Three-dimensional multilayer fabric structures for interactive textiles

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Abstract. The integration of performances in interactive textile fabric system has so far been rather complicated since they are based on multilayer or three-dimensional principles. These structures are today mainly put together by means of several processes, which is laborious and time consuming. In this interdisciplinary study we have combined the principle of a three-dimensional multilayer weaving process and interactive textiles structures in order to enable the manufacturing of interactive textile structure in one process. The process is investigated using a manual reconstructed loom and the approach has been to use the 3D structures in order to integrate and organize conductive and compressive spacer layers as a textile capacitive structure. Measurements on such a structure was done by construction a first order passive high pass filter and using the fabric sample as the capacitor and a 1MΩ resistor. The behavior of the measurement of the capacitive sensor is quite close to the theoretical calculation and already at this stage the structure might be used to indicate the presence of a pressure. In this project we have shown that a three-dimensional structure enables the development of interactive textiles in one process. Further the concept of using a rebuilt manual loom has shown great potential in early research stages. It is considerable saving time and resources since, in this case, it is easy to reconstruct the loom design compared to performing similar reconstruction on a machine. Future research will focus on developing other types of interactive structures. Another issue will be to scale down the size of the structures in order to get thinner and more flexible qualities.

Keywords: Three-dimensional, multilayer, weaving, interactive textiles, textile capacitor

1. Introduction

The integration of multifunctional values in technical textiles has become a special area of interest in recent years. During the last decades textile scientists have expanded from the ability to engineer performance in fibres, to engineer performance in complete fabric systems. The movement towards multifunctional textiles is expected to continue in the next generation of textile structures, so called smart or interactive textiles. These structures combine smart materials and integrated computing power into a new type of fabrics system, the interactive textile structure. The integration of performances in smart textile fabric systems have so far been rather complicated since they are based on multilayer or three-dimensional principles that mainly are put together by means of several processes. This is not only laborious and time consuming but also limits the applicability as some steps typically rely on input made by hand. The challenge of developing genuinely interactive electronic textiles then becomes an issue of scaling up the handmade prototypes into industrial processes.

Until recently the development of weaving looms has focused on accelerating the conventional weaving process [1]. In the last decades groups of researchers has focused on the development of three-dimensional weaving processes. There are various 3D textiles reported such as woven, knitted and braided structures [1-6]. 3D fabrics offer a lot of application possibilities due to a wide range of properties; low area densities, low bulk densities, comfort and thermo-physiological properties, tailor made tensile, elastic compression and permeability properties. 3D fabrics are most notably used in order to create composite structures to replace metal in different kinds of constructions in aerospace, automotive and military applications, with the intention to reduce w with the intention to reduce weight weight without compromising the strength and quality. Other applications are described such as protection for police force or security personnel applications for protective wear. There are also various projects and concepts in tissue research dedicated to the 3D -weave technology [1].

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There are two different approaches in the manufacturing of three-dimensional woven structures. One approach is to produce three-dimensional structures using custom made machines and the other is to produce three-dimensional structures using reconstructed conventional looms [3].

Interactive textile structures are structures exhibiting sensing, actuating and data transfer abilities. By combining these structures with computing technology they are also able to execute measures to enhance their functionality. Such system will have its own unique scenario – determined by the intended function. Interactive textile structures are mainly constructed as multilayered and three dimensional structures in a way that will challenge conventional manufacturing processes. The integration of functionalities in interactive textile systems has so far been rather complex and includes several processes including features of craftsmanship. The challenge of developing genuinely interactive electronic textiles is scaling up the handmade prototypes into industrial processes.

Data transfer structures [7], textile pressure sensors [8] and systems for bio physiological measurements [9][7] are examples of interactive structures based on three-dimensional and/or multilayer principles. A data transfer structures is one of the most basic principles. The structure can be constructed in several ways and in different textile techniques but there are three basic principles that affect the function and use of the data transferring structure, figure 1. The first basic principle is a single layer construction, where the leader is unprotected and available on both sides. The second is a two-layer construction where the conductivity is available from one side and protected from the other. The third is a three-layer construction where the conductivity is placed between two layers and totally protected.

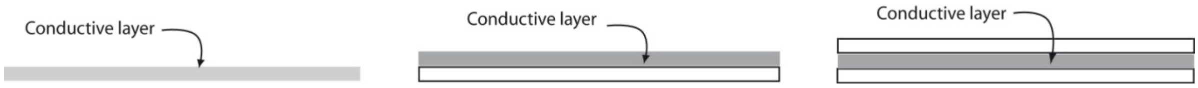

Fig. 1: Data transfer principles

The principle of a press or contact sensor is a structure that is touch or pressure sensitive. This may be achieved based on mechanical operations or capacitive changes to define touch. A common textile capacitive switch is based on two conductive layers separated by a compressible spacer layer, figure 2.

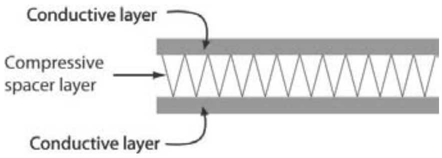

Fig. 2: Capacitive principles

In this project we have used a weaving process where three-dimensional multilayer structures enable the development of interactive textile structure in one process. The weaving method is based on the use of conventional weaving technology by means of a rebuilt loom. In this paper we present a textile capacitive structure made in one process using the 3D weaving technique. The result is a generic capacitive sensor, a textile capacitor, which may be utilized in various application areas.

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2. Methods

In this project, we made a pilot study of the possibility to use this 3D-woven structure as a textile capacitor. The three-dimensional woven multi-layer structure is designed to demonstrate the potential to produce a capacitive textile structure figure 3. The process creates several separate layers designed to fulfil each layers and the applications requirement in one process.

A: Conductive layer
B: Insulating layer
C: Separating layer
D: Insulating layer
E: Conductive layer

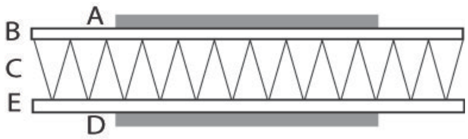

Fig. 3: Schematic representation of the capacitive structure

In the prototyping phase it is time and cost efficient to use a traditional loom and reconstruct it to fit the current project. In order to produce an interactive structure, in this case a textile capacitor, readymade out of the loom (i.e. in one continuous process), a 16 shafted computerised loom were prepared with five warp beams. The control system for the loom was Weave for Windows. The thread settings were 16 thr/cm in warp A, B, D and E. In C the set up was 8thr/cm. The weft consisted of the same polyester and the conductive yarns which were used in the warp set up. The weft settings were prepared as a square setting.

The finalized first prototype of the textile capacitor was evaluated by introducing a 10 kHz signal over a first order high pass filter made using the fabric sample of the textile capacitor and a 1MΩ resistor. The characteristics of the textile capacitor were compared to the ideal.

Two measurements were done. In both cases a load was applied to the fabric sample in order to change the distance between the conductive layers in the sample. The distance was varied from 15 mm to 5 mm. In the first case, *the "first try"*, the sample was supported by two Plexiglas plates. In a second measurement, *the "second" try,* the fabric sample was glued to the Plexiglas to prevent lateral movements of the conductive layers.

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3. Results

A first prototype of a textile capacitor was made using the novel weaving method. The textile structure presented in figure 4 was made in one process using the 3D weaving technique and represents a generic capacitive sensor, a textile capacitor, which may be utilized in various application areas.

The woven structure is made up of conductive layers (A and D of figure 4), insulating and stabilizing layers (B and E) and the middle layer (C) which act as bearing, distancing and insulating layer.

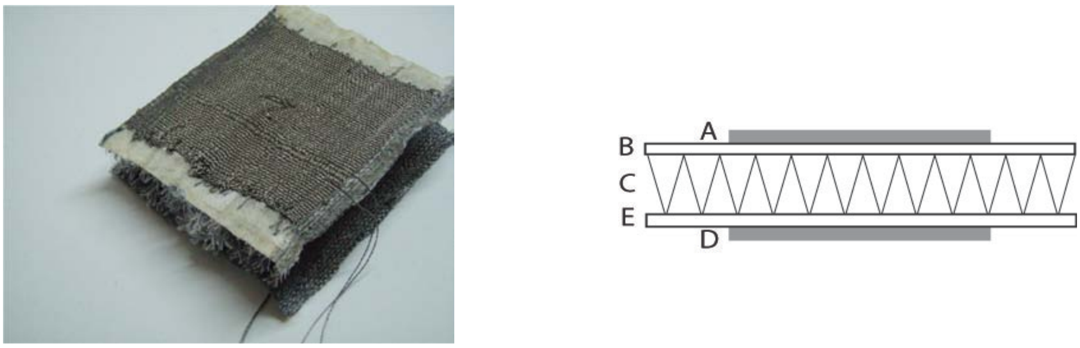

Fig. 4: The 3D woven structure with conductive yarns at the outer layers at specified areas realizes the basic structure of parallel plate capacitor.

The 3D woven structure was finalized as a textile capacitor by connecting the conductive layers to the same type of conductive yarn that was used for the conductive layer, thereby providing the connection terminals of the capacitor. This indicates how the electronic routing can be made in future applications and thus incorporated in the manufacturing process.

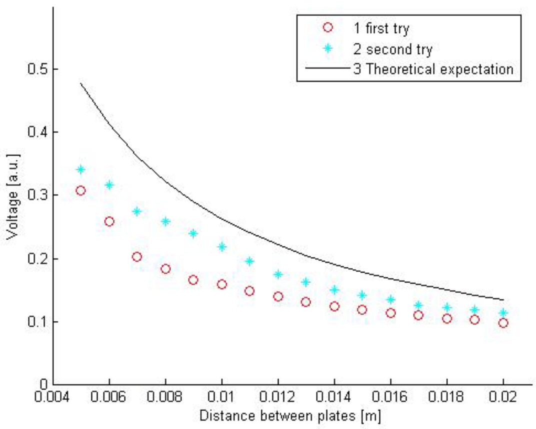

Fig.5: The results of the measurements along with the theoretical expectation.

As can be seen in figure 5, the behavior of the textile capacitor is quite close to the theoretical model, and it is obvious that the structure already at this first prototype stage might be used to indicate the presence of a pressure. As seen in the figure, the *second try* behaves more like the expected one, which can be explained

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by the prevention of lateral movement of the conductive layers. The kink at $d \approx 7$ mm may be explained by non-uniform distribution of the applied load.

4. Discussion

In this interdisciplinary project we have shown that a three-dimensional weaving technique enables the development of interactive textiles in one process. This was demonstrated by realizing a textile capacitor. The behavior of the capacitive sensor is quite close to the theoretical model and already in this first stage prototype the structure might be used to indicate the presence of a pressure.

Several advantages have been achieved thanks to the three dimensional multilayer structure. As demonstrated all of the layers may comprise yarn that provides a certain utility, e.g. conductive yarn, which would lead to a fabric that is associated with electrical properties. These properties may be further utilized by combining them in three dimensional structures. The set-up allows the construction of other interactive textile structures.

Further, the concept of using a rebuilt manual loom has shown great potential in early prototype stages. It is considerable time and resource saving, since it is easy to reconstruct the loom design compared to performing similar reconstructions on a machine.

The 3D weaving process could also be successfully applied in other areas than interactive textiles. An example of that is the possibility to replace conventional laminated material including polyurethane foam in upholstery products, for example office chairs and automotive seats. Being manufactured in one step, the 3D multilayer structure may be collected directly from the machine and brought to use without any further lamination or assembling process. Moreover, by relying entirely on recyclable materials, the final product will be completely recyclable providing an environmental friendly alternative to present laminated polyurethane products.

Future research will focus on developing other types of interactive structures and applications in other areas. Another issue will be to scale down the size of the structures in order to get thinner and more flexible qualities.

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