Development of a system for detecting filling with urine in reusable diapers

Opracowanie systemu wykrywającego zapełnienie moczem pieluchomajtek wielokrotnego użytku

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Abstrakt

Praca badawcza swoim zakresie obejmuje opracowanie i wykonanie systemu tekstronicznego wykrywającego zapełnienie moczem pieluchomajtek wielokrotnego użytku. Celem jest zastąpienie dotychczasowych rozwiązań na wyrób gotowy wielokrotnego użytku wraz z mobilnym system defektującym wypełnienie moczem. Taka propozycja minimalizowałaby nadmierne zużycie pieluch jednokrotnego użytku oraz narażenie na wszelkiego rodzaju podrażnienia, zakażenia i głównie zapobiegałaby powstawaniu pieluszkowego zapalenia skóry. W celu przygotowania prototypu zbadano materiały wchodzące w skład wyrobu gotowego budujące różne jego warstwy w celu analizy ich właściwości użytkowych. Wykonano trzy wzory haftów nicią elektroprzewodzącą – jeden jednowarstwowy oraz dwa dwuwarstwowe. Przeprowadzono badania użytkowe materiałów oraz haftów, które obejmowały czynniki obecne w codziennym użytkowaniu wyrobu gotowego. Po analizie uzyskanych wyników wykonano prototyp pieluchomajtki oraz zbadano jego pracę podczas symulacji. Wyniki wykazały poprawną pracę stworzonego prototypu.

Abstract

The scope of the research work includes the development and implementation of a textronic system that detects the filling of reusable diapers with urine. The goal is to replace the existing solutions with a reusable ready-made product with a mobile urine filling defect system. Such a proposal would minimize the excessive use of disposable diapers and exposure to all kinds of irritation, infections and mainly prevent the formation of diaper dermatitis. To prepare the prototype, the materials included in the finished product, building its various layers, were examined to analyze their functional properties. Three designs of electroconductive thread embroidery were made - one single-layer and two double-layer. Usage tests of materials and embroidery were carried out, which included factors present in everyday use of the finished product. After analyzing the obtained results, a prototype of the diaper pant was made, and its operation was tested during the simulation. The results showed the correct operation of the created prototype.

Słowa kluczowe: Tekstronika, czujniki wilgoci, haft, arduino, badania użytkowe

Keywords: Textronics, moisture sensors, embroidery, arduino, application research

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1. Introduction

In recent years, monitoring vital signs and activity has become very fashionable and available at one's fingertips [1-3]. Technology is developing to make life easier and easier access to information about medical data or the number of steps taken during the day. In addition to available devices, combinations of textiles and electrical systems are appearing on the market. Textronics combines knowledge from several leading fields of knowledge - electronics, textiles, and computer science, using concepts and tools in the field of automation and metrology [4]. The development of textronic systems means that solutions can have many skills. In addition to the necessary functions of measuring life processes and analyzing external factors, they may have alarm or data transmission functions [5]. The first need for such solutions appeared in high-risk professions. The firefighter's profession, due to its specific nature, was the first to need such solutions the most. The design of the intelligent firefighter suit included not only monitoring the user's heartbeat or breathing, but also having many additional functions, such as a body temperature sensor, ambient temperature sensor, hazardous gas sensors and a locator [6].

Textronic solutions have begun to enter the market dealing with the production of diapers and nappy pants. The main purpose of this procedure was to help not the users themselves, but the people taking care of them. It has become a support for nurses and carers of the elderly and disabled, and for children in hospitals and nursing homes [7]. This allowed the personnel to be informed about an overfilled diaper in a timely manner and to replace it efficiently without exposing the patient to infection or irritation. This problem also applies to the smallest patients. Nursing care in the first hours of a child's life, or later care by a parent at home can be improved and become more controlled through textronic solutions in diapers and nappy pants. In children, and especially often in infants aged 6 to 12 months, diaper wearing is accompanied by frequent inflammatory reactions in response to external or internal factors. These may be the presence of moisture, infections, mechanical friction, or insufficient hygiene. Risk factors for infection or irritation may include mainly humidity and skin contact with urine and feces, the increased enzymatic activity of which, because of the conversion of urea into ammonia, causes a change in the skin's pH. The cause of excessive skin moisture may be a large amount of urine. It is estimated that a baby up to six months can urinate up to 20 times a day. When conditions are favorable for the appearance of diaper rash, the skin becomes irritated, becomes red and inflamed, and loses its protective barrier function [8].

Panty diapers are a product that is very similar to a disposable diaper. They are supposed to provide comfort of use, be very absorbent and provide a feeling of dryness. The main difference between diaper pants and diapers is the way they are put on, because in the case of the former we will not find velcro to fasten them. The method of putting on is the same as in the case of the lower part of the underwear - just slip them on the buttocks. The lack of velcro has an additional advantage, namely children cannot take them off by themselves. When removing them, disposable diapers can be torn off at the sides, and reusable ones can be slipped off. The most important difference between the two products is the way they are maintained and disposed of. While at the very end they end up in the same place, the life of reusable diapers is much longer [9].

From an ecological point of view, already in 2016, the population living in the United States noticed the problem of the price paid by the environment in exchange for the convenience of using disposable diapers. At that time, approximately 20 billion pieces of this product were used each year, generating 3.5 million tons of waste. One diaper takes at least 500 years to decompose, and during this process it produces methane and other toxic gases. Their production uses volatile chemicals that also pollute the ecosystem. According to the report of the US Environmental Protection Agency, there are consequences of the penetration of pathogens into the environment [10]. Scientists agree that most of them end up in water, which results in contamination of drinking water. Another disadvantage is the annual consumption of approximately 200,000 trees just to produce disposable diapers [11,12].

The subject of the research work is the development of a textronic system that detects the fullness of urine in reusable diapers. The motivation to undertake research on this subject is several very important aspects of present life on earth. The first is the increasingly popular topic of ecology [10]. Segregation and, more importantly, minimization of waste produced is a salvation for the planet we live on. Secondly, considering ecological considerations, it is necessary to consider the convenience of use for children, their parents and mainly medical staff who have more than one small patient under their care. Reusable diapers will be machine washable, and their main advantage will be the detection of the diaper's filling with urine.

Currently, there are several projects and products using the idea of smart diapers. American Patent US 20015 /0080819 A1 describes a solution using an RFID radio tag. The article aims to provide a diaper structure which includes a body part formed by a fabric layer, a leak-proof layer, and an absorbent material layer successively from the inside to the outside, a communication chip, a metal antenna attached to the outer surface of the leak-proof layer, which are connected to each other to create an RFID tag. When the absorbent material absorbs urine passing through the fabric layer and the inner surface of the anti-leakage layer contacts the urine on the surface of the absorbent material layer, a change in the relative permittivity of the leakage layer causes a change in the impedance value of the metal antenna and, consequently, a change in the electromagnetic wave signal transmitted by the RFID tag. This enables quick detection of a wet diaper [13].

Patent No. 5,557,263 discloses an apparatus mounted in a diaper for detecting the presence of electrically conductive fluids, including urine and other body fluids such as wound exudate. It contains spaced apart electrodes covered with an absorbent material along with a housing containing a signaling device that produces a perceptible vibration, sound, light, or radio signal when a fluid in the absorbent material provides a conductive path between the electrodes. Spring contacts on the housing provide connections to the electrodes and serve to secure the signaling device housing to a structure supporting the absorbent material. The encoded signals from many of these sensors can be identified and recorded so that they can be reproduced by machine along with other patients' data and analyzed statistically by a computer. Body fluid detection devices are particularly in demand for preventing diaper rash, for potty training infants, and for treating children with enuresis. The above equipment is intended for repeated use [14].

To sum up the introductory part, which introduced two problems related to changing diapers too or too rarely, and the ecological problem of avoiding and trying to stop these processes, this work presents a product that solves the problems mentioned above. By introducing an information system into reusable diaper pants, the product will provide information when the diaper is full and thus indicate when it should be replaced. This will prevent the child from being exposed to long-term skin contact with feces and from excessive monitoring.

2. Materials and methods

Method of developing the textronic system for detecting filling with urine consisted of three steps. In the first step the materials, type of metal thread, sizes of embroidery, arrangement method and densities of embroidery were selected.

2.1. Materials

Diapers must meet many requirements regardless of whether they are used for children or adults. The materials from which they are made must provide a feeling of comfort through a complete sense of cleanliness, must not cause skin allergies or any type of irritation, must absorb and distribute moisture evenly as quickly as possible and eliminate the feeling of dampness, and must have elastic elements to ensure the highest degree of fit to the body. For this purpose, widely known and used products are used, such as polyethylene and polypropylene, polyester, polyacrylate polymers, synthetic rubber, and cellulose. Diaper pants often contain balm, which usually contains fatty substances, e.g., vaseline and/or liquid paraffin, plant extracts, mainly aloe, or may contain fragrances. In addition to carefully sewing all the elements together, adhesives made of thermoplastic polymers are used to keep individual layers of material in the right place [15].

Commonly used textiles to produce multi-layer systems such as diapers and diaper pants were selected. These materials have different raw material compositions and thus also different properties depending on the layer they are to be in the system. Absorbent, moisture-retaining and decorative properties can be mentioned, as in the case of the outer layer. Materials used in both single- and reusable products were tested to check their functional properties and possible predispositions for use in reusable products. The materials selected for the tests was: cellulose pad - skin layer, bamboo non-woven fabric - skin layer, viscose nonwoven - inner layer with embroidery, cellulose non-woven fabric with wood pulp - skin layer, microfiber - inner absorbent layer, laminate - internal layer that retains moisture, cotton knit - outer layer. Moisture-sensitive sensors was made of polyamide yarn, which includes silver. Noble yarn with the trade name X-STATIC was used. It is a yarn that has properties such as anti-static and thermoregulation. It also has high mechanical properties that ensure resistance to tearing. In addition, the product is characterized by the ability to absorb static and electrical discharges. The yarn is made of polyamide silk (85%) coated with a layer of pure silver in the amount of 15%. Sensors made of polyamide thread with the addition of silver were made in three different patterns on a viscose non-woven fabric. One of them includes only one piece of fabric with embroidery, the other two consist of two separate parts with a different element of the embroidery pattern. The purpose of such a procedure is to test which of the mentioned options for embroideries placement would have the best detection parameters. They consist of sensitivity to moisture and the right moment to inform about the need to replace the entire multi-layer system with a new one. Two-element sensor systems will be separated by layers of absorbent materials, and thus they will inform about the filling when the electrical conductivity between the upper and lower part appears. The designs were created based on European and American patents. Figure 1 shows the embroidered sensors.

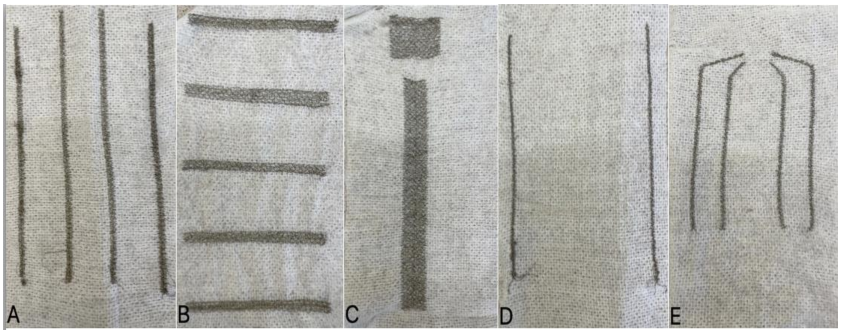

Fig. 1. A) First two-layer system - upper layer, B) First two-layer system - lower layer, C) Second two-layer system - upper layer, D) Second two-layer system - lower layer, E) Single-layer system.

2.2. Methods

The second stage was to perform functional tests of previously selected fabrics and embroidered sensors. The measurements were carried out on samples acclimatized for 24 hours in standard climatic conditions specified in the PN-EN ISO 139 standard, which currently specifies that the humidity should be 65±4% and the temperature 20±2℃.

- The test of determining the surface mass is carried out according to the PN-EN 12127: 2000 standard "Textiles - fabrics - determination of mass per unit area using small samples" [16].
- An attempt to determine the thickness of the tested samples was made in accordance with the PN-EN ISO 5084:1999 standard "Textiles - Determination of the thickness of textile products" [17].
- The air permeability test was carried out in accordance with the PN-EN ISO 9237 standard "Textiles - determination of air permeability of fabrics" [18].

- The grating resistance was determined in accordance with the PN-EN ISO 12945-2:2021-04 standard " Textiles - Determination of the surface tendency of a flat article to peel, pill and curl - Part 2: Modified Martindale method" [19].
- Determination of water vapor transmission through the products was carried out in accordance with EN 13726 - 2 "Test methods for direct wound dressings - Part 2: Transmission of moisture vapor through dressings with semi-permeable foil" [20].
- Determination of resistance to urine is a test of the resistance of the tested material to any staining. This test was carried out based on the PN ISO 105-C06: 1996 standard "Textiles - colour fastness test - colour fastness to household washing and communal.” The urine produced in the laboratory includes urea weighing 3.75 g, salt weighing 4 g, a drop of tea [21].
- The study of changes in surface resistance was carried out based on the guidelines of the PN-EN 1149-1 standard "Protective clothing - Electrostatic properties" [22].

2.3. Arduino Uno

Arduino is an open-source hardware and software company [23]. It is a type of software in which the copyright holder grants users the rights to research, change, and distribute the software under a free software license [24]. Arduino is a design and user community that designs and produces single-board microcontrollers and microcontroller kits for building digital devices. Arduino boards are available commercially on the official website or from authorized distributors. Board designs use a variety of microprocessors and controllers. Arduino boards come with sets of digital and analog input and output pins that can be connected to various expansion boards or breadboards and other circuits. Microcontrollers can be programmed using C and C++ using an API, also known as the Arduino language, inspired by the Processing language with a modified version of the Processing IDE [23].

3. Results

Materials and embroidered sensors were subjected to functional tests to confirm the materials and learn about their parameters in the manufactured sensors. All the results among the materials confirmed their intended use in the finished product. The rest of this subchapter will present the results of the embroidery use tests and explain how the prototype was created.

3.1. Determination of surface mass

Table 1 shows the results for embroidery. The lowest values are for the embroideries with the smallest surface areas. These are the embroideries of a single layer system and the bottom layer of the second double layer system. For them, 55.720 g/m^2 and 56.120 g/m^2 were achieved. The remaining embroideries had very similar surface areas, therefore the results of determining the surface weight for them are also very similar. For the upper layer of the first two-layer system, the value of the tested parameter is 59.780 g/m^2, for the lower layer of this system 60.200 g/m^2 and for the upper layer of the second two-layer system 60.060 g/m^2.

Tab. 1. Test results determination of surface weight for all tested embroideries.

Viscose nonwoven fabric with embroidery	**Surface mass [g/m^2]**	**Standard Deviation [g/m^2]**
Single-layer system	55.720	0.577
The first two-layer system – the upper layer	59.780	0.583
The first two-layer system – the lower layer	60.200	0.863
The second two-layer system - the upper layer	60.060	1.001
The second two-layer system – the bottom layer	56.120	0.876

3.2. Determining thickness

The thickest embroidery turned out to be the upper layer of the first two-layer system, and the thinnest was the lower layer of the same system. All the results obtained for embroidery are very similar. The smallest value of this parameter for the first two-layer system - the lower layer is only 0.4 mm away from the highest value for the same system but the upper layer. Please remember that the value for a single-layer system remains unchanged when incorporated into the finished product, but for two-layer systems, the results of both layers should be added up. According to the calculations, the first layer system together has a value for a thickness of 2.82 mm and the second two-layer system has a value of 3 mm. Figure 2 below shows very similar values for the thickness determination test for individual embroideries. Ten measurements were taken on the entire embroidery surface.

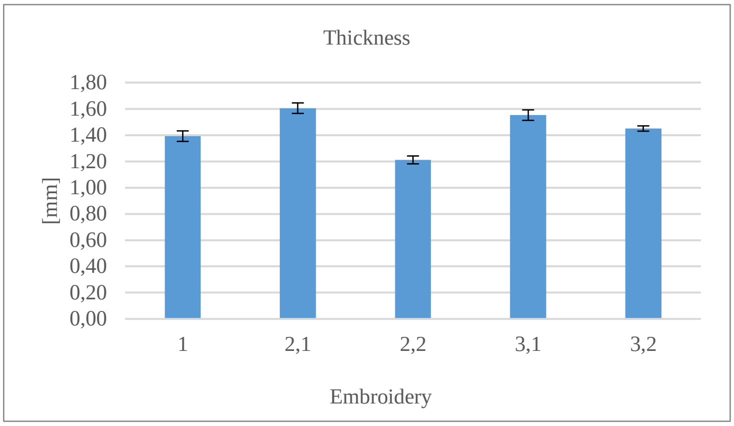

Fig. 2. Graphical presentation of the results of determining changes in thickness. Where: 1) single-layer system, 2.1) upper layer of the first two-layer system, 2.2) lower layer of the first two-layer system, 3.1) upper layer of the second two-layer system, 3.2) lower layer of the second two-layer system.

3.3. Determination of air permeability

Table 2 presents the results of the test for determining the air permeability of embroidery. As mentioned in Chapter 4, the embroidery was made on viscose non-woven fabric. The air permeability value for pure nonwoven fabric was 3232 mm/s. The results obtained for this embroidery study are very promising as the values are very close to the unembroidered fabric. The largest decreases are observed for the two top layers of the two-ply systems. Their results are 2868 mm/s and 2589 mm/s. It should be emphasized that these values are higher than all other results for unembroidered samples. The result closest to the pure nonwoven fabric is the bottom layer of the first two-layer system and is 3167 mm/s. The remaining results for the single-layer system and the lower layer of the second two-layer system also remain at a very high level, they are very similar to each other, within a small range of 24 mm/s and amount to 3157 mm/s and 3133 mm/s, respectively. Ten measurements were taken on the entire embroidery surface.

Tab. 2. Test results determining air permeability for all tested embroideries.

Viscose nonwoven fabric with embroidery	Air Permeability [mm/s]	Standard Deviation [mm/s]
Single-layer system	3157	71
The first two-layer system – the upper layer	2868	137
The first two-layer system – the lower layer	3167	59
The second two-layer system - the upper layer	2589	38
The second two-layer system – the bottom layer	3133	112

3.4. Determination of friction resistance

On a comparative scale from 1 to 5, the lowest number means the greatest noticeable changes in the structure of the tested material, the so-called pilling, while the highest one would indicate no changes in the structure. All tested embroideries obtained the same result for determining friction resistance, which was 1.5. It is worth emphasizing that they were made of viscose fibre, which obtained a value of 2 in the same test.

3.5. Determination of urine resistance

The study was conducted in the context of the occurrence of discoloration, and the embroidery items subjected to the study were compared with those that were not. For all embroideries on a scale from 1 to 5, the result was 5. Two tests were performed for each material and one for embroidery.

3.6. Determination of surface resistance

Below are the results of the tests for the embroidered sensors that determine which design was used in the diaper pant. The initial resistance test was carried out, followed by the test of determining the resistance to friction and the test of determining the resistance to urine. Figure 3 shows graphical representation of the obtained results. Resistance data was collected for 60 seconds.

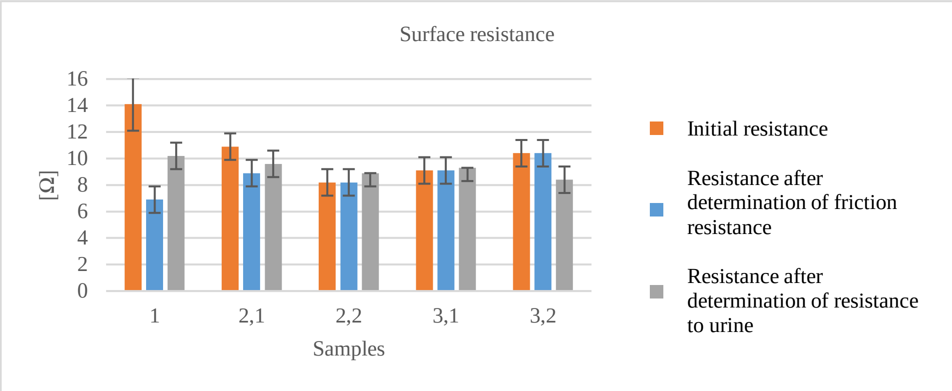

Fig. 3. Graphical presentation of the results of determining changes in surface resistance after utility tests for all tested embroideries. Where: 1) single-layer system, 2.1) upper layer of the first two-layer system, 2.2) lower layer of the first two-layer system, 3.1) upper layer of the second two-layer system, 3.2) lower layer of the second two-layer system.

The greatest changes in the resistance value were observed for a single-layer system. The results for this embroidery pattern range from 7 to 14 Ω. Other systems behaved more stable and changes in resistance values did not exceed 2 Ω. The lower layer of the first two-layer system and the upper layer of the second two-layer system deserve special mention. In these two cases the change was the least noticeable - within 1 Ω. Summing up the observations, the obtained results of the surface resistance are very even and remain at a similar level before and after the utility tests. Simulations of the sensitivity of the embroidery to the presence of moisture were made using an Arduino board with a previously prepared ohmmeter program. Simulations were performed for about 50 seconds, starting with a dry material, and then imitating the process of urination by the user, water was sprinkled. The results were collected until the system stabilized after the two embroidery paths related to moisture.

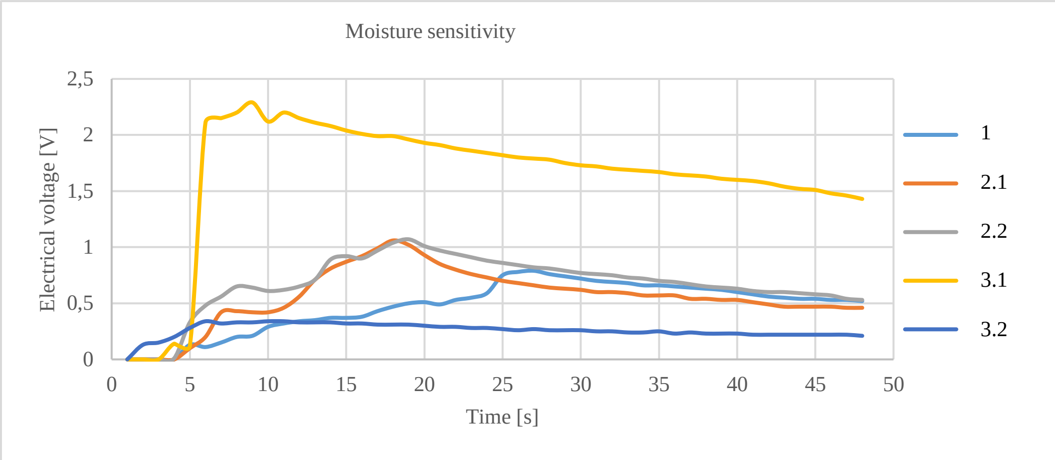

Fig. 4. Moisture detection simulation for tested embroideries. Where: 1) single-layer system, 2.1) upper layer of the first two-layer system, 2.2) lower layer of the first two-layer system, 3.1) upper layer of the second two-layer system, 3.2) lower layer of the second two-layer system.

The Figure 4 shows the difference during the simulation for embroidered detectors. For single-layer system after connecting the two paths of electrically conductive yarn with water, the electric voltage increased rapidly from 0 to 2.27 V and slowly decreased during the process. The electric voltage values collected for this system are twice as high as for the other tested embroideries. The first two-layer system achieves the value of the examined parameter slightly above 1 V. It is worth noting that the course of the simulation is very similar for both layers. The lowest values can be seen for the second two-layer system. The first layer recorded its highest value of electric voltage at the level of 0.7 V, while the second layer did not exceed 0.5 V. During the analysis of the obtained results, a dependence was noticed that the further apart the conductive embroidery paths are from each other, the lower the electric voltage arises between them when tested with the same volume of water.

The prototype of the diaper pant was made based on the products of diaper pants and disposable diapers already available on the market. A proven method of sewing a multi-layer product together was used. The materials tested in the previous chapters of the work were used - bamboo non-woven fabric and cellulose non-woven fabric with wood pulp as skin materials, viscose non-woven fabric on which embroidery was made, microfiber as an internal absorbent insert, laminate as a moisture-repellent membrane and cotton knitted fabric as an external material that holds the whole and decorative product, on which various types of patterns can be applied. The materials tested in the previous chapters of the work were used - bamboo non-woven fabric and cellulose non-woven fabric with wood pulp as skin materials, viscose non-woven fabric on which embroidery was made (two two-layers systems), microfiber as an internal absorbent insert, laminate as a moisture-repellent membrane and cotton knitted fabric as an external material that holds the whole and decorative product, on which various types of patterns can be applied. In addition, on the outer layer, the product has press studs, thanks to which it is possible to easily install the detachable electronic system. The electronic system itself based on the Arduino board is hidden and at the same time protected in the case. 3D printing technology was used to produce the case. Figure 5 shows the prototype made.

Fig. 5. A prototype of a reusable diaper pant with a pattern for boys.

To read the data coming from the inside of the diaper-pants, it was necessary to build an electronic system and write a program that supports it. The system includes the Arduino UNO Rev3 board, two LEDs in red and yellow, four resistors (two 220 Ω and two 270 Ω), a set of connecting cables, breadboard, battery adapter and 9V alkaline battery. To check the correct operation of the prototype and the correlation of the finished product with the electronic system, simulations were carried out. The measuring station consisted of two computers recording changes in electric voltage and changes in heat, a thermal imaging camera, a syringe and hot water, and was presented in Figure 6. The electronic system based on the Arduino board was placed in a housing made by 3D printing from polyacrylonitrile.

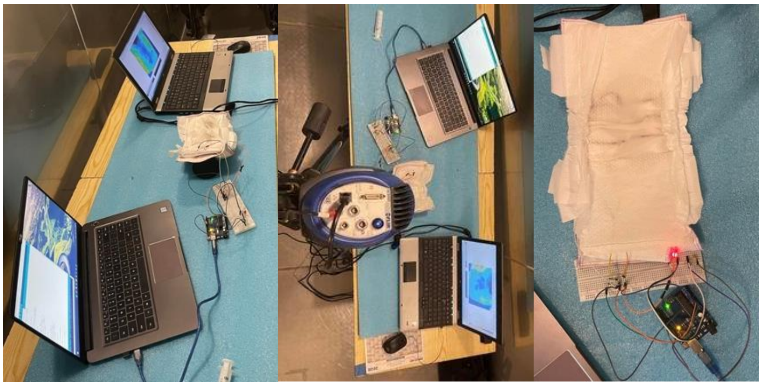

Fig. 6. Measuring station to simulate prototypes.

The electronic system has two detection elements that allow to check the current flow at two points. For the first two-layer system, the wires were connected to the two extreme paths on each layer, for the second two-layer system, the wires were connected to the paths responsible for belly-back and side-side detection. It is worth noting that the paths do not connect with each other and there is no current flow between them. If an electric voltage greater than 0.1 V was detected between the tested embroidery paths, one of the diodes lit up, informing about the presence of conductivity at the expected point. Three floods of warm water with a volume of 20 ml per center of the panty diaper were made. The results of the simulation from the point of view of the thermal imaging camera are presented in Figure 7 below. The photos were taken dry and each time after pouring 20 ml of warm water.

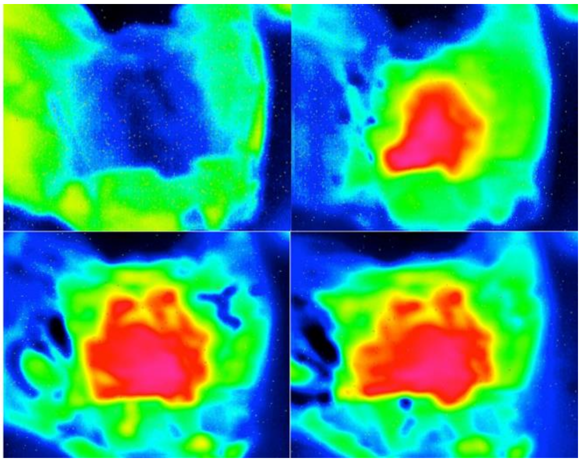

Fig. 7. Pictures taken with a thermal imaging camera in the following order: upper left corner - before the first flooding, upper right corner - after the first flooding, lower left corner - after the second flooding, lower right corner - after the third flooding.

4. Conclusions

The aim of this research was the development of a textronic system for urine leakage detection in reusable nappies. Tests allowed for the selection of the base material with the appropriate properties and size of the embroidery. The constructed prototype proved its correct operation during simulation of its operation. The key findings of this research are that the size, shape, and number of layers of the embroidered sensors has a significant impact on the functional properties of final products and affects its conductive properties, tests of the conductive properties of embroidered materials confirm the possibility of making textronic sensors that respond to the moisture. Additionally we confirmed that the functional properties of each material have a significant impact on the role it can play in clothing, the distribution of paths in one- or two-layer embroidery has a significant impact on the detection of the diaper's fullness with urine, the embroideries made after utility tests show signs of wear through changes in the values of the tested parameters in a minimal way, chemical solutions imitating urine do not affect the appearance of the tested materials, conducted tests of the conductive properties of embroidered materials confirm the possibility of making textronic sensors reacting to moisture and the materials selected for the tests meet the requirements of materials used in the production of diapers and diapers.

Further development of the finished product can certainly take place in the modernization of the electronic system. Now, it is also small, but as the technology develops, electric cells will be created that will minimize the dimensions of the electronic system.

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