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Design of an Electronic Chest-Band

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Abstract. In this study, an electronic chest strap prototype was designed for measuring fitness level, performance optimization, mobility and fall detection. Knitting technology is used for production by using highly elastic nylon yarn. In order to evaluate comfort performance of the garment, yarn strength and elongation, air permeability, moisture management and FAST tests (Fabric Assurance Fabric Testing) were carried out, respectively. After testing of textile part of the chest band, IMU sensors were integrated onto the garment by means of conductive yarns. Electrical conductivity of the circuit was also assessed at the end. Results indicated that the weight and the thickness of the product are relatively high for sports uses and it has a negative impact on comfort properties. However, it is highly stretchable and moisture management properties are still in acceptable values. From the perspective of possible application areas, developed smart chest band in this research could be used in sports facilities as well as health care applications for elderly and disabled people.

1. Introduction

Electronic textiles (E-textiles) are subpart of smart textiles. They are also referred to as 'wearable electronics' as e-textile products are different from conventional fabrics in that analogue and digital electronic components —for example, small computers—are (more or less) seamlessly integrated into the knit, weave or other soft crafts technique [1-2]. Textile materials are seen as the most convenient interface for implementation new sensorial and interactive functions due to the 80% coverage of the skin as clothing. Functions such as sensing, transmission, and energy generation could be implemented via textile technology into a garment. In the production of these e-textile garments, functional yarns and fibers could be used so that electrical and computing properties are combined with the traditional mechanical characteristics of fabrics [3]. To design an e-textile product requires a multidisciplinary team work so that the clothing designer of e-garments usually are one of a team including textile technologists, garment engineers, electronics experts, biologists, multimedia experts and computer scientists. However, the economic potential of wearable technology is enormous and there are still several ongoing researches and projects to develop commercial innovative products [4-6].

The aim of this research is to design and manufacture an electronic sportswear chest band. By this purpose, a smart chest band prototype was developed by a team consisting of textile engineers and computer scientists. Fabric and yarn performance tests were carried out for comfort assessments. The sensing unit and other possible application areas of the garment were also specified at the end.

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2. Designing and Manufacturing of E-Chest Band

Designing of an electronic textile garment requires a comprehensive research on both existing market products and recent developments in the literature with focusing on design requirements for an electronic apparel and wearable sensors.

2.1. Literature Research and Fundamental Design Issues

Electrical conductivity is the main physical property that is capable of transforming a textile material into a sensing material and that plays a significant role in the development of e-textile garments. In traditional textile production, metal components in the form of fibers, filaments, or particles are typically used for technical applications [3, 4, and 6]. Various stable products based on silver have appeared on the sportswear market in the last decade [7-8] and have been used for sensing applications, such as the women's SuperNova Seamless Glide bra by Adidas and the H2 heart rate sensor by POLAR. Another important requirement property for sensing applications is elastic recovery of the fabric, which is the consequence of combined use of elastic and functional fibers. Sports garments are usually made of fine knitted fabric that consist of 75%-80% polyester or nylon and 20%-25% elastomeric filaments which stretch and recover back to their original shape during physical movements of the body [3-9]. For textile carriers, comfort for the duration of the activity is critically important. The key requirements for comfort are fit, feeling on the skin, effective moisture and temperature management and protection against the environment. Wash ability, cost, design, manufacturability and durability are also other significant design issues [10-14]. In terms of safety, the major challenge in wearable electronics is that the wiring necessary to carry an electric current to the components may be quite power-hungry. Components should be protected against shorts or breakage, and should not become entangled during wear or unnecessarily inconvenience the wearer. After safety concerns, the electronic sensing system must be creatively incorporated into apparel in unobtrusive ways while remaining durable enough to withstand normal wear and tear and cleaning procedures. At the very base level wearable sensors must be comfortable to wear during activity and at rest [12]. The wearalibity of electronic garment also should be considered for designing a product. The guideline parameters for wearalibity can include placement, shape, movement, perception of space, sizing, body diversity, attachments, containment, weight accessibility, sensory interaction, thermal, aesthetics and long-term use [10, 15 and 16].

2.2. Market Research on Electronic Chest Bands

Nowadays, consumers becoming health-conscious are focusing on tracking their own health. Chest straps are very common for both men and women. They are generally about an inch or two wide, worn just under the breast. The most common chest straps in the market are heart rate monitors, which usually comprise two elements: a chest strap transmitter and a wrist receiver (which usually doubles as a watch) or mobile phone. While heart rate is generally measured by separate chest straps, these can be also integrated in a T-shirt or bra. Other physiological parameters of interest may be skin temperature or skin humidity. Estimations of sweat rate might be useful to indicate optimal fluid intake during sports activities. Additionally, sport clothing can be equipped with angle sensors for measurement joint angles during sports activities. So, the amount of overstretching can be monitored, and preventive measures can be taken when required [9, 17].

In terms of use specifically for sports, Table 1 gives a brief summary of the main commercially developed sensorised chest-straps. As seen from the table, cardiac data is the most monitored physiological parameter. Cardiac Data (Heart Rate), breathing, accelerometer (Posture, Activity Level, Peak Acceleration, and Speed), GPS, temperature, and calories can be measured through a chest band depending on the sensing unit [19].

Table 1. Commercially developed wearable sensors for chest-straps [18-21].

Product Brand	Manufacturer	Format	Measurements
miCoach	NuMetrex/ Textronics Inc./Adidas	Bra, chest strap, tank top, men's shirt	Heart rate
BioHarness 3	Zephyr Technology Corp.	Chest straps	Cardiac data, breathing, accelerometer (posture, activity level, peak acceleration, speed), GPS, temperature, calories
Polar Soft/ Polar WearLink	Polar Electro	Chest straps	Heart rate
Sigma-R1-Comfortex	Sigma Sports	Chest straps	Heart rate

2.3. Manufacturing of an Electronic Chest Band
According to design criteria above, a chest band was designed and a prototype was produced by knitting technology on a Stoll CMS340TC 12-gauge machine. The selected yarn for production is a special elastomeric yarn. It has a special construction, comprised elastomer in the core and 3 x nylon filaments around. The knitting structure of chest band was chosen as tubular single jersey due to the good wicking and moisture management properties. Manufactured chest band is seen in the Figure 1.

Figure 1. Chest band as a textile carrier.

IMU (Accelerometers + Gyroscope) sensors were chosen to use to integrate into the chest band focusing on fall detection of users. Accelerometers are the most common wearable sensors. They are small in size and cheap; they can be easily placed in any part of the human body. As a conductive yarn, silver plated nylon with a linear resistance of 50ohm/m was chosen because of conductivity, manufacturability, and textile handling properties. For e- textile transmission, a circuit was designed by sewing conductive yarn on the chest band. The circuit's elements and the designed circuit are shown in the Figure 2. Data transmission can be supplied by Bluetooth in this system.

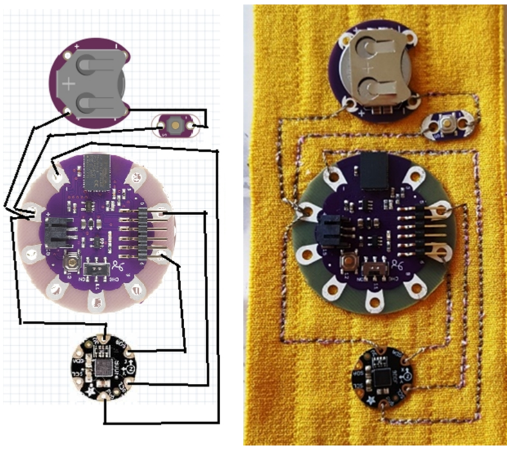

Figure 2. Circuit design and sensors on the garment.

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3. Testing of Chest Band

In order to evaluate comfort properties of the textile carrier of the product, Tensile Strength and Elongation of Yarn (BS EN ISO 2062:1995), Air Permeability (BS 5636:1990), Moisture Management (AATCC 195) and FAST Tests (Fabric Assurance Fabric Testing) were carried out.

3.1. Tensile Strength and Elongation of Yarn

Tensile strength and elongation of yarn was tested by INSTRON 3345 device and a software according to BS EN ISO 2062:1995 standard. Findings could be seen in the Figure 3.

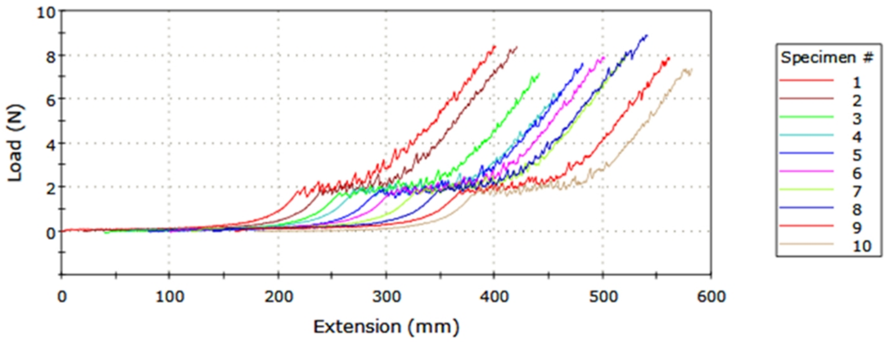


Figure 3. Tensile Strength and Elongation of Yarn Test Results.

As seen from the results, Elongation of yarn was found around 400 %, which is highly suitable for a compression garment as it leads to better stretch fabric.

3.2. Air Permeability Test

The air permeability of the fabric was determined by SDL ATLAS M021A test device with a pressure applied of 200 Pa, according to BS 5636:1990. Five samples ran for this test. All results are demonstrated on Table 2.

Table 2. Air Permeability Test Results

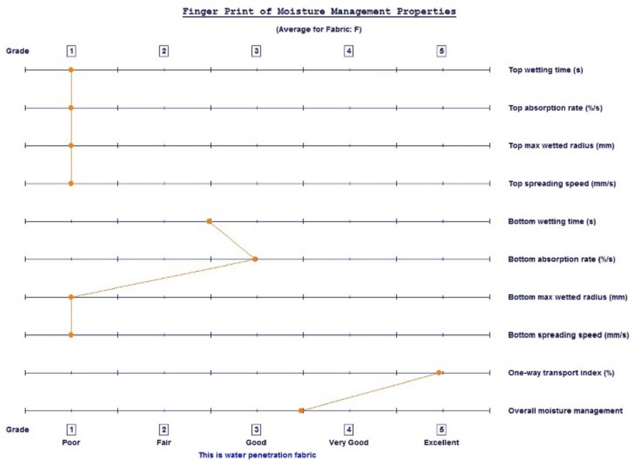
Sample No	Air Permeability values ($l/m^2/s$)
1	56
2	52
3	53
4	52
5	54
average	56,4

Results showed that air permeability of fabric is quite low due to the high fabric weight and thickness.

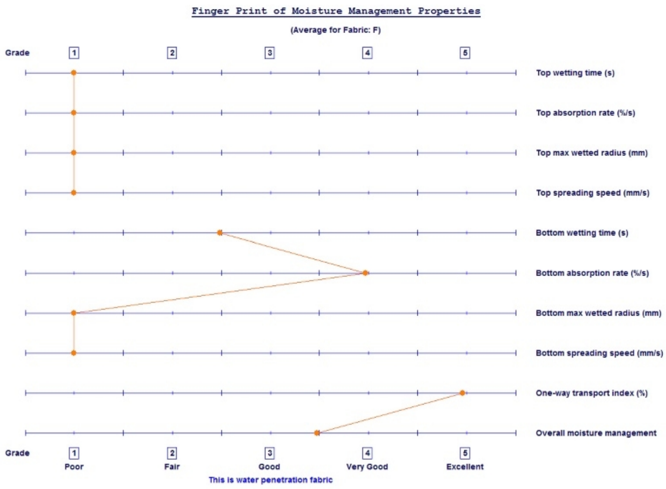
3.3. Moisture Management Test (MMT)

Moisture Management test was performed by SDL ATLAS M290 MMT test device according to AATCC-195 test standard. Three samples were used in this test. Figure 14 shows all the fingerprints and classification test results. As seen from the Figure 4, top wetting times and bottom wetting time values are quite low and absorbing rate is medium. This could be as a result of high fabric thickness and weight. However, overall moisture management was found as 3.5/5 for all three samples, which indicates that the fabric is in the category of very good liquid moisture management fabrics.

(a) Sample 1



(b) Sample 2



(c) Sample 3

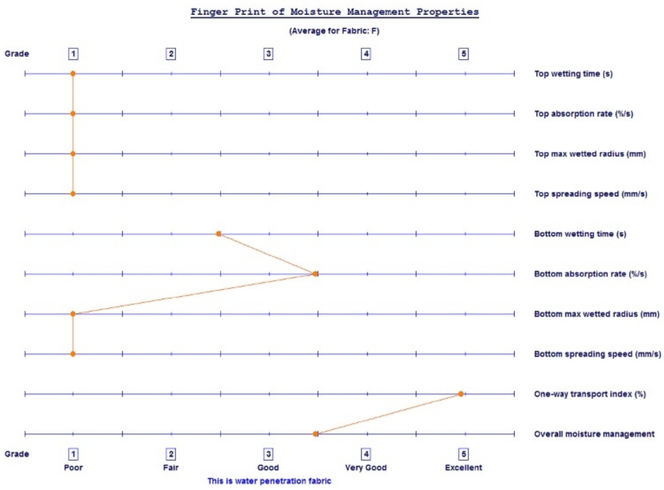


Figure 4. Fingerprint of the evaluation indices and the classification result.

3.4. *FAST Test*
Fast is a simple system of fabric objective measurement for assessing aspects of the appearance, handle and performance properties of fabrics. FAST-1 Compression meter, and FAST-3 Extension meter were used to evaluate samples.

3.4.1. Compression Meter. FAST-1 consists of a compression meter which measures fabric thickness at two predetermined loads. The pressure at which thickness is measured is controlled by adding weights (2 g and 100 g) the measuring cup. Five samples were performed in this test. The thickness results are shown on Table 3.

Table 3. Fabric thickness results in FAST-1

Sample	1	2	3	4	5	Average
T2	3,593	3,404	3,503	3,391	3,615	3,5012 mm
T100	2,478	2,365	2,59	2,541	2,545	2,5038 mm

3.4.2. Extension Meter. FAST-3 is an extension meter which operates on a simple level principle. By removing weights from the counterbalancing beam, the extensibility of the fabric can be measured at 3 different loads, thereby simulating the kind of deformation of the fabric is likely to undergo during garment manufacture. Three samples were performed in this test. The extension results are shown on Table 4. Extension values are suitable for highly stretchable sport garment.

Table 4. Fabric extension results in FAST-3

Warp Direction					
Sample	**A**	**B**	**C**	**Average**	
E5	1,30	1,20	0,60	1,03	%
E20	9,40	9,10	8,20	8,90	%

4. Conclusion

In this study, a smart chest band was designed and manufactured. In order to obtain highly stretchable fabric structure, highly elastic special elastomeric nylon yarn was chosen for knitting. The electronic components such as IMU (Accelerometers + Gyroscope) sensors were then integrated onto chest band via sewing method using silver plated conductive yarn for mobility and fall detection. The developed chest band was evaluated in terms of comfort properties. Therefore, Tensile Strength and Elongation of Yarn, Air Permeability, Moisture Management and FAST Tests (Fabric Assurance Fabric Testing) were performed. Although, the thickness of the product seemed to be a negative factor, overall moisture management results was still in the category of good liquid moisture management fabrics. However, the research is still undergoing to test its mobility and fall detection performance. This study therefore only summarizes the preliminary design architecture of electronic chest pad with its comfort properties.

Beside usage in sports, this multipurpose design allows the item to be used in various application areas, such as an underwear, medical purposes for elderly people. In addition, it can be also suitable for disabled people by its easy to wear and easy to wash properties.

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