Demo of PolySense: How to Make Electrically Functional Textiles

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Abstract
We demonstrate a simple and accessible method for enhancing textiles with custom piezo-resistive properties. Based on in-situ polymerization, our method offers seamless integration at the material level, preserving a textile's haptic and mechanical properties. We demonstrate how to enhance a wide set of fabrics and yarns using only readily available tools. During each demo session, conference attendees may bring textile samples which will be polymerized in a shared batch. Attendees may keep these samples. While the polymerization is happening, attendees can inspect pre-made samples and explore how these might be integrated in functional circuits. Examples objects created using polymerization include rapid manufacturing of on-body interfaces, tie-dyed motion-capture clothing, and zippers that act as potentiometers.

Author Keywords
eTextile; Fabrication; Sensing; Piezoresistive

CCS Concepts
•Human-centered computing $\rightarrow$ Human computer interaction (HCI);

Introduction
Piezo-resistive materials change their resistance when subject to strain. They have become an important part of in-

Figure 1: Measuring the monomer

Figure 2: Preparing oxidizing agent

Figure 3: Non polymerized (white) and polymerized (black) samples

How to Polymerize Fabric:

(1) *Choose amount of Water* – The fabric should swim in the water without lumping together, so that monomer and oxidizing agent can reach it everywhere. As a rule of thumb, by weight the ratio of water to fabric should be about 5:1, by volume no more than 4:3.

(2) *Dilute the Monomer* – Add pyrrole (Figure 1) to water, creating a water to pyrrole solution with a volume ratio of ∼1000:0025. In other words, for each liter of water, add 25ml of pyrrole. Once the monomer is added, stir the solution, until they are well mixed.

(3) *Add Fabric* – Once the fabric is added, stir gently for 10 to 15 minutes. or until satisfied that the fabric has thoroughly soaked up the monomer mixture.

(4) *Add oxidizing agent* – Add Iron Chloride (Figure 2). The mass ratio of Water to Iron Chloride should be 100:001 (i.e., 10mg for every liter of water). The iron chloride can either be directly added to the monomer mixture, or the powder can first be diluted with a small amount of water, to improve dispersion.

(5) *Wait for polymerization to complete* – Continuously stir, so that all monomer is brought into contact with fresh Iron Chloride, allowing it to polymerize. Once polymerization progresses, the fabric starts turning black (Figure 3). After about 30 minutes, when all fabric is evenly black, polymerization is complete.

(6) *Remove, Rinse and Dry* – Once polymerization is complete, remove the fabric and wash it thoroughly in cold water. It can then be simply hung up to dry, or ironed, to speed up the drying.

Table 1: Instructions - more: http://CounterChemists.github.io

teractive eTextile systems. They can be found in eTextile systems for detecting body movements [12] or posture [8], they are commonly used for soft pressure sensor matrices [3, 15], medical monitoring [5], or performing arts [9]. Piezo-resistive sensing is largely robust to the electrical noise introduced by the body [10], and piezo-resistive materials are often malleable and flexible. This makes piezo-resistive sensing the preferred method for wearable eTextiles, which are, by their nature, soft and conform to the body.

We demonstrate a method of creating such piezo-resistive materials, through *polymerization*. The method presented allows conductive polymers to form in and around textiles, coating their individual fibres. The process is *in-situ*: it occurs within the material which is intended to be piezo-resistive, at the location where piezo-resistivity is needed. The method we present is designed to be as accessible as possible: All materials and learning resources are easy to find and affordable. Additional documentation can be found in our full paper [4].

Related Work

Organic *Conductive Polymers* demonstrate piezo-resistive behavior. They have been attached to fabric in the form of plastic bands [12], or polymer sheets. Alternatively fabric has also been coated with conductive polymers [2] and piezo resistive fabric can be commercially obtained. Conductive polymers are also increasingly used by the HCI community to create interactive objects. For example, PEDOT:PSS is often used as a conductor, as it can be printed with a traditional printer [6], and can be used for creating micrometer thin interfaces [13]. While PEDOT:PSS has found some use within the HCI community, other conductive materials such as polypyrrole (PPy) or polyaniline (PANI) have received relatively little attention.

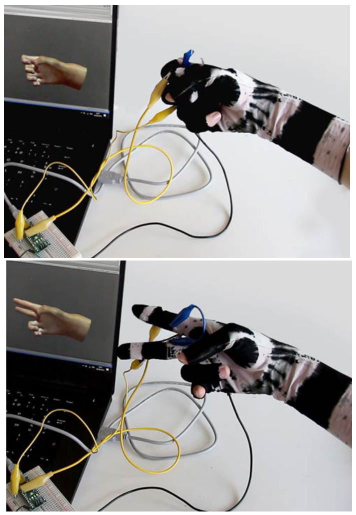

Figure 5: Motion capture gloves

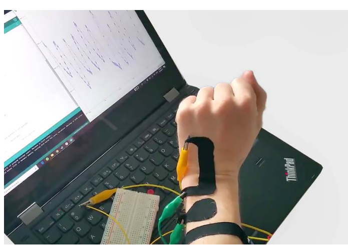

Figure 6: Wrist Movement Sensor for Epidermal UI

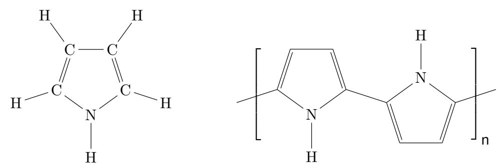

Figure 4: Left: a single pyrrole molecule. Right: Polypyrrole

This is surprising, as PPy is comparatively easy to polymerize. Polymerisation of pyrrole has been used for creating bio-compatible batteries [1, 7] or electrothermal materials [14]. In fact, polymerization of pyrrole is not uncommon in the material-science communities [2]. In our demonstration we show that the process is simple and provide hands-on experience to help others replicated the process.

Polymerization

Polymerization is the process by which polymer chains are created from monomers. For example, when pyrrole (Figure 4, left) is exposed to Iron Chloride, bonds to to the hydrogen atoms are weakened and monomer molecules bind to each other, forming polymer chains (Figure 4, right). These polymer chains – PPy – have a backbone of conjugated carbon-chains. This means that they are intrinsically conductive, as electrons can move along these chains. If other materials are present during this process – such as fabric – the polymer will form in and around these materials. A fabric treated this way takes on the electrical properties of PPy. It becomes electrically functional and can be used as a sensor, heating element, and other circuitry. Instructions on how to polymerize fabric can be found in Table 1. We chose PPy as it is easy to synthesize in a DIY setting. *Iron(III) Chloride (Hexahydrate)* was chosen as oxidizing agent for the polymerization of *pyrrole* to PPy. The Iron(III) Chloride has the additional effect of adding traces of Chloride to the polymer, which increases its conductivity. Pyrrole solution and iron chloride were sourced from Glentham Life Sciences Ltd. The only tools needed are bowls and a mixer for mixing the fabric and other materials, a syringe to measure the pyrrole and a scale for measuring the iron-chloride. For more even results and larger batches, the mixer can be replaced with a small washing machine, for example the DB003 by OnceConcept (∼135€). As the iron chloride water-based solution is slightly acidic, we recommend the use of glass or plastic tools – see also our discussion on limitations. While the specific results are strongly dependent on the textile chosen, there are two main mechanisms by which the conductance of the resulting functionalized textile can be manipulated, independently of the material:

1) Changing the degree to which the fabric is polymerized: If the material is only partially polymerized, the resistance increases. Partial polymerization can be achieved by shortening the duration the fabric is submerged in the monomer bath, after the oxidation agent is added. For increased precision in stopping time, one can reduce the amount of pyrrole and iron-chloride, which slows down the process.

2) Regulating the conductivity of the polypyrrole: Increasing the amount of iron-chloride relative to pyrrole increases the conductivity and decreasing the iron-chloride makes the fabric less conductive. However, this only is effective within bounds. Above a certain level, the effect of adding more iron chloride diminishes, while adding too little iron-chloride might inhibit the polymerization process (see also the formal evaluation by Baptista et al. [1]).

Results

Polymerized objects can take on a variety of functions. For example, using polymerization we create motion capture gloves (Figure 5), epidermal UI's (Figure 6) [11], and Zippers that act as potentiometers, sensing their own state (Figure 7). We are excited to find out what other uses the HCI community will come up with.


Figure 7: A polymerized zipper can sense its own state. When open, the resistance is high because the path travelled is long. When closed, the resistance is low, as electricity can flow through the zippers teeth.

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