Fabric Selection for Textile Moisture Sensor Design

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***Abstract* – In order to improve the sensor comfort properties, a modular sensor should be replaced with an embroidered textile sensor. In this paper, quality and comfort properties of a moisture textile sensor have been studied. The speed of moisture sensor signal detection significantly depends on textile substrate wettability; therefore, the study of textile material wettability and moisture management properties has been carried out.**

Keywords – quality, comfort, textile moisture sensor, wettability

I. Introduction

The use of wearable sensors for monitoring of various health-related biometric parameters during daily activities has attracted increasing interest recently [1]. One of wearable sensor types is a moisture sensor that measures body fluids, such as blood, sweat, and urine. Sensors can be used in different fields of application. One of possible applications is medicine, where the health of patients can be controlled by, for example, monitoring of blood leakage or treating nocturnal enuresis.

In order to improve sensor comfort properties, a modular moisture sensor should be replaced with a textile sensor, which can be embroidered with conductive yarns on fabric. Conductive yarns are a preferable material for such sensors, since they blend with the textile structure of underwear and bed sheet, inducing less stress on the treated person. During the design of the textile moisture sensor, it has been found that the speed of sensor signal detection depends not only on conductive yarn parameters and distance of electrodes, but on textile substrate wettability, as well. Therefore, it is necessary to study textile material wettability and moisture management properties in order to determine an optimal textile material that would be suitable for the sensor, satisfy comfort properties of the sensor and provide a fast enough operation of the sensor.

II. Operation of Textile Moisture Sensor

Moisture sensor consists of two single electrodes with a gap between them. Liquid presence is signalled when there is an electrical connection between the two electrodes induced by the contact with a conductive liquid. The operation of textile moisture sensor is shown in Fig. 1.

While designing the moisture sensor on the textile substrate, its wettability and moisture management is especially important. It has direct impact on the speed of sensor signal detection – how fast the drops of liquid will be absorbed and spread through the fabric surface, forming contact between the two electrodes.

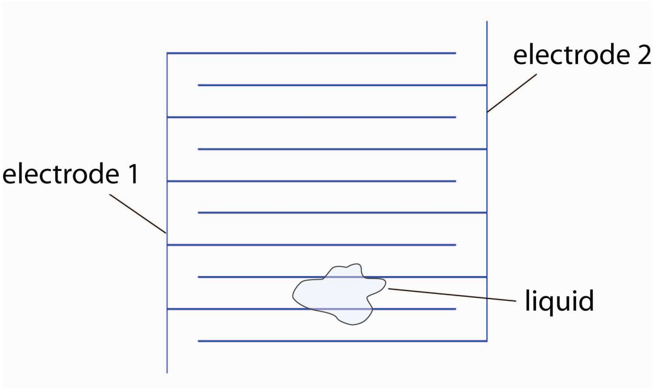


Fig.1. Operation of textile moisture sensor

III. Wettability of Textile Substrate

Wettability and moisture management depends on many factors, so that it is quite difficult to mention a specific type of fabric that is most suitable for moisture sensor application. The transportation of liquid into yarns and fabrics may be caused by external forces or capillary forces, i.e., wicking. This property can be characterized by wettability of textile fabrics. Wettability of fabric depends on fibre characteristics, as well as on fabric surface properties and specific characteristics of fabric manufacturing. Absorption of moisture is affected by yarn texture, chemical properties of fibre surface, geometrical properties of fibre, type of weave and construction parameters, variations in interlacing, capability and moisture absorbency of fibres, geometric configurations of the pore structures (pore size distribution and fibre diameter), viscosity and density of the fabric surface. Wicking increases with the rise in viscosity of the liquid and decreases with the increase in the surface tension of the liquid, capillary radius, and contact angle. Surface energy of a textile structure is important, as well. Surface energy determines the inherent ability of a material to interact with another material, and the contact angle is the result of such interaction. The fabric surface energy is largely dependent on the structure of the fibre, as well as on the yarn, fabric, capillary forces, cover factor, area density, level of projected fibres, and surface roughness. The surface energy of fabric is influenced by the finishes, which react with the fibres or self-cross link on the fibre surface, and the residual content of salt or catalyst is used. Moreover, the alkaline or acidic bath used in finishing also affects the properties of fibres and roughness of the fabric surface [2-6].

There are two facets to the absorption of water:

- total amount that can be absorbed regardless of time;
- The speed of uptake of the liquid.

In this case, the second aspect is important, which can be tested by wettability test using standard BS 4554:1970 (method of test for wettability of textile fabrics). Wettability is defined as the time in seconds for a drop of water to sink into the fabric. Fabrics that give time exceeding 200 seconds are considered unwettable [7].

Since the moisture sensor is provided for integration into the bed sheet or underwear, it is necessary to select appropriate fabric what would be suitable for this application.

Usually cotton and linen fibre fabrics are used for bed linen due to the following fibre properties:

- good absorption of water and vapour;
- good air permeability;
- good thermal conductivity;
- influence of rather high temperatures is allowed during washing and ironing.

Fabric crumpling is one of the main drawbacks of linen fibre fabric that makes it difficult to care. Nowadays the improving technologies of synthetic fibre production are used for mixed-fibre material of bed linen. Likewise cotton, textured synthetic filament yarns absorb moisture very well, but the water returns to the environment more rapidly. The presence of synthetic fibre reduces the crumpling of fabric. The most common material used for bed linen is cotton and polyester blended fabric. Polyester fibres have all of the properties of synthetic fibres. One of negative polyester fabric properties is fabric pilling during usage.

The majority of bedding fabrics are manufactured in plain weave; satin weave fabrics are used, as well. Often plain weave is combined with satin weave for bedding fabrics, forming longitudinal bands [8].

Fabrics must be safe for health, they should conform to hygienic properties; they cannot contain toxic elements and other chemicals that are hazardous for the health and environment. Important factors are washability, visual appearance, smoothness and long-wearing [9]. Quality standard LVS EN 14878:2007 "Textiles – Burning Behaviour of Children's Nightwear – Specification" [10] defines fire safety terms for children nightwear that is related to burning behaviour of fabrics. Other regulations, which limit the usage of specific fibre fabrics for children nightwear or bed linen, have not been found. Different knitted fabrics are used for children nightwear/underwear. Different fibres can be used in fabric composition – natural fibres (cotton, wool, merino wool) and chemical fibres – cellulose fibres (viscose), synthetic fibres (acryl, polyester, polyamide, polypropylene).

IV. Materials and Methods

Wettability of different textile substrates for the moisture sensor has been tested according to standard BS 4554: the fabrics of natural fibres (cotton, linen), synthetic fibres (polyester) and mixed fibres (cotton and polyester). During the tests, the specimens have been clamped onto frame, so that they have been held tight and away from any surface as shown in Fig. 2.

A burette with a standard tip size has been clamped 6 mm above the horizontal surface of the sample. The fabric has been illuminated at an angle 45° and viewed at 45° from the opposite direction, so that any water on the surface reflects the light to the viewer. At the beginning of the test, a drop of liquid is allowed to fall from the burette, and the timer is started. When the diffuse reflection from the liquid vanishes and the liquid in no longer visible, the timing is stopped [7]. Fifteen areas of each specimen have been tested. In total, twenty samples of different fabrics have been tested; results are presented in Table 1. Fabrics are used for bed linen.

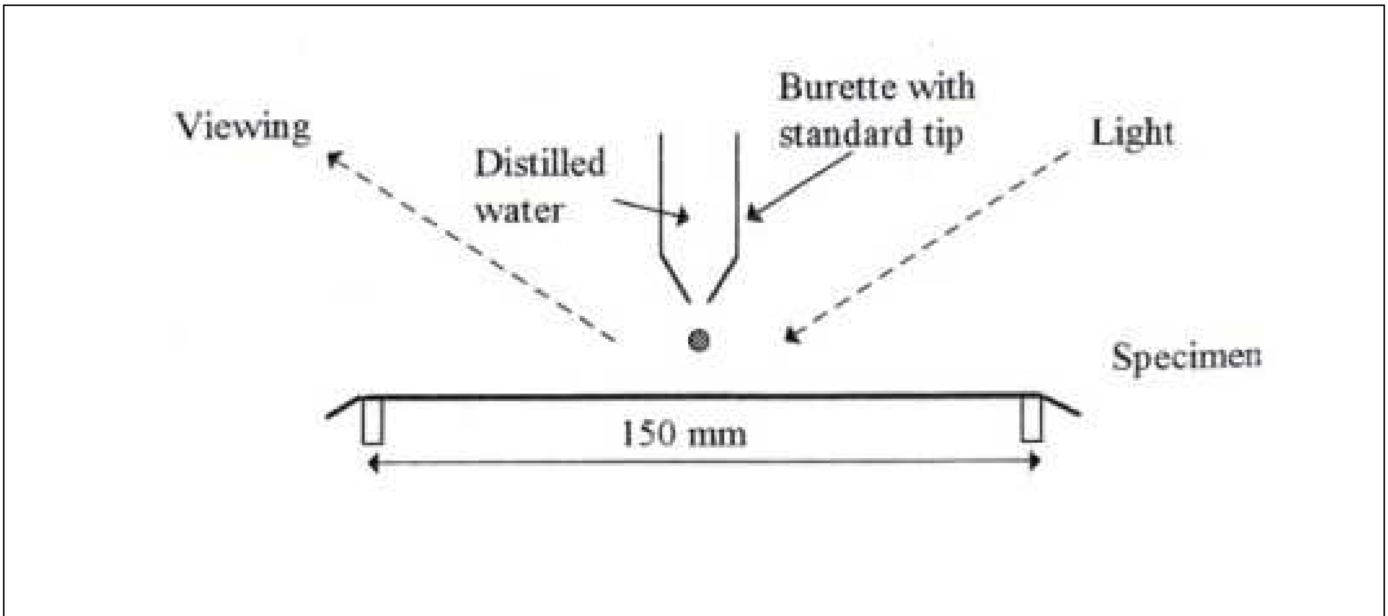


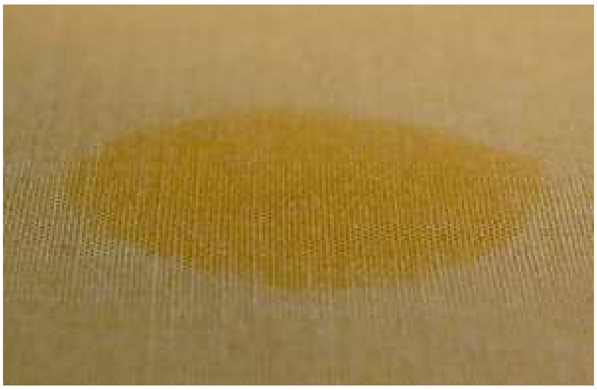
Fig. 2. Test of wettability [10]

TABLE I
RESULTS OF WETTABILITY TEST

Composition of fabric	Code	Mass per sq.meter, g/m^2	Thickness, mm	Type of weave	Wettability, max/min, s	Wettability, average, s	Wet area, cm (warp/weft)
Cotton 100%	C1	139.3	0.40	plain	26 - 57	40.5	3.3 / 2.9
Cotton 100%	C2	126.8	0.28	twill	140 - 357	185.9	3.5 / 3
Cotton 100%	C3	158.1	0.80	plain	-	<1800	-
Cotton 100%	C4	54.5	0.29	plain	266 - 445	340.4	2.3 / 2.3
Cotton 100%	C5	65.8	0.27	plain	-	<1800	-
Linen 100%	L1	125	0.32	plain	34 - 84	57.1	3.4 / 2.3
Linen 100%	L2	179.5	0.42	plain	375 - 695	527.0	2.3 / 3
Linen 100%	L3	160.6	0.35	plain	51 - 93	67.8	3.8 / 2.,6
Linen 100%	L4	116.6	0.31	plain	89 - 145	113.8	3.8 / 3.3
Linen 100%	L5	197.4	0.46	plain	-	< 1800	-
Polyester 100%	PE1	111.5	0.27	plain	-	< 1800	-
Polyester 100%	PE2	88.3	0.25	plain	72 - 165	105.6	7.8 / 2.8
Polyester 100%	PE3	214	0.81	twill	55 – 105	80.2	1 / 2.5
Polyester 100%	PE4	130.3	0.32	plain	151 - 606	241.9	3.4 / 3.4
Polyester 100%	PE5	207.6	0.55	plain	252 - 1431	903.8	1.8 / 1.8
Polyester 100%	PE6	311.1	0.66	twill	1 – 1	1.0	1.6 / 2.1
Cotton 50% / Polyester 50%	Co/PE 1	125	0.29	plain	8 - 12	9.7	4 / 4
Cotton 50% / Polyester 50%	Co/PE 2	126.8	0.30	plain	-	< 1800	-
Cotton 50% / Polyester 50%	Co/PE 3	88.1	0.25	plain	452 - 965	712.8	3.3 / 2.3
Cotton 50% / Polyester 50%	Co/PE 4	117.8	0.30	plain	-	< 1800	-

As shown in Table 1, water absorption for different fabric samples of identical fibre composition can vary greatly – from excellent to weak. Relationships exist between variables: mass per square meter and thickness – correlation coefficient is 0.74. On the other hand, correlation of wettability with both abovementioned factors is very weak or it does not exist – correlation coefficient of wettability and thickness is

a



b

Fig.3. Surface energy of different textiles – a: cotton 100% (C3); b: cotton 50% / polyester 50% (Co/PE 1)

0.02, correlation coefficient of wettability and mass per square meter is negative -0.16. Therefore, it can be concluded that final finishing of textile has a very important role, which can influence properties of fibres and surface energy of a textile structure. Fig. 3 shows the condition of different fabric structures (cotton and cotton / polyester) 10 seconds after the drop of water falling onto the sample surface.

Not just the speed of absorption is important for the moisture sensor, but also the size of area impregnated with moisture – the larger the area, the faster the contact occurs between electrodes. Moisture spread varies in samples, both in warp and weft direction, and with evident predominance. For example, in one sample moisture spread area is 7.8 cm in warp direction and 2.8 cm in weft direction.

The fastest absorption of moisture (1 sec) has been achieved with polyester fabric sample PE6, but it has quite small size of area impregnated with moisture (1.6 / 2.1 cm). One of the best results has been achieved in cotton and polyester blended fabric sample Co/PE 1, which absorbs moisture rather fast (9,7 sec) and shapes quite large size of area impregnated with moisture (4/4 cm).

One sample made out of thermoactive knitted fabric has been tested, its composition is polypropylene 34%, polyester 60.2%, elastane 5.8%, mass per square meter 266g/m^2 and thickness 1.06 mm. The sample has had good wettability results – on average, moisture has been absorbed in 10.5 seconds. In this case, we cannot compare knitted and weaved fabrics by wettability, because it is necessary to make more tests with knitted fabric samples.

V. Sensory Comfort

Sensory comfort is concerned with feeling when fabric or garment is worn next to the skin. In paper [7], some factors are mentioned contributing to sensorial comfort: tickle, prickle, wet cling, warmth to touch. They can be referred to bed sheet and underwear sensors as well; however, the following comfort properties are the most significant:

Surface relief. The side that is located next to the skin should be as smooth as possible to avoid making it discomfortable for a wearer – irritation or marks on the skin. Therefore, in sensor designing it is relevant to notice weave of textile surface and fineness of conductive yarn. After sensor embroidering the thickness of fabric (0.4 mm) has increased approximately two times (+101% on average) using finer silver coated yarns (110/34 dtex 2ply) and approximately two and a half times (+166%) using rougher silver coated yarn (235/34 dtex 4ply) (Fig.4).

a *b*

Fig.4. Sensor surface: a – rougher conductive yarn; b – finer conductive yarn
Embroidery by U.Briedis

In this case, thicker yarn has better electrical properties, but it is not so good for comfort comparing to a thinner yarn. Thus, when projecting the sensor it is necessary to find a compromise between yarn electrical properties and the comfort level of garment.

Surface isolation. To protect sensors from abrasion and to improve sensor and skin sensory comfort, it is necessary to isolate the sensor surface. Isolation layer must be moisture permeable to avoid decrease in the operation effectiveness of the sensor. To provide tight contact between two layers, it is necessary to connect electrode traces with stitching.

VI. Conclusions

In the designing process of moisture sensor on textile substrate wettability and moisture management of fabric is especially important. It has direct impact on the speed of sensor signal detection – how fast the drops of liquid will be absorbed and spread through fabric surface, forming contact between the two electrodes. In wettability experiment different fabric samples have been tested (20 samples in total). For next sensor designing experiments, cotton and polyester blended fabric sample (Co/PE1) has been selected, which absorbs moisture rather fast (9.7 sec) and shapes quite large size of area impregnated with moisture (4/4 cm). This fabric is used for bed linen, so it is suitable for the bed sheet sensor designing.

In further experiments, moisture sensors will be designed with surface isolation to protect the sensor from abrasion and to improve the sensor and skin sensory comfort. It is necessary to find suitable material for an isolation layer.

VII. Summary

The use of wearable sensors to monitor various health-related biometric parameters during daily activities has attracted increasing interest recently. In order to improve the sensor comfort properties, a modular sensor should be replaced with a textile sensor, which can be embroidered with conductive threads on fabric. In this paper, the quality and comfort properties of moisture textile sensor have been studied. The speed of moisture sensor signal detection significantly depends on textile substrate wettability; therefore, textile material wettability and moisture management properties have been studied in order to determine optimal textile material that would be suitable for a sensor, would satisfy comfort properties of a sensor and would provide fast enough operation of a sensor.

Wettability and moisture management depends on many factors, so it is quite difficult to mention specific type of fabric that is most suitable for moisture sensor application.

Since the sensor is intended for integration into bed sheets or underwear, appropriate fabrics have been studied that are used for this purpose.

Wettability of different textile substrates for the moisture sensor has been tested according to the standard: fabrics of natural fibres (cotton, linen), synthetic fibres (polyester) and mixed fibres (cotton and polyester).

Quality and comfort characteristics have been evaluated from sensory comfort position, highlighting surface relief and surface isolation properties.

In the experiment on wettability 20 samples of different fabrics have been tested. For next sensor designing experiments, cotton and polyester blended fabric sample has been selected that absorbs moisture rather fast (9.7 sec) and shapes quite large size of area impregnated with moisture (4/4 cm). In further experiments, moisture sensors will be designed with surface isolation to protect the sensor from abrasion and to improve the sensor and skin sensory comfort.

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Inese Parkova, Inese Ziemele, Ausma Viļumsone. Pamatmateriāla izvēle tekstila mitruma sensora projektēšanai.
Valkājamu sensoru izmantošana dažādu ar veselību saistītu biometrisku parametru kontrolei ikdienas aktivitāšu laikā piesaista aizvien lielāku interesi. Lai uzlabotu sensoru komforta īpašības, tradicionālie moduļa tipa sensori ir jāaizstāj ar tekstila sensoriem, ko var izšūt ar elektrību vadošiem diegiem uz auduma. Pētījuma gaitā apskatītas un izvērtētas tekstila mitruma sensora darbības un komforta īpašības. Sensora ieslēgšanās ātrumu būtiski ietekmē tekstila pamatmateriāla mitruma uzsūkšana, līdz ar to veikts tekstildrānu mitruma uzsūkšanas un vadīšanas spēju pētījums, noskaidrojot optimālāko materiālu, kas atbilstu gan sensora pielietojumam un apmierinātu tā komforta īpašības, gan nodrošinātu pietiekami ātru sensora funkcionēšanu.
Drānu mitruma uzsūkšana un vadīšana ir atkarīga no dažādiem faktoriem, tādēļ izvēlēties vispiemērotāko drānas veidu šim pielietojumam ir samērā sarežģīti.
Tā kā mitruma sensors paredzēts integrēšanai palagā vai apakšbiksēs, tika apskatītas attiecīgas drānas.
Testējot mitruma sensora drānas paraugus uz mitruma absorbciju, tika pārbaudītas dabīgo šķiedru drānas, sintētisko šķiedru drānas un jaukto šķiedru drānas.
Sensora komforta rādītāji izvērtēti no valkāšanas sajūtu puses, izceļot virsmas reljefa un virsmas izolācijas īpašības.
Eksperimentā uz mitruma uzsūkšanu kopā pārbaudīti 20 drānu paraugi, no kuriem turpmākiem sensora projektēšanas eksperimentiem izvēlēta kokvilnas un poliestera jauktu šķiedru drāna, kas ātri uzsūc mitrumu (9,7 sek), veidojot pietiekami lielu ar mitrumu piesūcinātu laukumu (4/4 cm).
Turpmākajos eksperimentos tiks projektēti mitruma sensori ar virsmas izolāciju, lai noskaidrotu piemērotāko izolējošās virsmas tekstilmateriālu.

Инесе Паркова, Инесе Зиемеле, Аусма Вилюмсоне. Выбор текстильного материала для проектирования сенсора влаги.
Интегрирование в одежду сенсоров для контроля биометрических данных во время повседневной деятельности человека привлекает всё больший интерес исследователей. Для улучшения комфортности изделий, традиционные сенсоры модульного типа заменяются текстильными сенсорами, которые могут быть вышиты электропроводными нитями на текстильном полотне. В данном исследовании рассмотрены функциональные свойства и комфортность текстильных сенсоров. Скорость включения сенсора существенно зависит от способности ткани впитывать влагу. Для выбора наиболее подходящего материала текстильного сенсора проведены эксперименты на промокание тканей и оценивались их свойства комфортности.
Способность ткани впитывать влагу зависит от ряда факторов, поэтому выбор материала достаточно сложное задание. Тестам подвергались материалы для простыней и белья из натуральных, синтетических и смешанных волокон (хлопок и полиэфир). Ощущения комфортности оценивались рельефом поверхности и изоляционными свойствами. Было проверено промокание 20 образцов тканей, из которых для проектирования сенсора влажности отобран образец из смешанных волокон хлопка с полиэфирном, который быстро промокает за 9,7 секунд, смачивая площадь 4/4 см.
В дальнейших экспериментах будет определен наиболее подходящий изоляционный материал для сенсора влажности.