Design of Textile Moisture Sensor for Enuresis Alarm System

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Abstract **– To improve the comfort properties of nocturnal enuresis alarm system, a modular humidity sensor should be replaced with a textile sensor. During research, two-electrode textile moisture sensor has been developed to study its electrical properties. To define the optimal type of a sensor, several sensor samples have been made using different configurations of sensor electrodes, yarn type and distance between parallel seams. Samples of sensor have been tested in terms of signal detection speed.**

Keywords **– moisture sensor, conductive yarns, embroidery**

I. Introduction

Nocturnal enuresis or bedwetting is the involuntary loss of urine that occurs at night. Statistic data shows that 15-25% of children over the age of five wet the bed [1]. The problem remains for 1–3% of adolescents, as well. Different types of incontinence affect more than 150 000 people in Latvia [2], which disturb quality of life and can have an impact on children's personal development.

Enuresis may be prevented by regular use of medication, but the effect will be just as long as the drug is used. It is possible to have drug-free treatment – one of the most effective methods is nocturnal enuresis alarm [3,4]. In the previous study [5], available nocturnal enuresis alarm systems were discussed, analysing their strengths and weaknesses. It was found that when enuresis alarm system was used in medical therapy, child's involvement was important. Therefore, it is essential that the system is convenient and does not cause a psychological discomfort for the child. The existing enuresis alarm systems use wires that connect trousers with pyjamas, which can cause aversion to therapy. Besides, the wires are located near the child's neck and can pose certain security risks if they get entangled during a troubled sleep. Most of systems are rigid and inflexible, so that they are not comfortable, and it is awkward to use them. To improve the comfort properties of the system, a modular humidity sensor should be replaced with a textile sensor, which is embroidered with conductive threads on fabric. Conductive threads are a preferable material for enuresis alarm sensors, since they blend with the textile structure of underwear and bed sheet, inducing less stress on the treated person. To assess suitability of such threads for the application envisioned, it is necessary todevelop a suitable sensor configuration and to test the longevity and stability of the materials used.

II. The Operating Principle of Enuresis Alarm System

The alarm awakens the child when bed-wetting starts; the child gets out of bed and finishes voiding in the toilet. With time, a child learns to wake himself up, when his bladder is full. Child's involvement and desire to solve the issue are important for this therapy. It is, therefore, important that the system is convenient; its use does not hinder the child and does not constitute a psychological barrier. Alarm treatment is more effective if strong support is given to a child and family, and it makes treatment less uncomfortable. Several studies have shown higher results, when psychological or educational training is used with the alarm therapy [6].

There are several types of enuresis alarm systems available:

- Pad-and-bell alarms;
- Wearable wired alarms;
- Wearable wireless alarms.

Pad-and-bell alarms are bed-based, with the child sleeping on a pad or mat containing an electrical circuit. A bell rings if urine contacts the electrical circuit. Usually bed-mat is made out of waterproof plastic material, in which conductive (copper, foil etc.) material is embedded in a comb-like manner [7].

Wearable wired alarms are body-worn alarms, where the small sensor is attached to the child's pants, and the alarm is worn on the pyjama top. In the wireless version of alarm system, a sensor communicates with the alarm by a radio signal. In this case, the sensor is larger, since the sensor system includes a transmitter and a battery. Consequently, the sensor unit shall be completely isolated, which gives it additional stiffness [8].

There are different types of wearable enuresis alarm systems, but the operating principle of all such systems is similar; however, they differ in the arrangement of elements and in their size, materials, connection technology, sensor and alarm unit communication and signalling type, comfort level etc.

III. Materials and Methods

Textile moisture sensor can be designed based on two principles of operation:

- Change in reactive resistance. The sensor detects wetness by measuring the change in reactive resistance when the sheet is wet. The moisture sensor is based on interdigital weave, and the resistive signal is proportional to the actual moisture [9]. One of sensor configurations is shown in Fig. 1. In this case, stability of electrical resistance is important since it is necessary to establish the changes of impedance that turns on the signal at a fixed value. As found in earlier experiments related to the studies of the electrical behaviour of electric yarns [10], the operation of thread as a conductor of electricity is unstable, so there is a relatively high probability of an error.

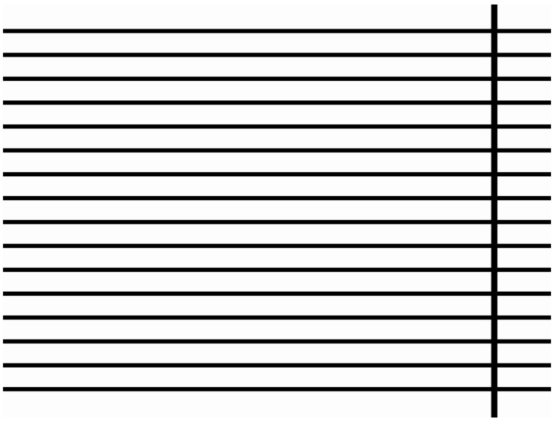


Fig.1. Configuration of sensor type: change in reactive resistance

- Two-electrode sensor. Liquid presence is signalled, when there is an electrical connection between the two electrodes induced by the contact with a conductive liquid. Several types of possible sensor configurations are shown in Fig. 3.

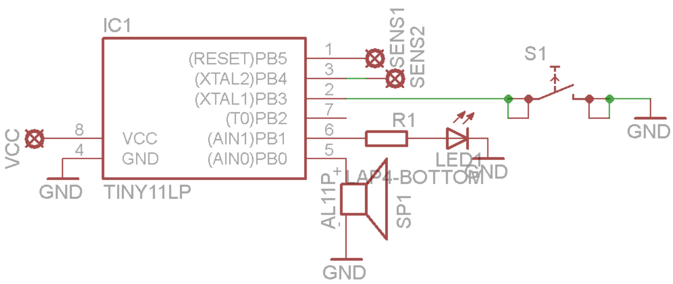
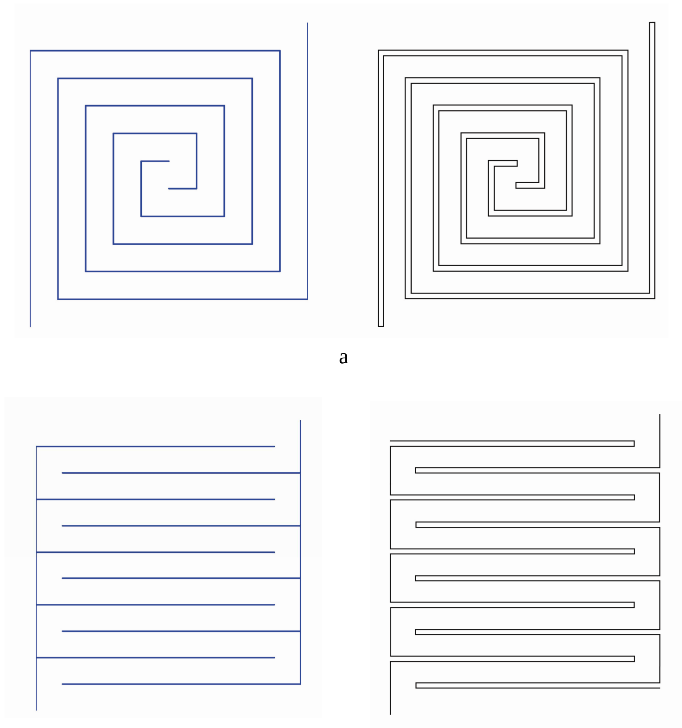


Fig.2. Circuit of two-electrode sensor

The second method is chosen for sensor designing – two-electrode sensor, which is more precise than the first one – the method of change in reactive resistance, especially using conductive yarns. Cotton fabric substrate and polyamide silver-coated conductive yarns are used for moisture sensor designing. Electrical circuit of sensor is shown in Fig. 2.

To define the optimal type of a sensor, 12 sensor samples have been made by combining different configurations of sensor electrodes, types of thread and distance between parallel stitches. Variable factors of the experiment and their variation levels are presented in Table 1.

Samples of moisture sensor have been embroidered with computerized embroidery machine on cotton fabric using 2 mm long straight lock-stitch seam. Size of sensors is 80x90 mm, distance between axis of electrodes is 8 mm. Technical drawings of sensors are shown in Fig. 3.



a

b

Fig.3. Technical drawings of two-electrode sensors: a – spiral type; b – comb type

TABLE I

VARIABLE FACTORS OF THE EXPERIMENT AND THEIR VALUES

	Variable factors	**Values**		
1	Type of thread, no.	N1 (Elitex 110/34 dtex 2ply)	N2 (Shieldex 235/34 dtex 4ply)	N3 (Shieldex 110/34 dtex 2ply)
2	Configuration of sensor, no.	A (spiral type)		B (comb type)
3	Displacement of parallel stitch, mm	0		2

TABLE II

BEHAVIOR OF CONDUCTIVE YARNS IN DIFFERENT SEAMS OF ELECTRODES

Yarn No.	Configuration of sensor							
	A 0		A 2		B 0		B 2	
	E1	E2	E1	E2	E1	E2	E1	E2
	Electrical resistance, ohms							
N1	**6.65** V=1.8%	**7.31** V=0.4%	**16.59** V=0.9%	**15.52** V=1.8%	**2.49** V=2.8%	**3.08** V=1.3%	**25.89** V=0.4%	**24.37** V=0.5%
N2	**8.92** V=1.1%	**9.16** V=0.7%	**8.83** V=1.1%	**9.02** V=1.5%	**3.96** V=4.8%	**4.14** V=1.2%	**31.26** V=0.3%	**31.5** V=0.4%
N3	**21.06** V=2.9%	**22.07** V=0.8%	**112.4** V=4.4%	**500** -	**9.65** V=6.2%	**4.38** V=2.9%	**193.2** V=29.4%	**127** V=3.2%

As Table 2 shows, the behaviour of conductive yarns in different seams depends on the type of yarn and stability of its electrical properties. In Table 2, electrical resistance measurements of both electrodes (E1 – the first electrode, E2 – the second electrode) are summarized.

As results show, electrical resistance measurements of the two electrodes differ; however, in this case it does not have an impact on sensor functionality. It is necessary to take into consideration its stability over time. Difference in electrical resistance between two electrodes for yarns N1 and N2 is rather low; on the other hand, yarn N3 shows quite unstable resistance, it has been difficult to get a signal in several samples (for example, A2 E2). Therefore, yarn N3 has been discarded for further experiments.

IV. Signal Detection Speed

Samples of sensors have been subjected to signal detection speed test. Urine has greater conductivity than water so that for this experiment salt water solution has been prepared. Saline solution has been dripped from drip funnel on sensor holding funnel at distance of 5 cm from the horizontal surface of sensor. Salt (NaCl) is an electrolyte, and when it is dissolved in water to form salt water, it turns into sodium ions (Na+) and chlorine ions (Cl-), each is a particle that conducts electricity. The more Na+ and Cl- in water, the more electricity is carried, and the higher the conductivity is [11]. For the experiment, 0.2 moles of salt per 1 litre of water solution have been used, because its conductivity corresponds to the average conductivity of urine [12]. Speed of reaction has been measured with the oscilloscope measuring voltage in the sensor circuit. Liquid detection speed (0.45 sec on average) is similar for all sensors, speed of reaction is related to funnel opening moment and speed of water reaching surface. Measurements of two sensors are shown in Fig. 4, similar results have been acquired for other samples.

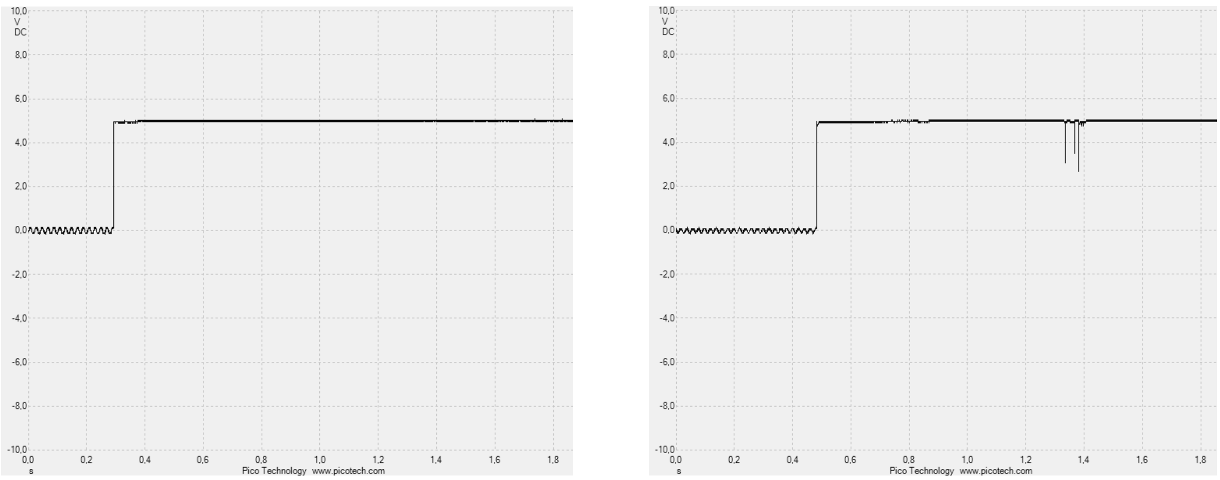


Fig.4. Measurements of signal detection speed

TABLE III

ELECTRICAL RESISTANCE OF BED SHEET SENSOR BETWEEN THE ELECTRODES CONNECTED BY LIQUID

Distilled water									
Time sec	9	18	33	45	67	95	138	168	194
Resistance, kΩ	9610	119	157	160	222	263	281	300	312
Salt water									
Time sec	15	30	40	50	60	70	80	100	140
Resistance, kΩ	77	40	19	21	28	30	33	32	34

At distance of 8 mm between electrodes, the signal has been detected very fast (0.45 sec on average). This distance between electrodes can be used for a sensor that is integrated into crotch of underwear. For bed sheet sensor liquid detecting area is larger, so it is preferable to use larger distance between electrodes to decrease consumption of conductive yarn and to avoid making bed sheet rough with stitches.

The sample of bed sheet sensor has been made. It consists of four connected 19.8 x 22 cm spiral-type sensors, distance between electrodes is 2.2 cm. Total sensor area is 46.5 x 47.5 cm. Embroidered bed sheet sensor is shown in Fig. 5.

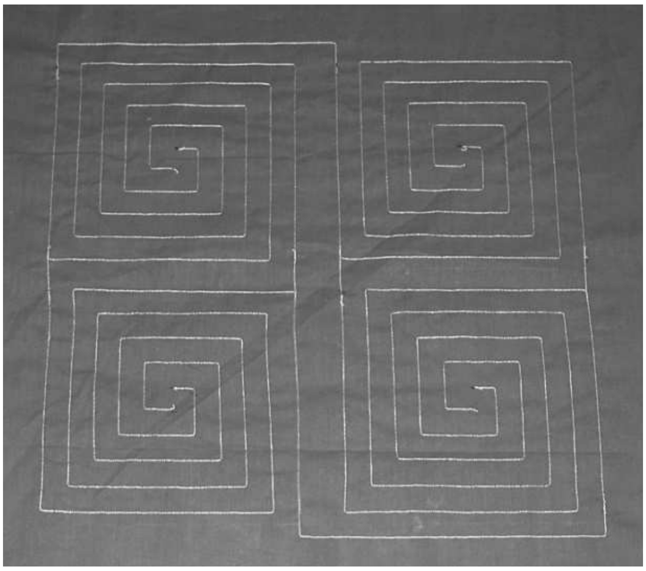


Fig.5. Embroidered bed sheet sensor

This type of sensor design is suitable, when embroidery machine cannot embroider all sensor area in one process as one full spiral. Circuit connection breaks are not preferable in the circuit, so that the number of points where the connection is broken must be reduced as much as possible.

Tests of signal detection sensor show that it functions, but signal detection speed is rather high (9–15 sec), so that in next samples the distance between electrodes will be reduced to 1.5–1.8 cm.

Table 3 shows the data on electrical resistance between the two electrodes that are connected by spilled liquid.

Measurements of electrical resistance of bed sheet sensor between the electrodes connected by distilled water and by salt water are presented during different points in time.

V. Conclusions

It is important to know the values of the actual resistance between the electrodes when the sensor becomes wet, because it will enable the designer to tune the detection system. One of the possible false positives is the launch of the system due to exposure of conductive liquid other than child's urine, for example, extensive sweating during the sleep. Information about the actual resistance values of the sensor, when it contacts urine, will help in developing a system that is prone to such errors.

Speed of sensor signal detection depends not only on conductive yarn parameters and distance of electrodes but on textile substrate wettability properties, as well. Therefore, it is necessary to research textile materials wettability and moisture management properties 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.

VI. Summary

Nocturnal enuresis is the involuntary loss of urine that occurs at night and is related to children over the age of 5. This problem mostly is urgent for preschool-age children; however, it can remain in adolescent age, as well. One of the most effective non-medical methods is nocturnal enuresis alarm. The existing enuresis alarm systems are not very comfortable and can cause aversion to therapy. In order to improve the system comfort properties, a modular humidity sensor should be replaced with a textile sensor, which is embroidered with conductive threads on fabric.

During research the two-electrode textile moisture sensor has been developed in different sizes to study its electrical properties. In order to define the optimal type of sensor, 12 sensor samples have been made using different configurations of sensor electrodes, yarn type and distance between parallel seams. Samples of sensor have been subjected to signal detection speed test. It is important to know the values of the actual resistance between the electrodes when the sensor becomes wet, because it will enable the designer to tune the detection system.

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 research textile materials wettability and moisture management properties in order to determine optimal textile material that would be suitable for a sensor, would satisfy comfort properties of sensor and would provide fast enough operation of a sensor.

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Inese Parkova, Aleksandrs Vališevskis, Uģis Briedis, Ausma Viļumsone. Tekstila mitruma sensora projektēšana enurēzes modinātāja sistēmai.
Nakts enurēze ir patvaļīga urīna noplūde naktī bērniem pēc 5 gadu vecuma – šī problēma lielākoties ir aktuāla pirmsskolniekiem, taču var saglabāties arī pieaugušajiem. Viena no efektīgākajām metodēm, neizmantojot farmācijas līdzekļus, ir nakts enurēzes modinātāja izmantošana. Esošās enurēzes modinātāja sistēmas nav īpaši ērtas un bērnam var izraisīt nepatiku pret terapiju. Lai uzlabotu sensoru komforta īpašības, tradicionālos moduļa tipa sensors ir jāaizstāj ar tekstila sensoru, ko var izšūt ar elektrību vadošiem diegiem uz auduma.
Lai izpētītu sensora elektriskās īpašības, eksperimenta gaitā tika izstrādāts divu-elektrodu tekstila mitruma sensors dažādos izmēros. Nosakot optimālo sensora veidu, izveidoti 12 sensoru paraugi, izmantojot dažādas sensora elektrodu konfigurācijas, pavediena veidus un attālumu starp paralēlajām nošuvēm. Izveidots arī salikts sensors, kas sastāv no 4 savā starpā savienotiem elektrodu pāriem. Sensoru paraugi tika pārbaudīti uz ieslēgšanās ātrumu ar sālsūdens šķīdumu. Tika fiksētas faktiskās pretestības vērtības starp elektrodiem mitram sensoram, jo tas ļaus noregulēt sensora signāla uztveršanas sistēmu. Sensora ieslēgšanās ātrumu ietekmē ne tikai elektrovadošo pavedienu īpašības un elektrodu attālums, bet arī tekstila pamatmateriāla mitruma uzsūkšana. Līdz ar to ir nepieciešams 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.

Инесе Паркова, Александр Валишевский, Угис Бриедис, Аусма Вилюмсоне. Проектирование текстильного сенсора влажности для системы энурезного будильника.
Ночной энурез - непроизвольное выделение мочи у детей старше 5 лет. Данная проблема наиболее распространена у детей дошкольного возраста, однако встречается и у взрослых. Эффективным методом лечения без использования лекарств является использование будильника ночного энуреза. Неудобные системы энурезного будильника могут вызвать неприязнь ребёнка к терапии. Чтобы улучшить комфортность изделий, модульные сенсоры влажности заменяются на текстильные сенсоры, которые могут быть вышиты электропроводными нитями на ткани.
Для исследования электрических свойств сенсора были разработаны двухэлектродные текстильные сенсоры влажности различных размеров. Для экспериментов было отобрано 12 образцов сенсоров с разной конфигурацией электродов, из различных видов нитей и с разным расстоянием между параллельными строчками. Также изготовлен сборный сенсор, который состоит из четырёх взаимно соединённых пар электродов. Образцы сенсоров проверялись на скорость включения при помощи соляного раствора. Для дальнейшей регулировки системы приёмника сигнала, зафиксированы значения сопротивления между электродами влажного сенсора. Скорость активации сенсора зависит от свойств электропроводящих нитей и расстояния между электродами, а также способности текстильного материала впитывать влагу. Поэтому необходимо провести исследование на выбор текстильного материала для сенсора, который обеспечивает достаточное промокание для быстрой активации сенсора и обладает хорошими тактильными свойствами.