Nano HydroGraphics - The push Towards Realising Electronic Skin

H. R. Jones[1] & M. T. Cole[1*]

Introduction

Electronic skin is a developing technology with amazing possibilities. These devices are electronic circuits that are placed on the human skin. They are used to perform measurements such as monitoring the users' health, to help individuals in day to day life by offering them a low cost imperceptible device [1]. Electronic skin devices can provide a huge aid to the health sector. This is shown by Figure 1 where Zhong Ma et al have developed multiple electronic skin devices giving an idea of the capabilities these devices can accomplish [2].

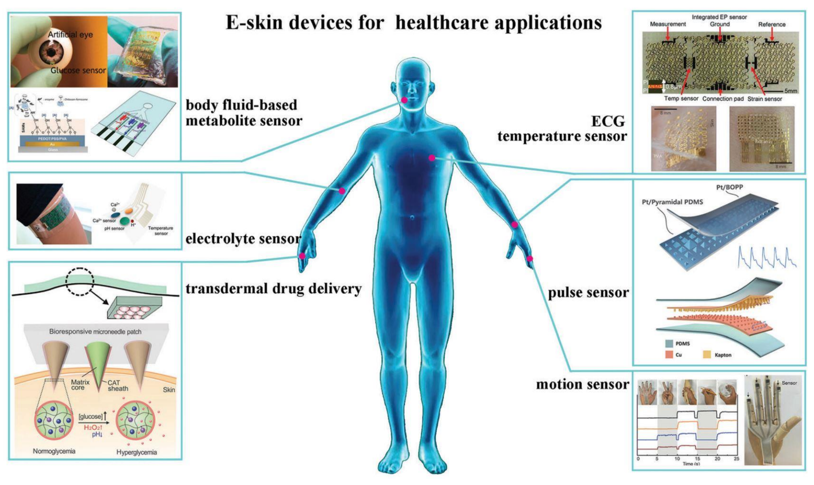


Figure 1. A diagram showing multiple electronic skin devices for healthcare applications developed by Zhong Ma et al [2].

Background

Literature was reviewed regarding the fabrication methods of electronic skin devices. These were specialised and inkjet printing, photolithography, screen printing and Dip pen nanolithography (DPN). These were critically analysed by the form of a ranking table shown by Figure 2.

Fabrication Methods		Specalised Inkjet printing		Desktop Inkjet Printing		Screen Printing		Photolithography		Dip Pen Nanolithography (DPN)		Comments (the higher the merit score.....)
Criteria	Weight (1-10)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	
Resolution	10	4	40	3	30	2	20	5	50	5	50	The higher the resolution in which the equipment it can print onto a substrate
Simplicity	8	4	32	5	40	4	32	2	16	3	24	The easier it is to use this equipment
Length of procedures	7	5	35	4	28	3	21	2	14	3	21	The lower number of procedural steps this has.
Mechanical reliablility	6	2	12	5	30	4	24	5	30	5	30	The more mechanicaly reliable it is
Running Cost	5	5	25	4	20	2	10	1	5	3	15	The cheaper it is for materials needed to use this machine
Capital Cost	5	4	20	5	25	5	25	2	10	2	10	The cheaper the equipment is
Typical print area	3	4	12	4	12	2	6	3	9	1	3	The larger the typical print area it can produce
Summation of Merit			176		185		138		134		153	

Figure 2. Ranking table showing the types of fabrication methods that could be used for the electronic skin device [1].

Figure 2 shows that desktop inkjet printing is the best method to use. This is due to its simplicity, its low capital cost and its ability to rapidly prototype electronic skin devices. The printer that was used was the HP7520. Further literature was reviewed by looking at paper substrates that are compatible with desktop inkjet printing this was also critically analysed by a ranking table shown by Figure 3.

Paper Substrate		Silhouette, temporary tattoo paper (TTP)		Hydrographic paper		Mitsubishi resin coated paper (NB-RC-3GR120)		Epson super glossy photo paper		Whatman cellusose paper		Office paper		Comments
Criteria	Weight (1-10)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	Evaluation (1-5)	Merit (WxE)	
Mechanical Flexibility	10	5	50	5	50	5	50	1	10	2	20	2	20	The higher the merit score the more mechanically flexible the substrate is.
Suitability for hydrogrpahic transfer	9	5	45	5	45	4	36	3	27	3	27	1	9	This determines if the substrate the following factors: Water resistant, adhesion qualities. The higher the merit score the more suited the substrate is to these factors.
Suitability for electronic skin purpose	8	5	40	4	32	3	24	2	16	2	16	1	8	This determines the following factors: level of impercibility, level of transparency, bio-compatible. The higher the merit score the more suited the substrate is to these factors.
Suitability being compatible with an inkjet printer	7	4	28	4	28	4	28	3	21	2	14	5	35	This determines the standard size of the substrate that they come by and how compatible is it with the inkjet printer, The higher the merit score the more suited the substrate is to this factor .
Suitablilty for conductivity of silver	6	4	24	3	18	4	24	4	24	3	18	2	12	Based on research of the conductivity results from the literature. The higher the merit score the higher the conductivity was achieved through research.
Cost per unit area	5	1	5	3	15	3	15	4	20	3	15	5	25	The higher the merit score the cheaper the substrate per unit area is.
Summation of Merit			192		188		177		118		110		109	

Figure 3. Ranking table showing the types of paper substrates that could be used for the electronic skin device [1].

Figure 3 shows Temporary Tattoo Paper (TTP) is the best substrate to use. Mainly based on the existing literature that, for hydrographic transfer TTP has key characteristics for this transfer technique as well as being able to print with an inkjet printer.

Silver nanoparticle (AgNP) inks were reviewed to see whether the AgNP ink has a similar viscosity to the HP7520 ink toner, which is 2 mPa.s [3] and also, the cost of this ink. It was found that the AgNP ink to use was Mitsubishi NBSIJ-MU01. As it had a viscosity of 2.30 mPa.s but also it had a cost of $3.40 per ml [4] [5].

References

[1] H. Jones, "Nano hydrographics - the push towards realising electronic skin - interim report", 2019.

[2] Z. Ma, S. Li, H. Wang, W. Cheng, Y. Li, L. Pan, and Y. Shi, "Advanced electronic skin devices for healthcare applications", J. Mater. Chem. B, vol. 7, pp. 173–197, 2 2019. doi: 10.1039/C8TB02862A. [Online]. Available: http://dx.doi.org/10.1039/C8TB02862A.

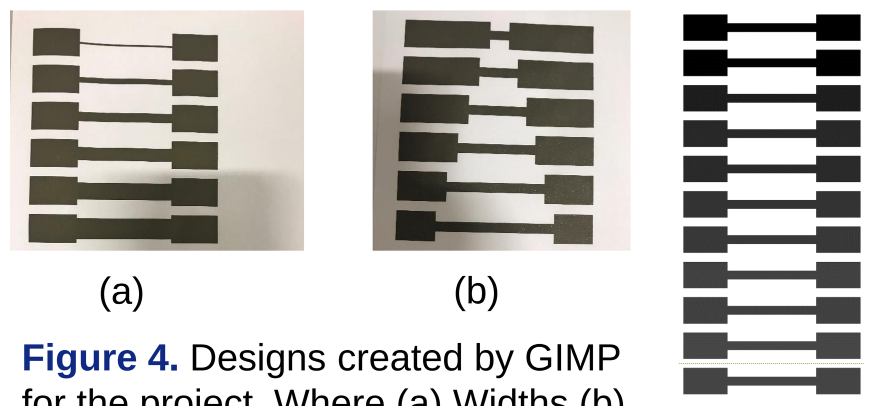
[3] Hewlett-Packard, Safety data sheet for cb316 series, 2019. [Online]. Available: http://h22235. www2 . hp . com / hpinfo / globalcitizenship / environment / productdata / Countries / us / ij _ cb316series_us_eng_v33.pdf.

[4] A. Mansour, N. Shehata, B. Hamza, and M. Rizk, "Efficient design of flexible and low cost paperbased inkjet-printed antenna", International Journal of Antennas and Propagation, vol. 2015, Sep. 2015. doi: 10.1155/2015/845042.

[5] M. paper mills limited, Silver nano-particle inks, 2013. [Online]. Available: http://www.k-mpm. com/agnanoen/agnano_ink.html.

Results

Experiments are now designed to analyse the characteristics and capabilities of the printable silver inks on paper substrates. To analyse the properties, designs were created using the software program GIMP. These can be seen in Figure 4. This shows a change of widths from 1 mm to 11mm, a change in lengths from 10mm to 60mm and a change in opacity from 100% to 90%. Another design was constructed which used the University of Bath logo; this was printed on TTP to perform the hydrographic transfer technique. Figure 5 shows the results.



(a) (b) (c)

Figure 4. Designs created by GIMP for the project. Where (a) Widths (b) Lengths (c) Opacities.

Figure 5. Results from the hydrographic transfer process using TTP

The first experiment designed was a sheet resistance time series of a duration of 4 weeks. This used the lengths series design which was printed on multiple substrates: office paper, TTP, Over head projector (OHP) slide, acrylic paper, card and photo gloss paper. To measure the sheet resistance a JANDEL Multiheight 4-point probe was used. Figure 6 shows the results for office paper.

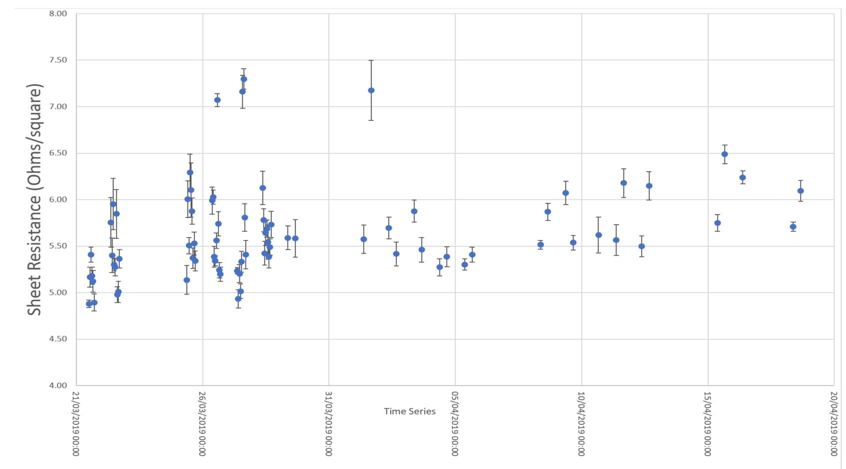


Figure 6. Results from the sheet resistance time series using the 4 point probe for office paper

The next experiment used a bend-rig to see how resistance of the ink varied being bent at angles from 0 – 100 degrees, and the samples being bent around a changing bend radius from 1 cm – 5 cm. The widths and lengths designs were used to see also how this changed the resistance measured.

The final experiment was to see how resistance changed over constant bending of 0 – 100 degrees which was repeated for 7000 iterations using a bend-rig. This was to simulate a limb bending constantly for a whole day. The opacity design was used for this experiment to see how a change in opacity was affected for 7000 iterations. Figure 7 shows the results for 100% opacity.

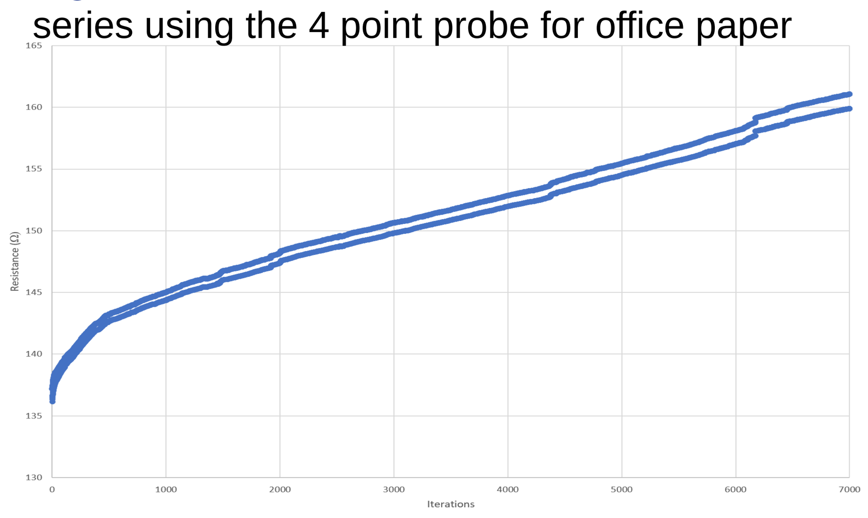


Figure 7. Results from bend rig where the resistance was for the widths design. measured from a bend angle of 0 – 100 degrees for 7000 iterations at 100% opacity.

Discussion and conclusion

The project has accomplished some key aims and milestones in terms of developing an electronic skin device. Throughout this project a cheap and simple fabrication method has been developed to create a printable simple flexible electronic device by printing conductive AgNPs on paper substrates.

The sheet resistance time series showed how the conductivity of AgNP varied on different paper substrates. It was found that office paper proved to be the most consistent at giving a low resistance value over the course of the 4 week experiment. This isn't ideal in terms of an electronic skin device when looking back to the ranking table shown by Figure 3 where office paper, scored the lowest out of those substrates. The 4-point probe also provided a few 'random' results from the damage this causes to the silver ink when a measurement is taken. Figure 8 shows the effects of this damage. The substrate TTP recorded a higher resistance which shows that the TTP needs to be analysed to look into possibilities to find out how to make this substrate have a higher conductivity so it can be successfully used for hydrographic transfer.

Through the software GIMP a resistor could be developed by changing the opacity value before printing.

This printed a more resistive AgNP sample making a unique solution for this electrical component. A thickness measurement of the AgNP ink was attempted for each opacity using a scanning electron microscope (SEM) shown by Figure 9. But these results were inconclusive due to the limitations of the paper substrates.

This project also looked into the limitations the AgNP ink when it is on the skin. Skin has lots of complex angles, so to see how the ink responds to it at these angles proved a success as the resistance had minimal change at angles from 0 - 100 degrees. Finally the simulation of 7000 iterations from 0-100 degrees at different opacities. This gave very useful information about the minimal increase in resistance at the higher opacities. It was also useful because the data set was so large this gave an insight to the problem of changing the opacity during printing as at higher opacities it gives a 'random' distribution result.

This project has met some of the aims which were set out at the beginning of the project. However, further substantial data are needed to develop a successful electronic skin device. Therefore, this project has given a solid base in terms of developing an electronic skin device which has the potential of changing not only the world's healthcare but also other sectors due to it having a cheap and rapid fabrication method.

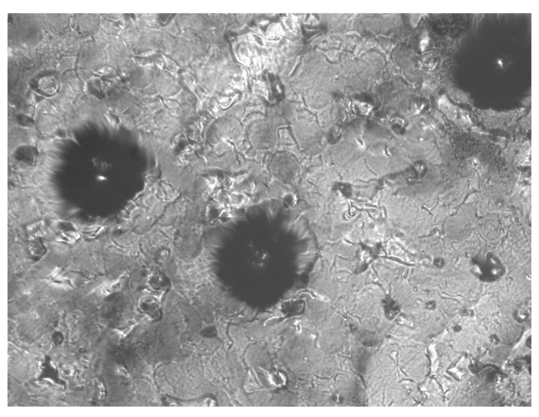


Figure 8. Image showing the damage the 4- point probe causes on AgNP ink on photo gloss paper at a magnification of 20x

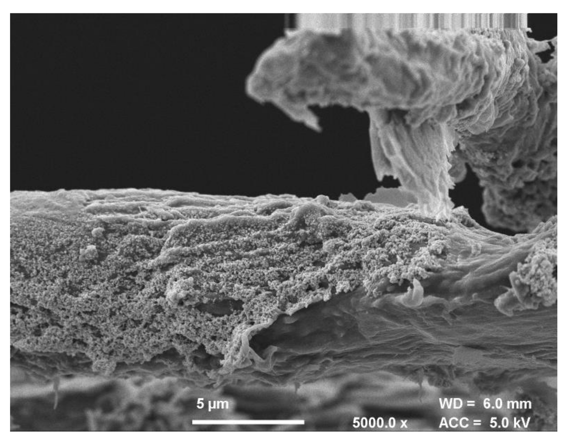


Figure 9. SEM picture for 94% opacity at 5000x magnification.

Department of Electronic & Electrical Engineering

UNIVERSITY OF BATH

[1] Department of Electronic & Electrical Engineering, University of Bath, Claverton Down, Bath, BA2 7AY, United Kingdom

* mtc47@bath.ac.uk