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Smart apparel design for urinary incontinence detection

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Abstract. A wide range of wearable devices are now used to help people with various health conditions. While approximately 10% of the Canadian population is affected by some form of urinary incontinence, there is a significant need for devices addressing this condition. This paper presents an ongoing research project for the design and development of an underwear fitted with urinary detection capacities. The paper focuses on the testing and comparison of three different solutions identified from scientific literature for detecting urinary leakage, namely by measuring conductivity, temperature, and humidity. These three detection modules have been integrated into a single prototype to ensure that they are tested under the same conditions. Our results point out that conductivity and humidity measurements appear to be viable for urine leakage detection in an absorbent pad, whereas temperature measurement has proven to be unsuccessful due to the rapid drop of the solution temperature and the time required for the liquid to reach the sensor. The temperature method is hence excluded from the next development stages. Finally, further tests on participants are still required to evaluate how body fluids other than urine might impact conductivity and humidity measurements.

1. Introduction

Recent developments in wearable electronics are now improving the quality of healthcare as well as the quality of life of many patients. Indeed, an increasing number of health practitioners are using them to monitor the health status of their patients in a continuous and remote way. Wearable devices also allow for the collection of a greater amount of data as they are typically meant to be worn for a longer period. For certain medical conditions, this data can be used for algorithm development to predict and detect health events [1]. This is notably the case for urinary incontinence (UI), a stigmatizing medical and social issue defined as any "complaint of involuntary loss of urine"[2]. In Canada, approximately 3.3 million people are affected by some form of UI [3].

Although there are a few connected devices for incontinence on the market, they are generally designed to be worn by newborns or children. As for those intended for adults, most of them are used by health professionals within a healthcare facility. Others are designed to be placed on the bed and are therefore only useful when the patient is lying down. Most importantly, to our knowledge, none of them foster patient dignity and autonomy.

A wearable fitted with both detection and prevention capabilities has been conceptualized to meet these needs. Since the detection module will be used for the development of prevention algorithms, the first step is to ensure that it accurately detects urinary leakages. Hence, this article focuses on the ongoing

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development of an absorbent pad integrating a detection module for autonomous individuals with functional incontinence [4] or with a reduced or absent bladder filling sensation.

Three methods for urinary leakage detection were identified and selected from the literature for their estimated cost, their wearability, and their technology readiness level: (1) conductivity [5–7], (2) temperature [7–10] and (3) humidity [11,12]. Although each of these three detection methods is well documented in the literature, to our knowledge, there is no study comparing their accuracy, advantages and limits when integrated in an absorbent pad. Accordingly, this paper aims at identifying which of humidity, temperature and conductivity measurements are the most suitable and accurate for detecting urine leakage in an absorbent pad.

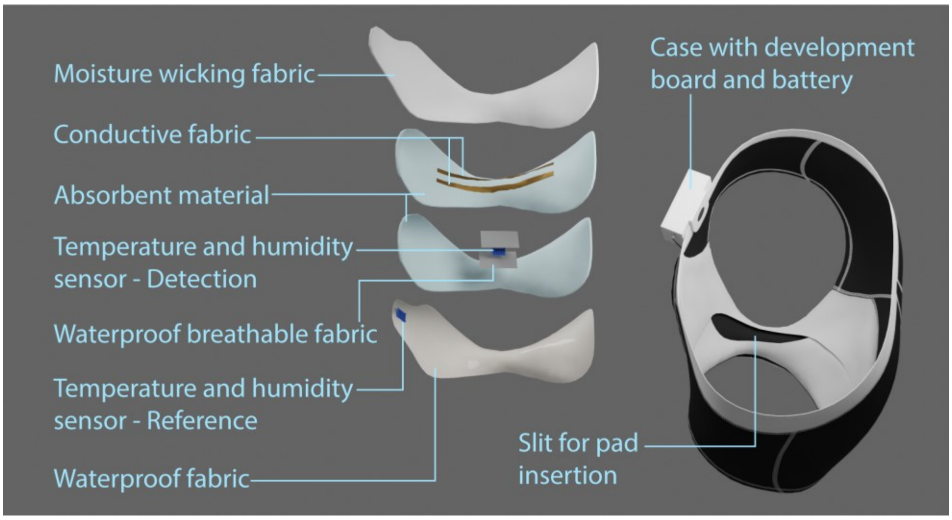

Figure 1. The prototype and its core components.

2. Material and methods

As depicted in Figure 1, the envisioned wearable takes the form of a regular underwear with an insertable absorbent pad. For testing purposes, the three detection modules have been integrated within a single prototype to ensure that they are all tested under the same conditions. The tests were performed on the absorbent pad laid flat.

For detection with conductivity, two parallel pieces of conductive fabric were placed in the absorbent pad and connected to the microcontroller (SparkFun ESP32 Thing) in an open circuit. When urine is absorbed by the pad, it creates an electrical connection between the two pieces of conductive fabric and thus closes the circuit (see Figure 2). Once the circuit is closed, a signal is sent by the microcontroller to indicate a urine leakage.

For detection based on temperature and humidity, the same sensor was used, the AHT20[3] since it can measure both. For both measurements, a detection sensor was integrated within the absorbent material, nearby the urethra, and a reference sensor was added in the pubic region for comparison (see Figure 3).

According to Eckford *et al.*, urine temperature may vary, but is always higher than 35.7 °C [8]. The microcontroller was hence programmed to detect a urine leakage with temperature when two conditions are met: (1) the detection sensor measures a temperature higher than 35.7 °C and (2) the temperature of the detection sensor is higher than the one measured by the reference sensor. Regarding detection with humidity, the code was written so that the microcontroller detects a urine leakage when (1) the relative humidity measured by the detection sensor is greater than or equal to 95% and (2) the one measured by the reference sensor is lower than 95%.

[3] https://www.adafruit.com/product/4566

Since the AHT20 sensor can be damaged by liquids, different waterproof and breathable fabrics have been tested to encapsulate it without affecting temperature and humidity measurements. These tests involved integrating a AHT20 sensor in a fabric pouch sealed with ultrasound and then immersing the pouch in warm water. The final choice of fabric to encapsulate the temperature and humidity sensor was based on four criteria, namely (1) its breathability, (2) how waterproof it is, (3) its thermal conductivity and (4) if it is well suited for ultrasound sealing. The chosen fabric is the 3L-WPB-STRETCH from Rockywoods.[4]

To simulate the average perineal temperature of a person sitting with legs uncrossed, a heating mat set to 34.1 °C was used [8] and folded over the prototype. A saline solution composed of 97.2% of water and 2.8% of sodium chloride at a temperature of 35.8 °C was used to imitate urine. To simulate a urine leakage, a syringe was used to inject 70 mL of this solution onto the absorbent pad, where the urethra would be located. Data were collected for 5 minutes after the injection and the pad had to be completely dry prior to the next test.

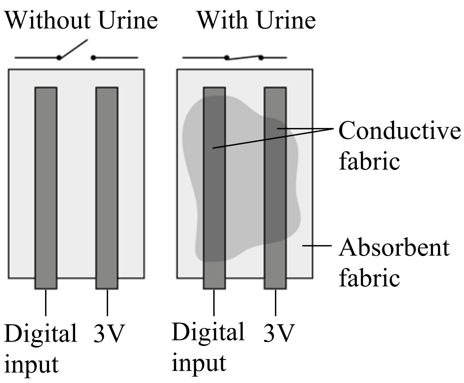

Figure 2. Basic principle for detecting urinary leakage with conductivity.

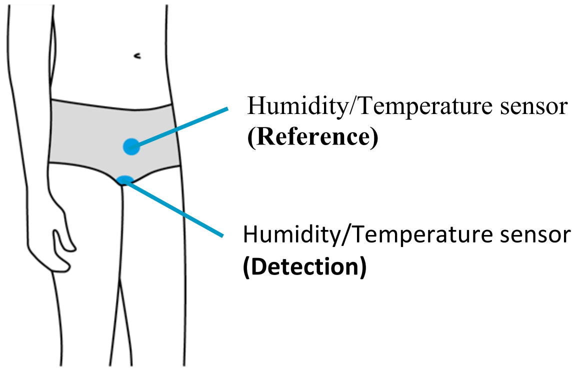

Figure 3. Basic principle for detecting urinary leakage with temperature or humidity.

3. Results and discussion

Ten tests were performed using the same prototype. The results are gathered in Table 1. For each test, the detection result is indicated (Yes/No), as well as the timespan between injection and detection – if a detection occurred. From an overall perspective, the simulated leakage was detected in ten out of ten tests with both methods using conductivity and humidity measurements. On the contrary, detection with temperature only worked in one out of ten tests.

With an average detection time of 19 seconds, measuring conductivity appears to be the fastest method for detecting urinary leakage in an absorbent pad among the three methods tested. In terms of advantages, the conductivity module has a great wearability. Indeed, it can be easily made with soft electronics, such as conductive fabric, conductive embroidery, or conductive ink, and is therefore well suited for a device intended to be thin and subtle. However, detection with conductivity does not allow to detect consecutive leakages as the pad needs to dry before detecting a new one. In addition, tests on participants are still required to determine how other body fluids, such as sweat or blood, might impact the results and whether repetitive contact with urine can degrade the conductive elements.

Similarly, other body fluids may interfere with humidity measurements, and would require further tests on participants. Furthermore, the prototype must also dry sufficiently before being able to detect a new leakage with humidity. Nonetheless, humidity measurements proved to be an avenue to further investigate.

Based on Cusick *et al.*, it was expected that temperature measurement would allow for the detection of multiple leaks without requiring the prototype to dry out, as long as temperature had time to lower

[4] https://www.rockywoods.com/3-Layer-Waterproof-Breathable-Polyester-Fabric-with-Stretch-Wild-Lime

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between events [13]. However, this could not be validated since leakage was only detected in one test. Detection based on temperature appears to be unreliable since the saline solution temperature drops rapidly after injection and leaves very little time for it to be detected by the temperature sensor. In fact, detection with temperature failed in nine out of ten tests, because the saline solution temperature was already below 35.7 °C by the time it was absorbed by the matter surrounding the sensor and passed through its protecting pouch. Nonetheless, it is important to note that the low detection rate can be due to the prototype construction and that it may be possible to overcome this problem by positioning the sensor closer to the pad surface or by using materials that channel the liquid towards the sensor. Regardless of how the prototype is built, other issues are expected to arise during tests on participants. Indeed, according to data collected by Eckford *et al.*, the perineal temperature can sometimes be higher than the temperature of urine itself, especially when a person is sitting with legs crossed [8]. This temperature increase in the perineal region can lead to false positive results. Therefore, according to our test results, measuring temperature with a fabric-encapsulated sensor placed between two layers of absorbent matter is not a reliable option as the sole means of detecting urine leakage.

	Detection with conductivity		Detection with temperature		Detection with humidity	
Test #	Yes/No	Detection time (sec.)	Yes/No	Detection time (sec.)	Yes/No	Detection time (sec.)
1	Yes	22	No	-	Yes	87
2	Yes	18	No	-	Yes	48
3	Yes	16	Yes	42	Yes	88
4	Yes	13	No	-	Yes	58
5	Yes	14	No	-	Yes	49
6	Yes	17	No	-	Yes	57
7	Yes	15	No	-	Yes	48
8	Yes	28	No	-	Yes	69
9	Yes	18	No	-	Yes	60
10	Yes	24	No	-	Yes	36

The prototype development will thus continue with detection methods using conductivity and humidity measurements. Both solutions have proven to be individually viable and their possible complementarity will be investigated during further tests on participants.

4. Conclusion

This paper focuses on identifying which of humidity, temperature and conductivity measurements are the most suitable and accurate for detecting urine leakage in an absorbent pad. The conducted tests have shown that conductivity and humidity methods appear to be viable candidates for the detection of urinary incontinence events and should be further investigated with tests on participants. A combination of these two detection methods is also considered. However, solely relying on temperature measurements to detect urine leakage has proven to be challenging as urine temperature drops rapidly after voiding and since perineal temperature can sometimes be higher than urine temperature [8]. For future work, a complementary module for urine leakage prevention will be developed using ultrasounds and/or body impedance along with algorithms for bladder volume assessment.

Acknowledgments

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Code availability

The Arduino code used to perform the tests is available at [14].

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