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# A Novel Low-Cost Sensor Prototype for Nocturia Monitoring in Older People

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**ABSTRACT** Nocturia is frequently defined as the necessity to get out of bed at least one time during the night to urinate, with each of these episodes being preceded and continued by sleep. Several studies suggest that an increase of nocturia is seen with the onset of age, occurring in around 70% of adults over the age of 70. Its appearance is associated with detrimental quality of life for those who present nocturia, since it leads to daytime sleepiness, cognitive dysfunction, among others. Currently, a voiding diary is necessary for nocturia assessment; these are prone to bias due to their inherent subjectivity. In this paper, we present the design of a low-cost device that automatically detects micturition events. The device obtained 73% in sensibility and 81% in specificity; these results show that systems such as the proposed one can be a valuable tool for the medical team when evaluating nocturia.

**INDEX TERMS** Nocturia, diagnostic test, conductivity, older adults, urination.

## I. INTRODUCTION

The International Continence Society (ICS) [1] defines nocturia as the need to wake and pass urine at night. Therefore, this definition requires that micturition be preceded and continued by sleep. In many cases nocturia is responsible for sleep disorders, which are also very common in the older people [2], [3], and in many cases nocturia is responsible for poor sleep quality. This can result in reduced concentration, cognitive decline, and poor levels of energy. This helps researchers understand some of the negative associations with overall quality of life (QoL) measurements that have been reported in the literature [4], [5]. Nocturia is not common among younger adults; it becomes more frequent in aged population reaching a prevalence of 90% in men and women. Often, Women present the nocturia symptom an age early, while men show this condition when they reach their old age [6].

Briefly, common causes of nocturia can be explained by two pathophysiological mechanisms. The first consists in an absolute increase in urine production, which can result from several diseases such as diabetes mellitus, diabetes insipidus, heart failure, or obstructive sleep apnea, among others. Several drugs, including diuretics and selective serotonin reuptake inhibitors can lead to nocturia as well. The second mechanism is tied to functional alterations of the urinary tract, such as bladder dysfunction. This phenomenon is frequently seen in diseases such as bladder outlet obstruction, detrusor overactivity, urinary tract infection, decreased functional bladder capacity, among others [7]. Moreover, nocturia is related to an increase in the risk of morbidity and, even, mortality; implicating for people that wake up two or more times during the night a QoL similar to that of diabetes type II [8]. Another risk that people with nocturia are exposed to are falls, this due to a person getting up to go the bathroom

to urinate, usually in a state of drowsiness and without paying sufficient attention to surrounding environment. A study performed with 1,500 ambulatory patients with an average age of 80 showed that individuals that got up two or three times per night to urinate had a higher probability of suffering a fall than those that did not get up [9].

Nocturia is currently assessed using interviews, micturition review charts, and questionnaires. The latter has been widely used to quantify and classify the overall severity of nocturia. A recent study carried out in [10] made a cross-sectional survey for predict nocturia and determine risk of falls in patients. Although these tools represent standard clinical practice, several limitations inherent to the subjectivity of measurements have raised concerns regarding the validity of these tools. Memory issues, which are also a common occurrence among the elderly, might further hamper the reliability of measurements; and severe impairments in cognition, such as those seen among patients with Alzheimer's disease, might even render these kind of surveys useless due to their reliance on patient reports [11]. In this work, the authors present a hybrid model for the early diagnosis of Alzheimer's disease. Furthermore, questionnaires require validation in order to allow reliable estimations to be made, which often limits their widespread use in heterogeneous clinical scenarios. Now, In [12] we can observe some specific prerequisites for the introduction of computer-based nursing process documentation systems. Having a device that automatically detects micturition events could be of great aid when trying to evaluate these symptoms; however, few investigations have been conducted in this area in an experimental form. This article presents the realization of a diagnostic test of a urination detection system based on the measurement of water conductivity found in the toilet.

In this work, we developed a low-cost system to detect nocturia and establish its overall diagnostic accuracy in both experimental and clinical settings by a diagnostic test. To evaluate our proposal, we do an exhaustive study on twenty-eight patients between 66 and 82 years-old. The proposal illustrated promising results, for example 22 patients (84.6%) showed poly-pharmacy and none had cognitive impairment. With respect to sensitivity and specificity were around to 73%, and 81%, respectively.

The article is organized as follow: Section II summarizes the work already realized in this area of study and the contribution of this present work. Section III details the development of urination sensors together with the methodology for the processing of data. Section IV establishes criteria for the selection of patients and the standard of reference. Results are shown in Section V and their discussion is detailed in Section VI. Finally, conclusions and future work are shown in Section VII.

## II. RELATED WORK AND CONTRIBUTION

Currently, very few alternative methods for micturition event detection are available in the literature. In [13], an unobtrusive and non-stigmatizing device that allowed objective measurements of nighttime micturition was proposed. The device was based on an ambulatory sensor that comprised two elements. The first was a multichannel system (SOMNOwatch(R)) that had to be worn by the user and was aimed at monitoring overall physical conditions; while the second was a room occupancy data recorder named HOBO(R) UX90-005M Room Occupancy/Light Logger (Onset Computer Corporatio, Bourn (MA), USA). The system collected data to train a classifier that allowed operators to ascertain whether a person was performing several activities of daily living. This method proved to be accurate, with an average misdetection rate of 0.32 events and a mean absolute deviation of 3.8%. Limitations of this system include that the sensor had to be worn at all times to allow a reliable detection of events, which can be uncomfortable for users, especially if long monitoring times are programmed. Associated costs were also a significant limitation. Another potential solution was reported in [14], where an Electronic Nose was developed to diagnose diabetes by odor analyses from urine. These kind of sensors permitted detecting the presence of some metabolites in urine, but again, elevated costs limited device massification.

A third potential approach to this problem consists of using the impedance method to allow detection of micturition events. This potential solution has been previously used in experiments aimed at analyzing human urine. Hisamori and colleagues [15] reported using the impedance method to quantify the amount of urine in the bladder. Given that different body components have different impedances, it was possible to perform this estimation providing an alternating current of 1[mA] and 8[Hz] to a volunteer in the abdominal area. By using Ohm's law, it was then possible to estimate the amount of liquid in the bladder. However, this experiment was not conducted in a clinical setting, thus precluding the widespread adoption of this method.

In this work, we develop a low-cost device that detects when an older people urinates, along with a diagnostic test that was used with 28 patients to validate the system. This solution, also based on the impedance method, does not need to be worn by the user to allow the detection of a micturition event. Sensors use measurements of voltage generated by the circulation of a constant current in toilet water to detect micturition events during daytime or night hours, thus allowing the detection of nocturia. The purpose of this study is to develop a low-cost system capable of detecting nocturia and to establish its overall diagnostic accuracy in both experimental and clinical settings.

## III. SYSTEM ARCHITECTURE

A non-invasive system was implemented that detects micturition events; the system is focused on older adults and the privacy of the user (see Figure 1), because we do not use invasive components, such as cameras or microphones. The tests and implementation of the system were approved by the Bioethics Committee of the University of Valparaiso (*Comité de Bioética de la Universidad de Valparaíso*).

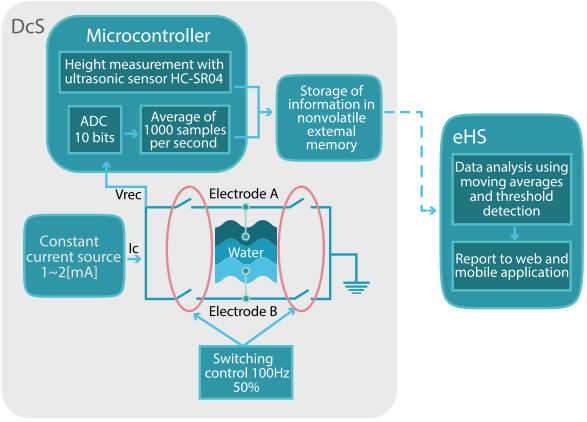



**FIGURE 1.** System architecture.

As shown in Figure 1, the micturition detection system is comprised primarily of 2 modules: the Data Capture System module (DcS) and the eHomeseniors Server module (eHS). The DcS system measures a voltage proportional to the conductivity present in the water in the toilet as well as measuring the height of the person that is using the bathroom with an ultrasound sensor. This information is stored in a MicroSD memory card each 1[s]; it is then uploaded manually to the eHS module for processing. Afterword, this data can be revised in the *http : //www.ehomeseniors.cl* web page by the patient, the person overseeing the patient, and the treating physician through a web and mobile application that is shown in Figure 2.


**FIGURE 2.** Web and mobile application.

## IV. METHODOLOGY - DIAGNOSTIC TEST

In this section first is explained the protocol used for the selection of patients who participated in the study, later the principle of functioning of the index test (sensor) is detailed and, finally, the procedure to detect nocturia is explained.

### A. SELECTION OF PATIENTS

To determine the degree of diagnostic accuracy of telemonitoring systems for the detection of nocturia, a cross-sectional study was conducted in a sample of 30 adults over 65 years old who were in medical control in the Geriatrics Service of the Limache Hospital (*Servicio de Geriatría del Hospital de Limache*). The protocol was designed based on the Standards for Reporting of Diagnostic Accuracy (STARD) for diagnostic test studies [16].

The participants selected were older adults presenting with urinary symptoms according to those established by the questionnaire International Consultation on Incontinence Questionnaire Short-Form (ICIQ-SF [17]). This tool was selected for its ease of use, its self-administering quality, and for being validated both in Spanish language and in the Chilean population [18]. Additionally, the participants had to be able to use the bathroom independently when urinating. Participants were excluded from the study if they had presented with a urinary tract infection within 30 days prior to the start of the study; if they had a form of physical impairment that prevented them from walking about freely or completing the above-mentioned questionnaire; if they had a permanent urinary catheter in place (Sonda Foley); or if they had no desire in participating in the study.

Furthermore, participants were evaluated with an initial visit to obtain a basic clinical profile and to certify the correct application of inclusion and exclusion criteria. During each visit, the ICIQ-SF questionnaire was applied and data was collected in respect to basic demographic characteristics, such as age and gender; comorbidities in agreement to those established by the Charlson Comorbidity Index (CCI) [19]; functionality baseline in activities of daily living set by the Barthel Index [20]; and the presence of concomitant geriatric syndromes. The screening visit was carried out by an occupational therapist not associated with the taking of measurement data. All data was prospectively recorded in relation to the application of index and reference tests.

### B. SENSOR DEVELOPMENT (INDEX TEST)

With the objective of detecting nocturia, an ambulatory system that measures a voltage based on the conductivity of water in the toilet to determine the time at which a person urinates was developed. Conductivity is a measurement of the capacity of an aqueous solution to transmit an electrical current and is equal to the reciprocal of the resistivity of the solution. This capacity depends on the presence of ions, on their concentration, mobility, valence, and on ambient temperature.

The DcS module describes the form in which the data is obtained. The electrodes were developed in the laboratory, which were built with two pieces of stainless steel and each one with a conductive surface of 20[$mm^2$] and separated by a distance of 2[mm]. Solid stainless steel was chosen for its great resistance to corrosion, presenting significant damage by electrolysis after one month of use, while other metals

such as aluminum and copper showed significant damage by electrolysis within a week of use which then result in a early reduction of the electrode's conductivity.This electrodes are immersed in toilet water to a depth approximated at 1[cm], where an electrical current of constant magnitude (Ic) is circulated in the environment in which they are located. To avoid electrolysis, current is injected in water through two square signals with inverted phases with a frequency of 100[Hz]. The current deployed by the Ic sensor is generated by a constant source using an amplitude of 1∼2[mA] and therefore the voltage recovered at Vrec can be obtained from Ohm's law: Vrec = Iin x R. Given that Ic is constant, Vrec is then proportional to water impedance. This variable is sampled at a frequency of 1000[Hz]. In order to reduce noise effects, samples acquired in one second are averaged and later stored in a MicroSD memory card. Therefore, the sampling frequency of the system is of 1[Hz]. In order to allow the identification of an individual using the toilet, an ultrasound-based sensor (HC-SR04) was installed in the ceiling of the bathroom and connected to the central microcontroller. Returning ultrasound waves set at a frequency of 40[kHz] were used to estimate individual patient heights. Figure 3 shows the location of the components in the bathroom.

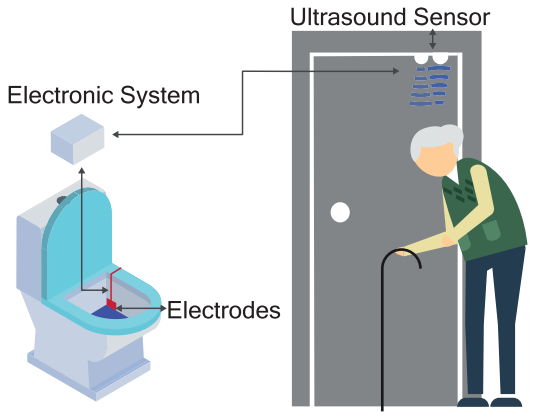



**FIGURE 3.** Disposition of the system in the patient's bathroom.

The sensor is comprised of an ATMEGA328P microcontroller, a 10-bit analog-digital converter, a 2GB MicroSD memory card, and a small source of current that circulates 1[mA] app for a pair of stainless steel electrodes. Figure 4 shows the designed and implemented system, which cost US $25 dollars.

### 1) MICTURITION EVENTS DETECTION

According to tests performed in the laboratory, the conductivity present in water can vary slightly throughout the day due to factors such as temperature, the presence of ions, and concentration, among others. Figure 6 shows the variation of voltage in relation to conductivity during the course of a day in the water of a toilet used for testing. The peaks that are observed in the image correspond to micturition events realized by academic personnel of the Universidad

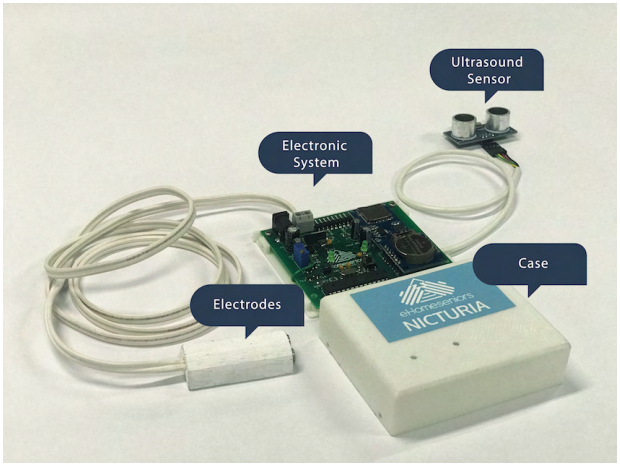



**FIGURE 4.** Details of the electronic system implemented.

de Valparaíso. Although the image shows a clear differentiation between micturition events, at times the event does not have great magnitude because of the small amount of urine evacuated and could be located within the range of variation of water conductivity from the toilet's own water. For this reason, to detect micturition events, the mobile average of the signal is first calculated by discarding the data that deviates too much from the average. A threshold is then defined to discriminate the micturition events.

The process of micturition detected by the system is dynamic, as seen in Figure 7. First, the process begins with a sudden increase of salts present in the urine, which increases conductivity due to its high salinity, followed by a small decrease in the conductivity due to the decantation of the urine in the bottom of the toilet (Figure 7 color red). The person then flushes the toilet, causing the urine to be, again, at a higher concentration with the electrodes due to the addition of water to the toilet (Figure 7 color blue). Finally, the water empties from the toilet almost entirely, which causes the electrodes to remain in the air, saturating the sensor at its maximum value (4.25 [V]) and then returning to normal levels of conductivity in the supply of potable water without urine (Figure 7 color pink).

The measured data $a_i$ are used to calculate the moving average of the signal $S_i$ using the Eq. (1).

$$\{a_i\}_{i=1}^{N} \rightarrow \{S_i\}_{i=1}^{N-n+1} \quad S_i = \frac{1}{n}\sum_{j=1}^{i+n-1} a_j \tag{1}$$

Once the mobile average is obtained, a threshold is applied at 200[MV] to this signal for the detection of the micturition events, which is established empirically. For an event to be considered micturition, it must not only fall under the established threshold but must also have a minimum duration of 10[s] under this threshold, which helps to filter out false positives present in the signal. In Figure 5, events 1 and 3 are correctly classified as micturition, while event 2 does not meet the minimum time required under the threshold that indicates a micturition event.

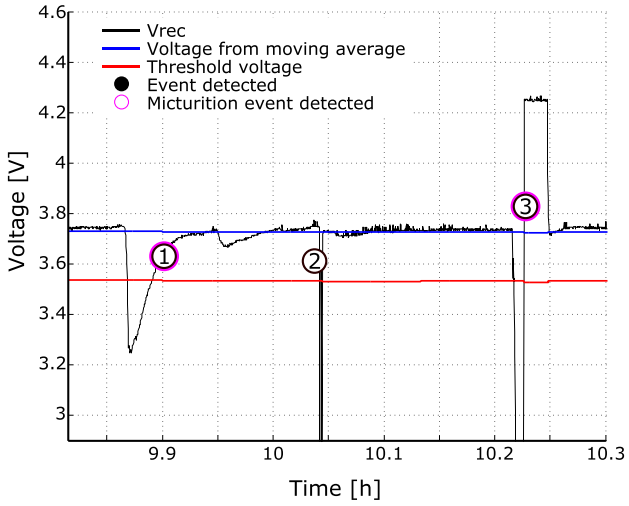



**FIGURE 5.** Detection of micturition events.

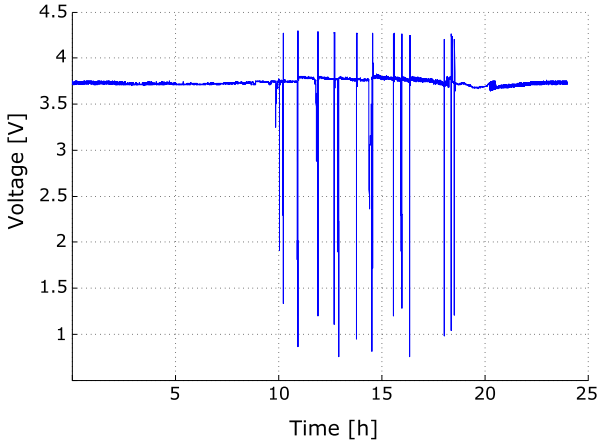



**FIGURE 6.** Voltage in relation to the conductivity captured during 24 hours with a sample rate of 1[s].

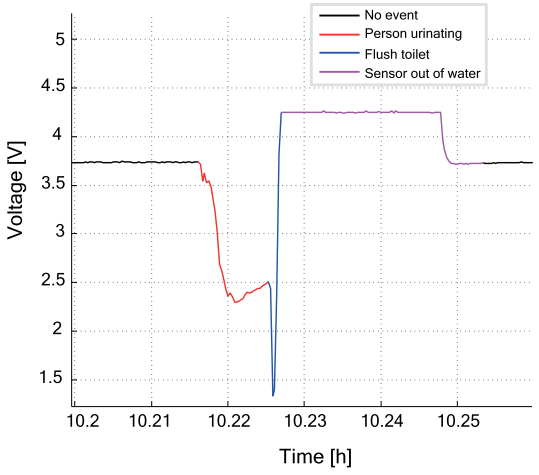



**FIGURE 7.** Dynamic behavior of micturition detection by the system.

### 2) DETECTION OF PATIENT USING ULTRASOUND SENSOR

Due to the fact that the bathroom in the home can be used by various people, and not only by the patient, it was necessary to implement a system to differentiate. For this task, an HC-SR04 model ultrasound sensor was used, which is capable of measuring distance using audio waves at 40[kHz]. This sensor was located in the ceiling close to the bathroom door, and therefore without the presence of people only measures the distance between the ceiling and the floor. Once a person passes under the sensor (Figure 3), it measures the distance between the head and the ceiling, thus determining the person's height. This data is captured at a frequency of 1[Hz] and saved together with the conductivity data. To be able to relate the conductivity data with the data from the ultrasound sensor, time windows are used. When the height of the patient is detected (different height from the other habitants of the home), an analysis is performed that determines whether micturition events exist in the underlying time window. For this diagnostic test, a time window of 10 minutes was determined, since a person, when entering the bathroom, could complete other tasks before urinating.

### C. REFERENCE STANDARD

Considering that the present study detects a symptom of alarm that may correspond to multiple causes, it is not possible to obtain an objective reference standard against which it can be contrasted. However, this situation can be effectively controlled by the application of various techniques [21]. For the present study, a panel diagnosis of the presence or absence of the nocturia symptom was used during the monitoring period. The diagnostic panel was formed by a group of 3 specialists who remained unaware of the results of the nocturia system (index test) to establish the presence of the symptom. As diagnostic criteria, the panel used the patient's reference to the frequency of nocturnal urination recorded in a voiding log (see Figure 8), the presence of comorbidities that could modify the probability of developing nocturia (heart failure, prostatic hyperplasia, etc.), and the results of the questionnaire ICIQ-SF obtained in the screening phase of this study. The last standard of reference was selected based on the symptomatic nature of the event to be detected and the ethical restrictions involved in the installation of other tests, such as camcorders, in the bathroom of the participating patients.

## V. RESULTS

In this section, first is shown a baseline characteristics of patients who participated in the study and then a summary of diagnostic capacity of the system is detailed. The older adults selected to perform the diagnostic test were evaluated in a first baseline visit where they were informed about the entire installation procedure of the systems and protocol of storage and data processing. Each of the older adults was individualized with a unique number to anonymize the databases, ensuring the privacy of the participants. Once the informed consent was signed, the ICIQ-SF questionnaire was carried out together with the Charlson Comorbidity Index and the Barthel Index. The results obtained by each patient are shown in Table 1.

Twenty-eight patients fulfilled the selection criteria and gave consent to participate in the study. Their mean age

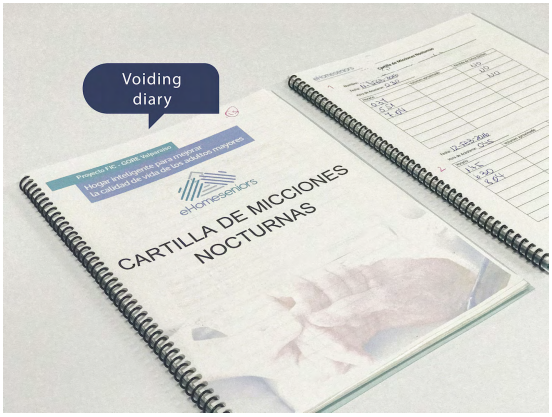



**FIGURE 8.** Voiding log used by the patient to record nocturnal micturition events.

**TABLE 1.** Results of the Barthel Index, Charlson Comorbidity Index, and ICIQ-SF questionnaire obtained by each patient.

| Patient number | Age | Sex | Bartel index | Charlson index | ICIQ-SF |
|---|---|---|---|---|---|
| 1 | 70 | F | 90 | 2 | 3 |
| 2 | 70 | F | 95 | 0 | 9 |
| 3 | 72 | F | 80 | 3 | 19 |
| 4 | 67 | F | 90 | 1 | 9 |
| 5 | 76 | M | 85 | 0 | 3 |
| 6 | 74 | F | 90 | 3 | 7 |
| 7 | 77 | F | 90 | 0 | 0 |
| 8 | 81 | F | 95 | 1 | 7 |
| 9 | 74 | F | 80 | 3 | 21 |
| 10 | 73 | F | 90 | 2 | 8 |
| 11 | 71 | F | 95 | 0 | 6 |
| 12 | 70 | F | 95 | 3 | 4 |
| 13 | 71 | F | 95 | 3 | 6 |
| 14 | 73 | F | 95 | 0 | 3 |
| 15 | 82 | F | 95 | 2 | 3 |
| 16 | 75 | M | 95 | 2 | 6 |
| 17 | 79 | F | 90 | 3 | 9 |
| 18 | 78 | M | 80 | 4 | 8 |
| 19 | 68 | F | 85 | 0 | 5 |
| 20 | 77 | M | 90 | 3 | 8 |
| 21 | 72 | F | 95 | 2 | 6 |
| 22 | 74 | F | 75 | 3 | 13 |
| 23 | 74 | F | 90 | 2 | 6 |
| 24 | 74 | M | 95 | 2 | 0 |
| 25 | 72 | F | 95 | 1 | 8 |
| 26 | 73 | F | 90 | 1 | 6 |
| 27 | 66 | F | 95 | 0 | 9 |
| 28 | 72 | F | 95 | 0 | 7 |

was 71.6 ± 3.9 years and most were female individuals (23 patients, 82.1%). Their median Charlson Index was 2 (IQR 0-3) points, thus indicating a moderate comorbidity burden; and the Barthel Index was of 90 (IQR 90-95) points, suggesting a slight dependency in basic activities of daily living. Ten patients (38.5%) presented a fall or a gait disorder; in 22 patients (84.6%) there was polypharmacy and none had cognitive impairment. All patients had urinary incontinence and 6 (22.2%) had also had episodes of faecal incontinence. The median score on the ICIQ-SF was of 7 (IQR 6-9) points. The baseline characteristics of each patient are detailed in Table 2 in supplementary material.

Participants were followed up for a median of 30 (IQR 30-31) days, adding up to a total of 832 patient-days.

**TABLE 2.** Baseline characteristics of patients.

| Characteristic | Total (n = 28) |
|---|---|
| Female gender (n,%) | 23 (82.1%) |
| Average age | 71.6 ± 3.9 |
| Previous falls from gait abnormality | 10 (38.5%) |
| Polypharmacy | 22 (84.6%) |
| Faecal incontinence | 6 (22.2%) |
| Cognitive impairment | 0 (0%) |
| Mood disorder | 13 (48.2%) |
| Sleep disorder | 13 (48.2%) |
| Malnutrition | 3 (11.1%) |
| **Results of Questionnaires** | |
| Average Charlson Index (RIC) | 2 (0-3) |
| Average Barthel Index (RIC) | 90 (90-95) |
| Median ICIQ Questionnaire (RIC) | 7 (6-9) |
| **Episodes of nocturia** | |
| Patients who present nocturia | 25 (89,3%) |
| Patients with 3 or more nocturia episodes per night | 25 (89.3%) |
| Median nocturia episodes per night (RIC) | 3 (2-4) |

A total of 2.468 nocturia episodes were registered by the patients in the void logs during this period. A median of 3 (IQR 2-4) episodes was registered per night. Table 4 in supplementary material shows the nocturnal micturition events registered in the logs, adding the '-' symbol when a patient did not register anything in the void log.

### *DIAGNOSTIC ACCURACY*

The system (test index) showed a sensitivity of 73.3% (95% CI 68.4% - 77.8%) and a specificity of 81.5% (95% CI 77.6% - 85%) to detect nights with nocturia. The associated positive predictive value was 76.4% (95% CI 71.5% - 80.7%), while the negative predictive value was 79% (95% CI 75% - 82.7%). The positive and negative likelihood ratios were 4.0 (95% CI 3.2-4.9) and 0.33 (95% CI 0.27-0.39). Table 5 in supplementary material details the events of the micturition events detected by the system and those that coincide within a range of 10 minutes with the data registered by the patients.

Upon relating the micturition data with patient detection (measuring patients height using an ultrasound sensor), the following values were obtained in relation to detecting micturition events: a sensibilty of 39.7% (95% CI 34.6% - 45.0%); a specificity of 93.0% (95% CI 90.2% - 95.2%); a positive predictive value of 82.2% (95% CI 75.7%-87.6%) and a negative predictive value of 65.6% (95% CI 61.7%-69.3%). The likelihood of positive verisimilitude was 8.8 (95% CI 5.8-13.4) and the likelihood of negative verisimilitude was 0.65 (95% CI 0.59-0.71). Table 6 in supplementary material details the micturition events upon identifying the patient using the ultrasound sensor.

A summary of the overall diagnostic capabilities of the system is provided in Table 3.

## VI. DISCUSSION

In this section the capabilities and limitations of the proposed system are analyzed based on the results obtained. We were able to successfully implement a noninvasive, low-cost noc-

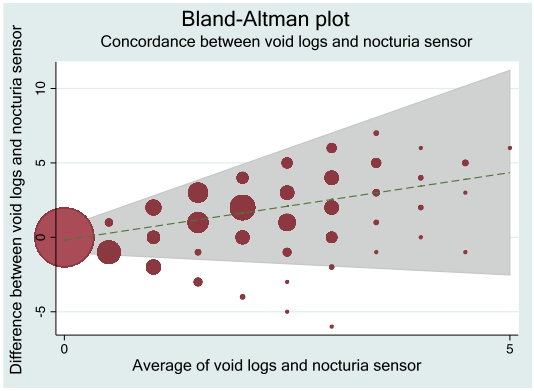
**TABLE 3. Diagnostic capacity of the system.**

| Characteristic | Diagnostic Accuracy | 95% CI |
|---|---|---|
| **Nocturia Sensor** | | |
| Sensitivity | 73.30% | 68.4% - 77.8% |
| Specificity | 81.50% | 77.6% - 85.0% |
| Positive predictive value | 76.3% | 71.5% - 80.7% |
| Negative predictive value | 79.0% | 75.0% - 82.7% |
| Likelihood ratio positive | 4.0 | 3.2 - 4.9 |
| Likelihood ratio negative | 0.33 | 0.27 - 0.39 |
| **Nocturia Sensor with Ultrasound** | | |
| Sensitivity | 39.70% | 34.6% - 45.0% |
| Specificity | 93.00% | 90.2% - 95.2% |
| Positive predictive value | 82.20% | 75.7% - 87.6% |
| Negative predictive value | 65.60% | 61.7% - 69.3% |
| Likelihood ratio positive | 5.7 | 4.0 - 8.2 |
| Likelihood ratio negative | 0.65 | 0.59 - 0.71 |

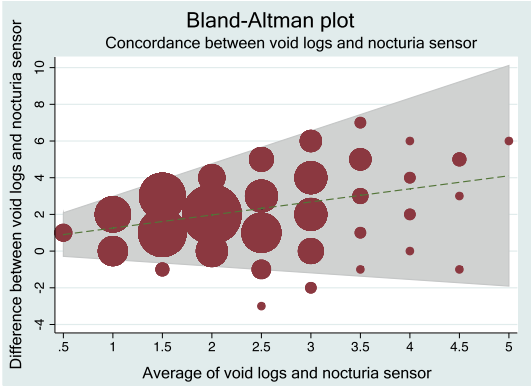
turia system in a real clinical setting. A significant limitation of the proposed system stems from the use of an ultrasound sensor to allow for patient identification. Ultrasound waves can be imprecise in establishing an individual's height due to a myriad of colloquial factors, such as the type of shoes worn by individuals, changing haircuts, or hats. However, this approach was chosen because of the ethical implications incurred in using more precise systems, such as video cameras, within an individual's bathroom. In addition, ultrasound sensors are relatively inexpensive and do not need to be worn by patients to provide readings.

When the overall concordance between the system and reference standard were analyzed, a bias (mean difference) of $-1.0$ events per night was noted. This suggests that the system tended to underestimate the frequency of nocturia episodes in this experience. The Bland and Altman's limits of agreement were $-2.7$ - $+4.2$. An increase in error rates was also found with increasing frequencies of nocturia episodes ($p<0.001$), which are shown in Figure 9(a). This phenomenon was more apparent when nights without nocturia were excluded from analyses, as shown in Figure 9(b). As in the previous case, the void log detected 1 more episode of nocturia than those recorded by the system with ultrasound during the follow-up period. The agreement limits of Bland and Altman were wide, between $-2.7$ and 4.8, noting also an increase in the variability and potential of error while more episodes of nocturia are recorded per night ($p < 0.001$), which are shown in Figure 10(a). This phenomenon was more apparent when nights without nocturia were excluded from analysis, as shown in Figure 10(b).

During the follow-up days, patients 10, 17, and 25 mistakenly disconnected the system on follow-up days 8, 5, and 3 respectively. In addition, several patients forgot to record some micturition events, were erroneously recorded, or were written in an illegible way to be admitted to the system, which affected the accuracy of the sensor. At the same time, the system showed a clear reduction of the detection of micturition events from day 22 of follow-up, this because the electrolysis produced by the circulation of electric current damaged the electrodes, affecting the measurements. An easy solution to this problem is to change the electrodes every 20 days,




(a)



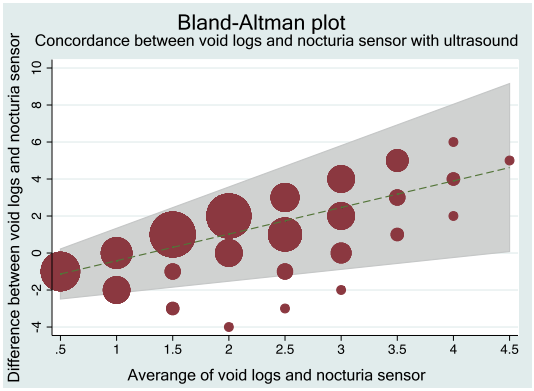

(b)

**FIGURE 9. (a) Concordance between system and void logs (all episodes). (b) Concordance between system and void logs (excluding nights without nocturia).**

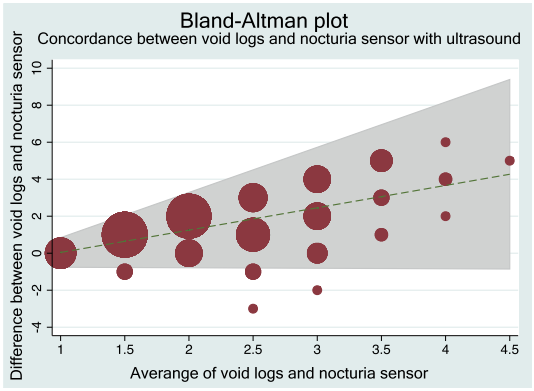
whose cost does not amount to more than US $1 dollar and is of rapid implementation.

A fair diagnostic accuracy was found in this experience, which could translate into a new telemonitoring platform aimed at improving symptom control of several diseases or treatments that might induce nocturia. Common examples include heart failure, diabetes, benign prostatic hyperplasia, and diuretic use, which are commonly prescribed drugs in the management of arterial hypertension. Symptom control could then result in improvements in quality of life, which is frequently diminished amongst patients with nocturia. A further niche for the system described here could be assisting rehabilitation programs for patients with urinary symptoms undergoing behavioral therapies. This device provides a reliable estimate of micturition events, thus providing valuable information regarding intervention effects at the caregiver's disposal. The low cost of the system presented here, it's easy installation and it's performance detecting nocturia make it a good alternative to the systems shown in [13]–[15].

One way to improve the nocturia detection system would be to implement better ways of modulating and intensity of




(a)




(b)

**FIGURE 10.** **(a) Concordance between system with ultrasound and void log (all episodes). (b) concordance between system with ultrasound and void log (excluding nights without nocturia).**

the current flowing through the electrodes to increase the life of these to more than 20 days. It would also be possible to improve the precision, specificity and sensitivity of the system through the implementation of recurrent neural networks that can analyze the conductivity signal in the search for nocturia events.

The impedance method might also be useful in detecting specific components within the patient's urine, such as leukocytes, red blood cells, or protein. This could in turn result in a system able to provide valuable information to screen for several other conditions ranging from diabetic neuropathy to neoplasms of the urinary tract. Also, using wireless technology like WiFi would be a useful technology for send nicturia events in real-time to server which could improve the analysis made by medical team.

## VII. CONCLUSION

The presence of nocturia is a common event studied among older adults. The intensity of the study was related to the selection criteria of the patients, which were implemented to ensure an adequate number of events to be detected by the system. In general, the nocturia system seems to have adequate diagnostic skills in detecting nocturia symptoms in older adults. The loss of sensitivity with the use of ultrasound to identify the patient suggests that this would not be a functional method for obtaining the proper identification of patients when conducting tests.

The concordance between the system and standard of reference composed with void logs and clinical evaluations by a geriatrician are acceptable, with very low levels of error when detecting few episodes of nocturia per night. However, error increases significantly when episodes of nocturia per night are increased. Future improvements for this device include real-time urinary component analyses, allowing the detection of significant metabolites, such as urea or albumin, to be made.

As future work, the nocturia detection system will be integrated into a monitoring platform for older people care, using the Internet of Things for Health (IoHT) [22], [23], via social systems (SIoT) [24], improving the data send process. This method can led the research toward new study lines, such as [24]. In addition, interoperability will be integrated through Middleware [25] to facilitate the integration of new systems such as remote heart rate monitoring [26].

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