5. Graph of the standard deviation in the difference between manual and laser measurement on each surface.

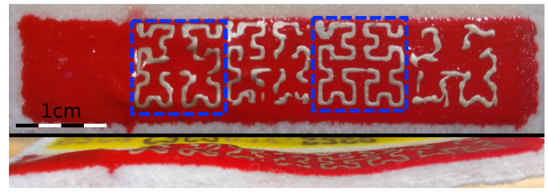

Fig. 6. Four test prints on red interface on a Mölnlycke Mepore dressing. The two highlighted in blue dashed squares were printed with height compensation, the other two were printed at a fixed height. The height compensated prints show significantly fewer breaks than the others, despite the leftmost one being printed on a particularly uneven section of interface.

Laser measured height compensated test prints conducted on red and yellow interface on polyester - cotton showed similar results to those done at a fixed height. This is because the surface of red and yellow interface on the flat polyester - cotton generally did not vary enough over the one by one centimetre print area for height control to have a significant effect. It does show though, that the laser's measurements do not have any detrimental effect on the printer's performance.

On the much less even surface presented by the wound dressings, the effect is more pronounced and using height compensation resulted in a significant improvement. As shown in figure ??, prints which utilised height compensation only failed to accurately print 6% of their paths' length compared to 31% for those printed at a fixed height.

While many height controlled prints made during testing do still have at least one break along their length, printing with multiple passes would make the process more reliable, making it viable for producing prototype or bespoke e-textile devices on uneven substrates without needing to deposit excessive amounts of paste.

IV. Conclusions

The versatility of the technique and the ease with which designs can be changed make dispenser printing an attractive means of producing one-off e-textile prints. However the stringent requirements on the distance between the nozzle and the substrate make it difficult to utilise on uneven fabrics.

Measuring and compensating for changes in the height of the substrate is possible with a laser displacement metre, if the surface being measured is sufficiently opaque and reflective for the laser to make an accurate measurement. When using a red laser, this means using a interface paste that has been coloured red or yellow.

When adding pigment, it is also important to ensure doing so will not adversely effect other properties of the paste, such as its ability to be cured as occurred with the blue pigment in this investigation.

With the right colouring, laser profiling can lead to a significant increase in reliability, making dispenser printing practical for prototyping e-textile designs on uneven substrates as well as smooth ones.

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