National Textile Center
FY 2007 New Project Proposal
Project No.
M07-PH05

Competency: Materials

Creation of Textile-Based Durable Printed Antenna Systems

Project Team:

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Objective:

Printed electronics have received a tremendous interest from researchers and manufacturers in the search to achieve ultra-low cost electronics circuits such as RFID tags. The main components of a passive RFID tag are a small antenna circuit tuned to the RF frequency, and an integrated circuit (chip) programmed with unique identification codes. The RFID antenna is made of a conductive material bonded to a substrate material. Printed antennas using conductive ink on coated paper or plastic that achieve high conductivity and low resistance suitable for RFID application have been reported (14,16). However, in all of these studies, the authors suggest investigating different substrates and the printing parameters.

The objective of this proposal is to design a low-cost RFID antenna printed onto a textile-based substrate with inkjet technology, which enables (1) the finer resolution in smaller application spaces with less materials, more than any other printing technologies, (2) a direct method to precisely place materials onto the fabric in one step, and (3) a continuous digital process to change outputs without intermediate stages. Textile-based antennas could be used to replace other materials currently utilized, such as Taslan, or these antennas could be incorporated into textile products, such as apparel and footwear, in which they could serve a variety of purposes. Printed, non-obtrusive antennas, in conjunction with RFID chips, could be used to track shipments of apparel, helping US Customs Service determine if a shipment of apparel is labeled authentically, thus decreasing instances of trademark infringement. These systems could also be utilized in uniforms, to ease in the tracking of uniforms or to prevent unauthorized use.

Relevance to NTC Mission:

Direct writing electrically conductive pattern with metal colloid are relatively new to the textile field. Most research has focused on non–porous materials (paper, glass and PED film). Although silver colloid ink is often utilized, there is currently no silver colloid ink formulation designed specifically for textile substrates. Very few publications examine its application to textile substrates, and little research funding is available to develop this field.

The goal of the project is to develop a fundamental knowledge base of printed RFID antenna fabrication onto textile substrates under different parameters of fabric construction, printing conditions, pre-treatment and post-treatment. Success in this research could lead to the US textile industry having the knowledge and ability to print RFID antennas on textiles and apparel for a variety of purposes, such as tracking finished products from production to sales as well as tracking products while in use, such as uniforms. These printed tags could eliminate hang tags and UPC labels that currently need to be attached to most textile products, and possibly lower costs of production. If fabrics prove to be better substrates than current materials, then this project will provide the US textile industry with the knowledge base required to produce the optimized fabrics for this application.

We have contacted several ink formulators such as Cabot Corporation, Cima NanoTech and Advanced Nano Products Co.Ltd, Five Star Technologies, as well as RFID manufacturers such as Vanguard Systems. The University of Arkansas, member of this research proposal hosts the Wal-Mart RFID Center, and the reliability of the printed RFID antennas to be designed will be tested at the RFID Center. Therefore, the continuous interaction between members of this project and the industry partners will enhance and expand the knowledge base of the industry.

State of the Art:

Redinger,et al. (14) developed a low-cost method of fabricating passive devices by printing gold nanocrystals on plastic substrates. They found the optimal printing conditions for polyimide dielectric layers and films as thin as 340 nm. Sangoi, et al. (15) printed RFID antennas using silver conductive ink, with rotary letterpress and flexographic printing. Their objective was to investigate different printing parameters (inking time, inking speed, printed speed, and printing force) on coated paper and plastic substrates. They found that antennas printed on coated paper substrates had physical and electrical properties superior to the plastic substrates. However, they suggest further investigation on different substrates and the adhesion of the ink. Bechevet, et al. (2) studied and determined the electromagnetic properties of plastic substrates. Then, they designed printed RFID antennas that operate around 2.45 GHz. Fuller, et al. (8) fabricated electrical and electromechanical devices by inkjet printing nano metal colloid ink on nonporous glass and polyimide plastic substrates. They printed active MEMS in 100 micron printed size with a speed of 400 layers per minute to prove potential cost savings over lithographic fabrication and molten-metal droplet deposition. Oguchi, et al. (12) developed nano silver colloid ink for inkjet printing. The ink contains 20 nm silver particles, which is encapsulated with a block co-polymer, and surfactants such as dispersion stabilizing agent, viscosity and surface tension stabilizing agent with metal loading of 30%wt. They found the optimal printing condition of 20 micron lines on nonporous substrates of paper, a polyester film, polyimide film, and glass-epoxy plate. They found that conductivity is dependent on sintering temperature and time. Bidoki, et al. (3) explored inkjet printing with an aqueous solution of a silver salt and reducing agent on various substrates of paper, PET plastic sheeting and textile substrates to form the silver *in situ* on the substrates. They found that conductivities and fastnesses of the prints depend on the substrates and their surface properties, and that the prints can be improved by altering the printing parameters and pre-treatment.

Most fibers utilized in the textile industry are electrical insulators rather than conductors. Much research has been conducted into creating textile materials, which offer electromagnetic shielding, for a variety of end uses. Some research has focused on making insulating fabrics, such as those with cotton or polyester, more conductive for use in intelligent textiles or anti-static apparel. This is accomplished by coating the fibers or blending these fibers with conductive fibers, such as carbon or metallic fibers, during the yarn spinning process (10-12).

The NTC has funded similar projects in the past. Carr (C02-GT07) had funding to examine the formation of ink jet droplets as well as the interaction between ink and the surface of the fabric. Pourdehimi (F04-NS17) currently has funding to investigate the possibility of printing circuit boards onto nonwoven fabrics using conductive inks. Thomas (F05-AE13) is currently exploring the use of metallic fibers embedded in geotextile fabrics for use as communication antennas. Patra, et al. (M06-MD01) investigates carbon nano tube conductive ink. However, none of these projects has focused on creating durable printed antennas on fabric for use in RFID identification devices.

Approach:

Conductivity of a printed antenna is dependent on many factors, including ink formulation, printing parameters, substrate, pretreatment of the substrates and post treatment of the printed substrates, as well as antenna parameters, such as size and pattern. Our research will have several different iterative phases, focusing on the fabric parameters, pre-treatment, printed line quality, antenna design optimization, and system evaluation. We will set the ink formulation as fixed values, ensuring optimal functioning of print head performance. Thus, all investigations will be conducted with the rest of the attributes of droplet sizes, printing parameters, pre-treatment, substrate, antenna design optimization and post treatment.

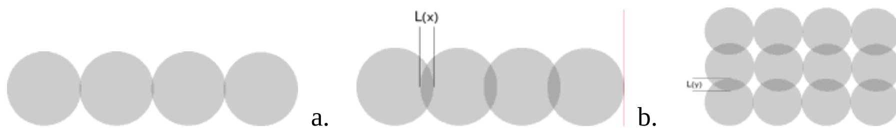
Since most fibers utilized in apparel are insulators, it is believed that these fibers would help in the creation of effective RFID devices, as the fibers would not interfere with or bleed off the signal given or received by the antenna. Although some research has been conducted to determine if fabric construction, besides the use of conductive yarns, affects fabric conductivity, there has been no comprehensive evaluation of this topic. This will be done, using the same fiber and yarn combinations but altering both woven and knit fabric constructions. Additionally, some fabrics will be finished via durable press or stain repellant finishes to determine if the finishes affect the conductivity of the fabrics. Changes in fabric conductivity as a result of structure or finish could render the antenna less effective, hence it is important to evaluate these variables.

Conductive nano-silver ink has been proven to work perfectly for UHF antennas as long as the substrate has a non-porous polymeric surface. Printed inks are heated-up and sintered to cohere and adhere the metal to the textile substrates. At this stage, the variables are heat, temperature and pressure. Thus, the second step of this research is to determine the required fabric pre-treatment substances such that, while printing the nano-silver conductive ink, we can create a highly conductive pattern with low contact resistance, good adhesion and good resolution. Pre-treatment, in inkjet printing, especially on porous textile substrates, functions to minimize drop gains (wicking) on the substrate due to the lower viscosity requirement, below 20 cps, than do conventional printing technologies. Depending on ink formulation and types of textile substrates, pre-treatment also enables the chemical bonds between colorants/functional particles and the substrates. Proper pre-treatment can improve the printing resolutions to minimize droplet gains to 1.5 % and improper preparation can result in as much as a 10 times diameter increase (8). In our research, we will experiment with polymeric resin binders, latex polymer binder, dielectric polymers, which attribute to the printing resolution and the silver colloid adhesion to the textile substrates.

A mechanism for measuring the electromagnetic properties of the fabric without physically contacting will be used to evaluate conductivity of different fabrics as well as different pre-treatments. The mechanism includes an electromagnetic energy transceiver having a transmitting and receiving antenna. The antenna will be positioned in close proximity but spaced from to the fabric being tested. Electromagnetic energy, which will be transmitted by the transmitting antenna and will be reflected by the fabric back to the receiving antenna, will be received at the antenna. By this method, the transceiver generates an output that is proportional to the reflected electromagnetic energy and, thus, is proportional to the non-reflected electromagnetic energy absorbed by the fabric being tested. The output signal will be used to indicate resistivity of the fabric to electrical transmission or other electromagnetic properties such as magnetic susceptibility. This will allow us to work with other parameters, such as optimized antenna design, in order to create the best performing antenna for each fiber/yarn/fabric/finish combination.

Optimized antenna design is the third area that will be investigated. Much research has already been completed in antenna design, and we will use those designs best suited to the chips we choose to use. However, those designs may need to be altered in order to account for fabric features, such as hairiness, that are generally not encountered with other materials. As such, we will determine the optimum antenna design for particular fabric types and pre-treatments. Part of this research phase will focus on line quality, as one method of reducing interference is to create an antenna by printing conductive ink lines that deviate little from the desired pattern. To date, little research has been done in this field. Park,et al. (13) discovered that fabric structure can affect print quality and line deviation for woven fabrics. However, this was a preliminary study, as their fabrics, while 100% polyester, were woven with different sized yarns as well as different yarn types. As part of this research, line quality of different fabrics, knits, nonwovens, and wovens, will be examined. Some of the variables to be examined will be fiber type, yarn type, yarn size, and fabric structure. As with the conductivity experiments, an understanding of print quality as a function of fabric attributes will help in the creation of effective printed antennas.

The second area of the antenna optimization stage is to investigate continuity of printed lines, a critical factor for the conductivity. We will determine optimal conductivity of various printing parameters including droplet sizes, droplet placements and width of line formations on different textile substrates. These parameters also attribute to the total drop quantity (ink volume) and numbers of printing passes and, consequently, influence production cost effectiveness. We will investigate several droplet sizes, widths, multi layer printing (by printing over the same dots' placement to increase thickness) and various placement methods including normal: (a) and various ratios of offset placements in x and y directions (dots' interlacing / staggering): (b) and (c).



a. b.

The printed antennas will be evaluated in the Wal-Mart RFID center at the Univ. of Arkansas. Based on the results, the best combinations will be selected to investigate the printing parameters in the second phase of the project. Evaluation will include fundamental tag sensitivity and responsiveness such as field range analysis including distance and speed effect, field strength with varying frequency ranges, and endurance test including moisture content of the substrate. The tag reliability and signal responsiveness experiments will be conducted to test the product for retail usage. These tests will include ambient effects (heat, natural stretch); packaging issues (package content, stacking methods etc.); and humidity of the package (humidity inside the nylon wrapping); as well as tests of the signal frequency hopping algorithms with different reader types, which are only available via experimentation.

At the point in which we are ready to insert the chips onto the optimized printed antennas, we will work with companies familiar with this process, such as Avery and Vanguard Systems. By pairing up with a company familiar with this process, we can ensure reliable placement of the chips onto the fabric.

Finally, the printed RFID tag (antenna and tag) will be evaluated at the Wal-Mart RFID center according to Wal-Mart specifications, as well as the reliability and accuracy of the produced RFID antenna. Enough experimentation will be conducted in order to evaluate the different patterns produced through this research, and the different applications that a given pattern could have such as item-level tracking, counterfeiting, package labels, etc. Concurrent to the antenna evaluation, we will conduct durability tests to determine how effective the antenna is after the fabrics have undergone use. In order for the RFID tag to be utilized in uses such as tracking of uniforms, it must be able to withstand use and care experienced by apparel. As such, the antenna will undergo abrasion, flexing, and laundering/drying evaluations under different conditions, to determine what it can withstand. Also, fabrics will be measured for hand and stiffness before and after printing to determine how the antenna increases alter the fabric.

Mid-Project Review Goals:

First year goal: investigation of textile substrates and pre-treatment for optimal conductivity and fastness (for application of metal colloid ink). After 17 months we expect to investigate how fiber/yarn/fabric/finish combinations affect material conductivity and will start to study the effects of varying printing parameters and antenna design on the effectiveness of the antenna. **Second year:** Study of the printing parameters and evaluation of printed antennas. **Third year:** Determination of the optimal printing conditions, chip incorporation, and evaluation of the RFID tags.

Outreach to Industry:

The following industrial partners have agreed to participate in the project:, Zhenwen Fu/ zfu@rohmhaas.com/ Rohm and Haas, Linda Creagh/ LCreagh@dimatix.com / Dimatix, Antonio Lopez Lopez.Antonio@Dystar.com / Dystar.

New Resources Required:

We will hire one graduate student and undergraduate student to work on this project at Philadelphia University.

We will outsource chip placement on the fabric, most likely to Avery or Vanguard Systems. A material deposition printer will be required to effectively attach the conductive inks to the fabrics.

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