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A wearable tracking device inkjet-printed on textile

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ABSTRACT

Despite the abundance of localization applications, the tracking devices have never been truly realized in E-textiles. Standard printed circuit board (PCB)-based devices are obtrusive and rigid and hence not suitable for textile based implementations. An attractive option would be direct printing of circuit layout on the textile itself, negating the use of rigid PCB materials. However, high surface roughness and porosity of textiles prevents efficient and reliable printing of electronics on textile. In this work, by printing an interface layer on the textile first, a complete localization circuit integrated with an antenna has been inkjet-printed on the textile for the first time. Printed conductive traces were optimized in terms of conductivity and resolution by controlling the number of over-printed layers. The tracking device determines the wearer's position using WiFi and this information can be displayed on any internet-enabled device, such as smart phone. The device is compact (55 mm × 45 mm) and lightweight (22 g with 500 mAh battery) for people to comfortably wear it and can be easily concealed in case discretion is required. The device operates at 2.4 GHz communicated up to a distance of 55 m, with localization accuracy of up to 8 m.

1. Introduction

Wearable devices are making an impact on several applications ranging from medical, safety, leisure and entertainment. E-textiles or smart fabrics are usually contributing towards the wearable technology field [1–3]. E-textiles have been used to incorporate energy management [4], memory [5], sensors [6,7], electrochromic [8], energy harvesting [9], nano-generator [10–12], battery [13], supercapacitors [14], communication [15–17] and health monitoring [18–22] based devices on or within fabrics to facilitate the human-device interaction. It is estimated by Grand View Research that global smart textile market will reach 1500 million USD by 2020 [23].

Localization i.e. ability to track the position of an object is another research area which has seen a tremendous boom in past couple of years [24–26]. A diverse range of applications have benefited from advancements in this technology, ranging from health care monitoring; generic child, pet or vehicle tracking; to a number of complex location aware services such as context aware marketing, crowd management etc. Global navigation satellite system (GNSS) provides a very viable solution for outdoor tracking owing to its global availability and excellent localization accuracy. However, a globally available indoor or integrated (i.e. combined indoor and outdoor) tracking technology is a challenging problem, receiving major industrial and research interest.

Combining localization technology with wearable devices opens door for many exciting applications in areas such as health care, environmental sensing, child, pet, elderly monitoring etc. However, currently there are no true E-textiles tracking implementations. A few examples of clothes with tracking features are realized by gluing, stitching or pocketing regular trackers onto textile [27]. Such incorporation of trackers can hardly be labeled as E-textiles. Since these trackers are rigid PCB-based, so result is an uncomfortable and non-practical clothing. Moreover, since the incorporation of such PCB-based tracking devices on T-shirts or dresses is not feasible, such tracking devices are usually featured on heavy duty clothes i.e. protective uniforms, coats and ski jackets where the size and rigidness of trackers are of lesser concern [27]. True E-textiles implementation can potentially be accomplished via conductive printing since printing the circuit layout directly on textiles, can eliminate the rigidness coming from PCB substrate, as shown in our previous work [28]. This method is already widely exploited to print on different substrates including paper and plastic [29–32]. The advantage of conductive printing process lies in its similarity to PCB fabrication. Conductive printing allows producing entire electronic circuits in a planar, highly repeatable and low-cost manner. However, the main obstacle in conductive printing on textiles is the substrate itself. Common textiles are constructed from yarn that is twisted and interwoven. Due to the interlacing of warp and weft yarns,

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a textile structure is usually very rough and has significant dips that can be visibly seen. Such surface structure is highly unfavorable for direct conductive printing on textiles since ink will not be distributed evenly across the surface; thus, proper linking will not occur and reasonable conductivity will not be achieved. Consequently, to perform successful conductive printing, fabric surface should be made flat and uniform.

To overcome the roughnesses and porosity of textiles, a thick interface layer can be printed on the textile. The interface layer method can be an intermediate screen-printed polyurethane-based dielectric layer that can cover the surface profile of a material rendering it flat and relatively smooth. There are few reports utilizing the interface layer method, wherein simple structures consisting of interconnect, patches, and MEMS were studied [33–36]. However, a complete circuit or system on clothes for wearable electronic applications has never been demonstrated. Also, current research is bound only to a single dielectric paste material, Fabink UV-IF4 supplied by Smart Fabric Inks, Ltd (http://www.fabinks.com/). Unfortunately, this interface layer ink is expensive (340 USD/100 g). Other low cost dielectric materials have never been investigated for interface layer formation purposes. Optimizing a low cost general purpose dielectric material will ease the access to the interface layer method and decrease the overall cost of prototype production.

This work, for the first time, demonstrates a complete system printed on a polyester/cotton T-shirt, which enables tracking of the person who is wearing that T-shirt through a smart phone or any internet enabled device. A comparatively low cost (50 USD/100 g) dielectric material (Creative Materials 116-20 Dielectric ink) is used to print the interface layer through manual screen printing method. The circuit layout and antenna was inkjet printed on fabric with silver nanoparticles based conductive ink and its conductivity on interface layer was optimized. Utilizing WiFi technology, this wearable tracking system can locate the position of lost children, senior citizens, patients or people in uniforms, lab coats, hospital gowns, etc. Investigation on the direct printing of circuit layouts on textiles can potentially lay down a strong foundation for future development of E-textiles and open the path for realization of diverse applications such as Internet of Things (IoT).

2. Materials and methods

2.1. Materials

UV-curable dielectric ink, 116-20 (CM 116-20) is purchased from Creative materials (http://www.creativematerials.com/). The silver nanoparticle based ink, DGP 40LT-15C, is purchased by Advanced Nano Products (http://anapro.com/) is used as the conductive ink. 100% cotton and 65%/35% polyester/cotton fabrics were purchased from general purpose clothing department stores. 85%15% polyester/cotton textile with the brand name "Luminex 310" was purchased from Klopman International (http://www.klopman.com/).

2.2. Printing of interface layer and conductive ink

The dielectric interface layer is printed by manual screen printing using PET stencil and Doctor Blade. The conductive printing is accomplished by ink-jet printing via special ink-jet printer Dimatix DMP 2831 printer. This printer utilizes one and ten picoliter cartridges to deposit conductive drops onto the substrate in a predefined pattern. The jetting process is all digital, thus is easily configurable. Ten picoliter cartridges are used to print the circuit layout. The distance between drops is critical to establish good structure conductivity. The drop spacing of 20 μm was experimentally found to perform well providing sharp line edges and almost no side overspills. After printing, the deposited layers were each sintered for 20 mins at 130 °C in a thermal oven. The chosen curing process is suggested by ink manufacturer and also can be safely used with textile substrates selected for this work. The 20 min thermal sintering at 130 °C was performed after the printing of each two layers.

2.3. Characterization of conductive film and dielectric interface layer

The structural properties were examined using scanning electron microscopy (FEI NovaNano FEG-SEM 630). The thickness and uniformity of printed features on substrates were performed using a surface profiler (Veeco Dektak 150) and 3D interferometry (Zygo, Newview 7300). The permittivity and loss tangent of the textile and interface layer stack up was measured using Agilent (E4991A) impedance analyzer.

2.4. Antenna design and its measurement

The inverted F-antenna (IFA) for the on-textile circuit was optimized in Ansys™ High Frequency Structure Simulator (HFSS). The simulated IFA model and corresponding parameters are given in Supporting information Fig. S1(b) and Fig. S1(a) respectively along with the details of the antenna operation. This model and its simulation results are used to validate the antenna design printed on textile. The antenna is connected to a surface mount coaxial connector that is RF compatible with the nominal characteristic impedance of 50Ω. The conductive epoxy AA-DUCT 2919 was used to glue the connector to the antenna feeding point. The fabricated antenna's reflection coefficients S11 were measured using Keysight N9923A FieldFox Vector Network Analyzer.

2.5. Localization prototyping on fabric

The prototype uses the ATMEGA328p in DIP package and also DIP socket whereas the final circuit will use the ATMEGA328p in TQFP package. Such change was administered to facilitate the testing of the on-textile prototype. The socket usage allowed for easy troubleshooting and debugging. Microcontroller houses the control code of tracking device, written in C++ using the Arduino development environment. Basically, the code operates the RN-171 WiFi module to scan ten nearby WiFi access points. This information is then sent to a server computer, by connecting to a known WiFi network, using the RN171 module. The control code is also responsible for establishing serial data communication between RN171 and the microcontroller, as well as operating a status LED. LED is needed mainly for indication and debugging purposes and can be eliminated if necessary.

3. Results and discussions

3.1. Printing on textiles

The interface layer method is suitable for production of smart fabrics from a verity of textile materials while preserving the natural elasticity of the clothes. To verify the versatility of this method, three common woven fabric substrates were selected −100% cotton (black), 65%/35% polyester/cotton (white) and 85%/15% polyester/cotton (yellow). In this work, the manual screen printing, also called "Doctor Blading", is employed. The "Doctor Blading" technique is conceptually similar to the standard screen printing process, but, instead of an automatic or semi-automatic machine movement, the squeegee is slid manually. This method is not as accurate as the standard screen printing, but it is much more flexible and faster which is beneficial for prototype development. Furthermore, a screen of PET film with thickness of 0.3 mm has been employed. PET film stencils can be easily and quickly altered using laser-cutting or simple manual carving, thus allowing flexibility during screen printing. The process steps for interface layer formation are shown in Fig. 1. The PET stencil is placed on top of the fabric textile (i), then CM116-20 dielectric paste is poured onto the stencil (ii). A squeegee is used to scrape dielectric paste across