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Proceeding Paper

Reverse-Offset Printing for Fabricating E-Textiles †

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Abstract: Printing electronics directly onto fabric to create e-textiles is a promising technology, but it is currently limited by the achievable printing resolution. The suitability of a bespoke reverse-offset printing system for use in printed e-textile devices has been explored because of the higher resolution it can achieve compared with alternatives such as screen printing, while still being scalable due to its roll-to-roll nature. The process has successfully achieved high-resolution patterns, as fine as 30 microns, on flexible polymer substrates suitable for lamination onto textiles and printing directly onto coated fabrics. The printing system comprises a gantry stage with a PDMS-coated roller and a base section that holds the cliché (patterned plate) and substrate. The system is controlled using LabVIEW software to ensure precise synchronization of the linear-stage movement and roller rotation. The results demonstrated a significant improvement in printing resolution compared to conventional methods such as screen and inkjet printing. This work showcases the potential of reverse-offset printing for fabricating advanced electronic devices on flexible substrates, creating new possibilities in the field of wearable technology.

Keywords: reverse offset; printed electronics; electronic textiles; roll-to-plate; high resolution

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1. Introduction

The blossoming research in wearable devices seeks to fabricate highly flexible electronics that accommodate human motion, enabling increased comfort for wearable devices. Thus, printed electronics on flexible substrates can meet the needs of high flexibility and can achieve a range of functionalities depending on the characteristics of the ink [1]. Integrating flexible and soft electronics into textiles which is described as electronic textiles (e-textiles) has attracted high attention for wearable-device applications [2].

There are various methods for printing electronics such as screen printing [3], inkjet printing [4], reverse-offset printing [5], and gravure printing [6]. The reverse-offset printing method has high-resolution printing patterns because there is less restriction on ink particle or screen mesh sizes and because it is suitable for printing thin-film electronics (e.g., transistors and organic electronics). It has not previously been evaluated for the fabrication of electronics on fabrics, which presents challenges associated with surface roughness, porosity and flexibility/shear. In comparison to alternative printing methods, reverse-offset printing faces challenges related to ink rheology, in addition to a high cost of printer manufacture and the need for specific operating skills. This study presents initial results from investigations of reverse-offset printing on textiles and paves the way for high-resolution e-textile printed devices. By offering insights into the capabilities of reverse-offset printing, this research aims to contribute to ongoing advancements in wearable technology and its applications in the development of electronic textiles.

2. Reverse-Offset Printing System

2.1. Roll-to-Plate Reverse-Offset Printer

A schematic diagram of the reverse-offset printing process, which contains three main steps, is shown in Figure 1: (1) coating process: coating functional inks on the polydimethylsiloxane (PDMS)-covered roller (PDMS blanket) via a slot-die coater to obtain a flat and uniform ink film; (2) removal process: when the roller moves across the cliché, which has high surface energy and deep features, inks will be selectively passed to the cliché by adhering to the raised parts, leaving the negative image of the cliché on the blanket; and (3) pattern process: after the removal process, the remaining ink on the blanket is deposited on the substrate as the roller passes across their surface.

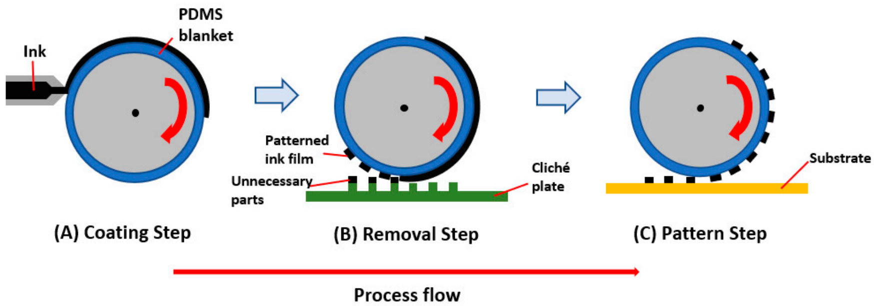


Figure 1. Schematic diagram of the reverse-offset printing process.

Based on the general process, a reverse-offset printer was developed in the lab, as shown in Figure 2, which is composed of a moving gantry stage and a base part. The gantry stage has an ink-coating system and two stepper motors (TITAN-IMX-T23): one allows the gantry containing the offset roller to move linearly and one rotates the roller. The key to a successful printing process is to synchronize the linear and rotational movements of the roller to avoid any smearing or distortion of the pattern. Additionally, two load cells are affixed to the gantry stage, detecting the pressure exerted by the roller against the cliché or substrate plate. The base component features two micro-positioner stages, designed for precise alignment during the printing process of multiple layers. Each micro-positioner is equipped with a vacuum plate connected to a vacuum pump, serving to secure the cliché or substrate plate in place.

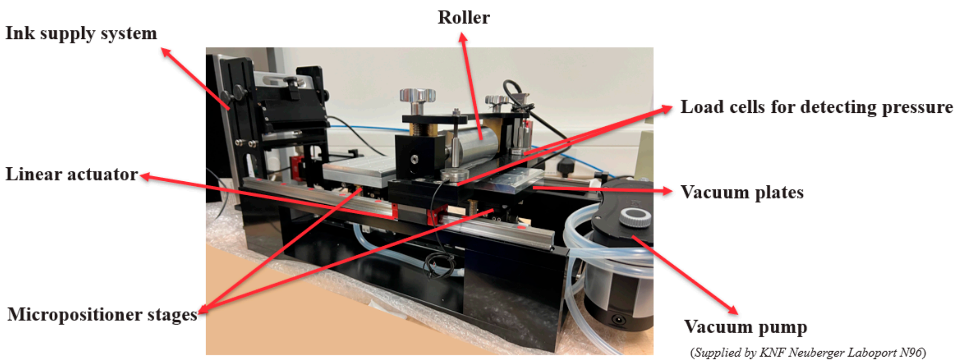


Figure 2. Bespoke reverse-offset printing system developed in this work.

2.2. Printing Movements Control System

The control system for the printing process has been created in LabVIEW software to enable simple but precise control of the printer and inherent speed synchronization of the linear-stage movement and roller rotation, with the overall operating interface shown in Figure 3.

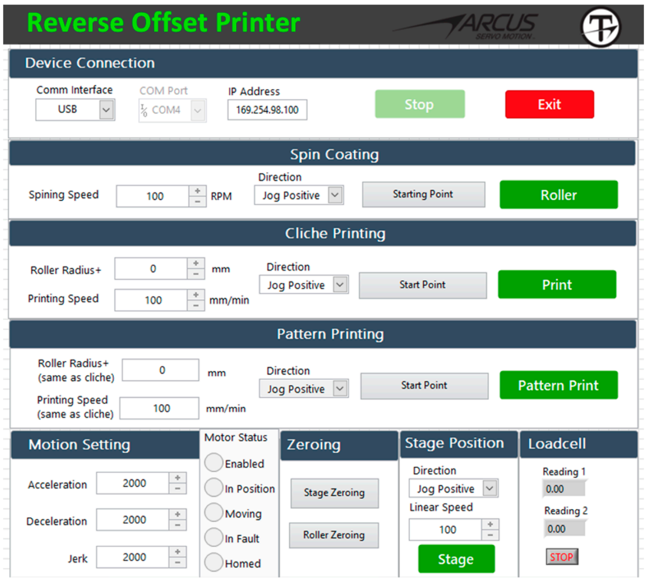


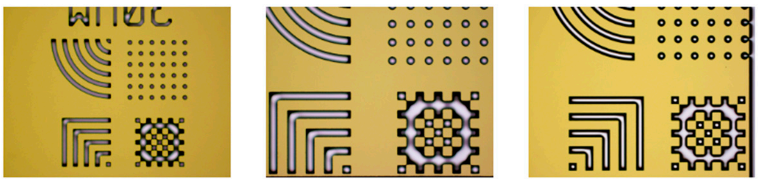
Figure 3. Printer movement control system developed via LabVIEW.

The control system mainly enables the following functions:

i. Moving the roller stage to target positions such as the starting point of the coating step, removal process and pattern printing step.
ii. Varying print speed whilst ensuring a speed synchronization between the linear and rotational movement of the roller.
iii. Independent control of each step (spin coating, cliché printing, and pattern printing) to ensure immediate starting or stopping.
iv. Monitoring the pressure detected by load cells.

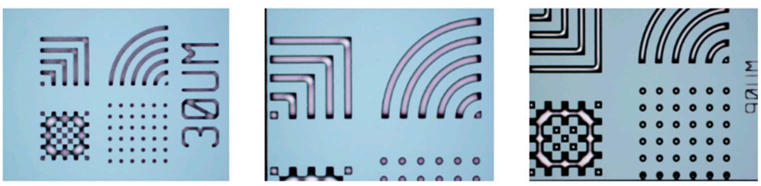
2.3. Design of Printed Patterns with Various Sizes

Silicon cliché plates, which are used for creating patterns, were fabricated through photolithography and deep reactive ion etching (DRIE) processes. Two cliché plates named A and B have been fabricated to achieve different etch depths and thickness of the silicon dioxide mask on top of the plate. The microscope images in Figures 4 and 5 showcase various pattern sizes on the cliché plates of different depths. The plates have clearly defined features, with clear edges and sharp angles down to 30 µm feature sizes.



(A) 30 μm (B) 50 μm (C) 90 μm

Figure 4. Various (**A**) 30 µm, (**B**) 50 µm and (**C**) 90 µm feature size patterns with 90µm depth on cliche plate A.



(A) 30 μm (B) 50 μm (C) 90 μm

Figure 5. Various (**A**) 30 µm, (**B**) 50 µm and (**C**) 90 µm feature size patterns with 125 µm depth on cliche plate B.

3. Results

The fabrication process successfully yielded patterns with an impressive resolution as fine as 30 microns on a polyethylene terephthalate (PET) film which was attached to removable silicon paper (Policrom Screens, Carvico, Italy). It is noteworthy that the achieved resolution was constrained by the features present on the cliché used in the process. Subsequently, the patterned PET films underwent thermal lamination at 190 °C onto textiles.

Figure 6 displays the printed patterns onto textiles using three different inks: blue offset ink, functional dielectric ink, and conductive silver ink. The patterns showcase varying sizes, specifically 30 µm, 60 µm, and 100 µm, emphasizing the versatility of the printing process.

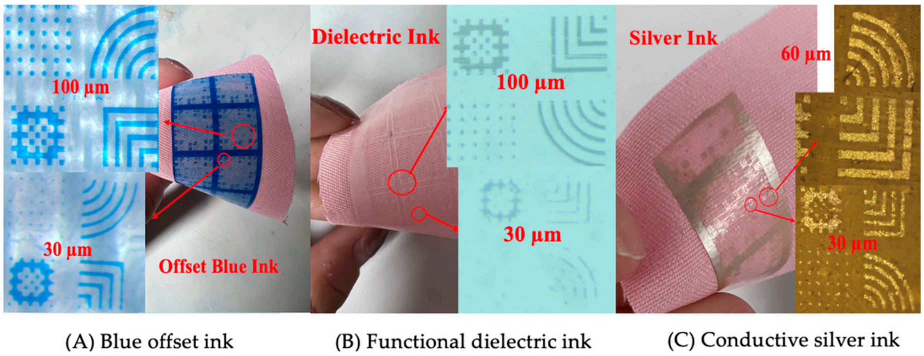


Figure 6. Printed patterns with various inks on PET films subsequently laminated onto fabrics.

Throughout the printing process, the inks exhibited a viscosity of approximately 7500 centipoises (cP). To adjust the viscosity to optimal levels, a thixotropic pine oil was judiciously added. This modification ensured that the inks maintained the necessary fluidity for continuous and accurate printing onto the substrates, contributing to the overall success of the fabrication process.

The surface energy of the substrate is a critical factor influencing the printing process. It was observed that successful printing occurred when the surface energy of the cliché/substrate plate (Silicon/PET film) exceeded the combined surface energy of the PDMS film and the surface tension of the inks. Notably, the surface energies of PDMS, silicon, and PET were measured using a Kruss DSA30 tensiometer at 30.1 mN/m, 72.7 mN/m, and 54.7 mN/m, respectively, highlighting the substantial differences between the surface energy of the cliché/substrate plate (Silicon/PET film) and PDMS film. This difference is crucial for ensuring the effective transfer of patterns onto textiles.

4. Conclusions

This work has demonstrated the application of a new reverse-offset printer for printing high-resolution conductive patterns onto fabrics. The printing resolution of the electronics printed onto fabrics via this method was improved by at least a factor of three when compared with typical screen and inkjet printing. It is hypothesized that, by utilizing a higher resolution cliché, it will become possible to improve the printing resolution to <10 microns, and this will be investigated next now that the working principle of the printer has been established.

Author Contributions: H.D. carried out the printer and cliché design and experiment implementation and wrote the manuscript draft. R.T. provided supervision for the research work, material selection and edited the manuscript draft. S.B. provided supervision for the research work, printer and cliché design, and edited the manuscript draft. All authors have read and agreed to the published version of the manuscript.

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