FUNCTION INTEGRATION - INNOVATIVE KNITTED FABRICS FOR LIFE 4.0

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ABSTRACT

The internet of things (IOT) and industry 4.0 are main drivers for new developments. Consequently the interaction of virtual and real world by smart interconnecting of devices in our everyday life is the basis idea of the Cluster of Excellence "Centre for Tactile Internet with Human-in-the-Loop" (CeTI) at TU Dresden. To enable a user-centric approach in CeTI innovative textile structures, mainly knitted fabrics, and their functionalization by integration of sensors and sensor yarns are under investigation. In the first phase suitable sensor yarns and innovative structures are developed and characterized as a reference for later investigations.

Key Words: SMART TEXTILES, SENSOR YARN, KNIT, E-TEXTILES

1. INTRODUCTION

Today's Internet has created an important infrastructure component for our modern world that touches almost every aspect of our daily lives. The Internet democratises access to information and enables emerging economies to participate in the modern world economy. We are now approaching the next big wave of Internet innovation: the tactile Internet. This means an interaction of humans and/or machines which perceive, manipulate or control real or virtual objects or processes in real time via remote access [1]. The research objective of the Cluster of Excellenz "Centre for Tactile Internet with Human-in-the-Loop" (CeTI) is the development of new interactive solutions for co-working of machines and humans, also considering the psychologically and physiologically learning behaviour of humans and machines. From this, application scenarios are created which are suitable for the development of input and output devices for these kind of interactions. Textiles are very well suited for this purpose as they are especially suited to target close-to-the-body interactions, and can withstand enormous stresses and strains while still being lightweight and highly flexible [2]. The integration of electronics, such as sensor or actors, into the textiles opens up completely new fields of application for textiles. These textiles, known as smart textiles, are also gaining more and more economical importance. To full fill the demands especially knitting technology offers a great potential for production of net-shape smart textiles that offer a high degree of flexibility in terms of functionalization and wearing comfort [3]. One approach in this context is the incorporation of conductive materials into the knitted structures very locally and individually according to the using scenario.

2. STATE OF THE ART

2.1 Knitted smart textiles

In principle, the production of smart textiles is conceivable with all textile processes. Processes such as weaving, warp knitting and nonwoven are generally more economically applicable for the production of flat structures. Other processes, such as embroidery or tailored fibre placement (TFP), are very well suited for local functionalization of a wide variety of textile structures. [4, 5]. However, embroidery is a process in which the textile structure already exists and is functionalized in an separate additional process. For the combination of several materials in one structure, however, the machine must be retrofitted several times and the application process must be carried out separately for each material. The knitting process, on the other hand, has a decisive advantage: it permits the flexible and economic manufacturing of products in batch size 1 but still allowing for local introduction of a wide range of different materials directly during manufacturing process. A wide variety of yarn materials, including conductive materials, can be used in the various yarn systems (machine, weft and warp yarn systems) while at the same time the net shape geometry of a textile structure can be produced directly in one step process [6].

Conductive knitted structures have already been considered by research and industry for some time, e.g. washable capacitive strain sensors based on a silicon matrix, resistive strain sensors made of conductive nylon yarn and silver-coated conductive polymer yarn, piezo resistive breath monitoring sensors, temperature sensors made of copper, nickel, tungsten, Platinum and braided nickel wire, pressure sensors made of copper-coated acrylic cotton yarn, stretchable and washable self-loading power textiles, as electro-myo-stimulation for rehab therapy, electrodes for electrocardiography or resistance sensors made of silver-coated PA 6.6 and merino wool [7 – 9]. Other examples are the direct manufacturing of heating elements [10, 11] or textile switches [12] by integration of conductive materials (cf. Figure 1 a and b).

a)

b)

Figure 1. Overview - smart textiles with integrated conductive yarns a) Stoll Smart Balaclava with heating system in the mouth area [10] b) ProGlove MARK 2 with textile trigger at the side of the index finger [12]

2.2. Textile sensors

Electrically conductive yarns are mainly used for the production of knitted textile sensors. These can be produced in various ways. For example, by coating the yarns with metal, incorporating metal fibres into a yarn, spinning conductive polymers and spinning polymeric nanocomposite fibres.[13].

Knitted textile sensors largely consist of strain, pressure and capacitive sensors, which send signals to a transmission unit by means of a change in resistance or capacitance. It is important to note that when the resistances change, this is first due to structural changes, which then change into a material strain. [14, 15]

2.3. Conclusion of state of the art

There are already many studies and products in the field of smart textiles available. These approaches focus mostly on the integration of yarns mainly as conductive element. A direct integration or manufacturing of sensor modules, additional elements and batteries not only but als from these yarns is not yet possible. This also includes tactile modules which will allow a feedback to the user. So far, just a data recording has been realized that enables only a one-way communication from the smart textile to an e.g. computer, but not a communication in the reverse way towards the user.

Following one long-term research objectives is derived from this and includes development of textile technologies to direct manufacture or integrate additional modules during the textile manufacturing process and thus e.g. the introduction of tactile modules for mutual communication between smart textile and humans.

3. EXPERİMENTAL PLAN

The above mentioned above-mentioned long-term research objectives is devided into different phases as listed with the respective research object in Table 1. The work on the phases overlaps in some areas.

Table 1. Overview of project phases

	object of investigation	
	yarn level	**structure level**
1. phase	- electrical behavior of single yarns - - change of electrical behavior when the yarn is subjected to stress	- electrical behavior of yarn within the structure depending on the binding element (loop, tuck stitch, miss stitch, weft inlay, warp yarn) - textile bindings (single jersey, double jersey, interlock, spacer fabrics) - flat structres (partly) out of sensor yarn
2. phase	- Connection of the sensor yarns among each other (e.g. by knotting, soldering,...)	- flat structures with integrated holding positions for additional modules and placing of yarn ends for contacting - 3D-structures with the integration of sensor yarns -connection of electronic components and sensor yarn (yarn ends) of flat and 3D-structures
3. phase	- connection of electronic components and sensor yarn while manufacturing process	- integration of additional modules into the manufacturing process

4. MATERİALS AND METHODS

In the framework of the research on integration of yarn-based sensors into smart textiles, the ITM at TU Dresden is continuously investigating electrically conductive yarns with regard to their suitability for use in such sensor structures. As described in chapter 3, for futher investigations it is important to deeply understand the electrical behavior of single yarn, which is therefore first priority of the investigations. The aim is constantly expanded this investigations to be able to set up material library for lateron easen the process of selecting a suitable yarn depending on the application. As an example, two suitable yarns are listed in Table 2. T1 is a silver coated polyamide, which is suitable for knitting. T2, a carbon black filled silicone yarn, is suitable for interlining as weft or standing yarn.

Table 2. Properties of the examined sensor yarns from the data sheets [16, 17]

	T1	**T2**
base material	polyamide	silicone
conductive material	silver	carbon black
type of conductive modification	coated	filled
yarn count	272 dtex	4000 dtex

electrical resistance	500 ± 100 Ω/m	< 200 Ω/m

5. EXPERIMENTS

5.1. Knitting tests

As mentioned in chapter 3, the possibilities of integrating sensor yarn into flat and 3D structures is deeply investigated (Figure 2). Within the flat structure, the yarns are inserted into the structure as a separated area, using inlays or plating technology, or as weft or warp yarn. The integration will be investigated by means of different binding elements (loop, tuck stitch, miss stitch, weft inlay, warp yarn). In the later course of the project a connection between these binding elements and the determination of the influence on the conductivity of the structure will follow.

a) b)

Figure 2. samples of textiles with integrated sensor yarn a) into a flat structure b) into a 3D-structure

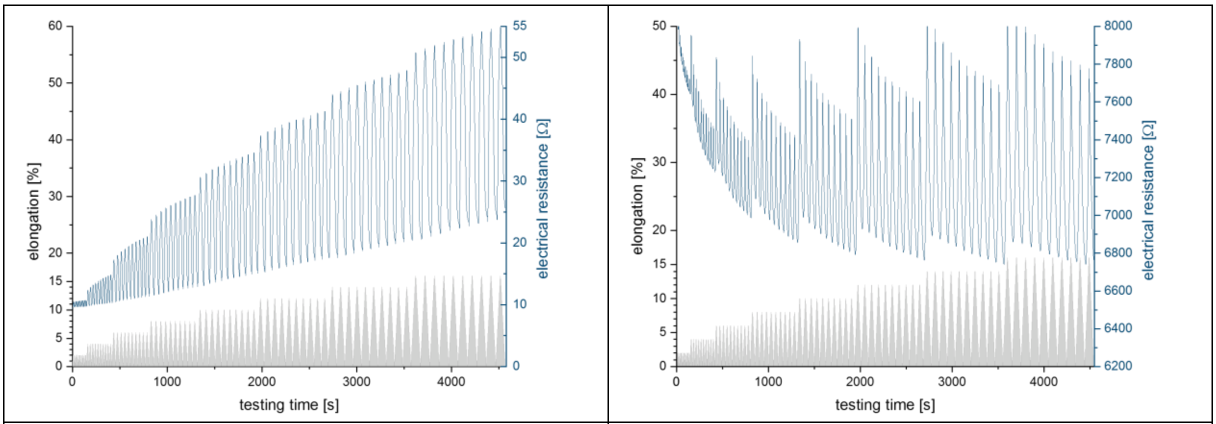
5.2. Analysis of mechanical and electromechanical properties

A combination of commercially available mechanical tensile testing machines from ZwickRoell GmbH & Co. KG and a precision laboratory multimeter type Fluke 8846A were used to investigate the electromechanical properties of sensor yarns. In the first phase of the project, the electrical behavior of the single yarns is measured as base for later setting up of complex networks. These investigations are done using specimens in relaxed and in pre-stretched state during a cyclic tensile test.

6. RESULTS

Figure 3 shows exemplarily the results of the electromechanical yarn characterization of the yarns T1 and T2. As can be seen from the figure the maximum elongation was rised after every 10th cycle. The yarn T1 is explicitly marketed by its manufacturer as a sensor yarn for large elongations. The measured value of T2 is well above the manufacturer's specification. This can be justified by the fact that the manufacturer has not assigned this value to any gauge of the yarn. The value of T1 is within the range of the manufacturer's specification.

It can be seen that the response signal of T1 in the relevant strain range of 0 - 15 % generated significantly enhanced correlation and a more reproducible sensor. There was a smaller drift of the sensor signal compared to T1. Since T2 is apparently designed for even larger elongation ranges (of up to 40 %), T1 was selected as sensor yarn for the introduced experiments.



a)	b)

Figure 3. Results of elctromchancial yarn characterization a) yarn T1 and b) yarn T2 (0 - 16 % elongation)

7. OUTLOOK

Within the scope of the first investigations, sensor yarns were tested for their conductivity and processability. These investigations will be continued in order to classify as many sensor yarns and wires as possible. Furthermore, as in chapter 3, the structures are investigated to classify the influence of binding elements and types on the electrical resistance.Within the scope of the first investigations, sensor yarns were tested for their conductivity. These values serve as a reference in the further course of the project. In addition, the knitability of the sensor yarns listed above will be investigated. For this purpose, the yarns are inserted both as inlays and as a stand-up weft yarn combination. In addition, the extent to which the binding elements loop, tuck stitch, miss stitch, weft inlay and warp yarn and binding typs like single jersey, double jersey, interlock and spacer fabrics have an influence on the resistances is investigated. Furthermore, different conductive yarns and wires are examined and tested for processing characteristics (which have already been determined at ITM in initial investigations [20]). In addition, a test method is being developed to simulate the load of the textile on the resistance.

In the later project process, the sensor yarns will also be inserted into textiles in order to complete functional tests.These are to be used to control robots, to support the learning of an instrument or to support movement therapies of patients with limited mobility.

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