An Ambulatory Sensor-Based System for Quantification of Nighttime Micturition for Accurate Nocturia Assessment

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***Abstract*— Nocturia is a widespread condition where patients need to micturate frequently during the nighttime. In order to define treatment and measure therapeutic success in nocturia, questionnaires are traditionally used for ambulatory assessment. However, questionnaires were reported to suffer from compliance, embarrassment and subjective bias. An automatic sensor-based system for quantification of nighttime micturition for accurate nocturia assessment would not suffer from these disadvantages, and its development was therefore the purpose of this study.**

We defined a sensor-based system for ambulatory use, consisting of a sensor watch and a room occupancy sensor. Using this system, we so far collected data from 6 participants and 82 nights in an ongoing study. We report the details of the system, as well as the data analysis. The system is very accurate, with an average misdetection rate of 0.32 and a mean absolute deviation of 3.8 % when comparing the average number of nighttime micturitions. This novel sensor-based nighttime micturition quantification system has the potential to be used as an objective ambulatory assessment tool for nocturia diagnosis and treatment.

I. Introduction

Nocturia is defined by the International Continence Society as "the complaint that the individual has to wake at night one or more times for voiding" [1]. Different studies report nocturia to be a widespread condition [2, 3], becoming more common with age. More than 50 % of men and women over the age of 60 have been measured to suffer from nocturia [4, 5]. Nocturia negatively impacts sleep quality, concentration ability, mood, and ultimately the overall quality of life [6].

Traditionally, in order to define treatment and measure therapeutic and medication success in nocturia, the attending physician hands out questionnaires to patients for ambulatory employment. The International Prostate Symptom Score (IPSS) is the most common example for such a questionnaire [7]. It measures, amongst other parameters, the frequency of nighttime toilet visits (micturition) over a period of 14 consecutive nights.

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However, the use of questionnaires introduces several potential error sources. It requires the patients to give precise feedback on the typical frequency of an automatic and therefore difficult to remember task. Answering specific questions about prostate function might be embarrassing and therefore lead to false reports. Furthermore, as the authors of [8] have shown, the subjective assessment of the nocturnal frequency in the IPSS only agrees poorly with objective assessment. Therefore, it is assumed that an automatic, sensor-based measurement system for ambulatory nocturia assessment would allow measuring objective data and provide better accuracy for treatment definition and medical intervention evaluation. There is an unmet clinical need for such a system. The constraints for its development are that it has to be unobtrusive, non-stigmatizing, and work with minimal interaction by the patient.

Automatic, sensor-based assessment systems with similar constraints have been developed that allow automatic assessment of sleep [9], daily life activities [10], and several medical conditions like Parkinson's disease [11], stroke [12], and arrhythmia [13]. Such sensor-based, wearable computing systems have opened numerous possibilities for ambulatory patient monitoring over extended periods of time [14]. However, to the best knowledge of the authors, a sensor-based system for the application in ambulatory quantification of nighttime micturition has not been presented so far. Therefore, the purpose of this paper is to propose such a system and evaluate its accuracy in objectively quantifying nighttime micturition.

II. Methods

A. Ambulatory Sensor System

The ambulatory system was chosen in order to be unobtrusive and non-stigmatizing for the patient. Furthermore, it was also required to necessitate minimal interaction with the patient, and to record data for at least 14 consecutive nights (the same period that the IPSS questionnaire measures).

The proposed system consisted of two components that were given to study participants for ambulatory use. The first component was a sensor watch (Somnowatch plus, SOMNOmedics GmbH, Randersacker, Germany; Fig. 1), which was worn by the participants and collected activity data. The second component was a room occupancy sensor (HOBO UX90-005M Room Occupancy/Light Logger, Onset Computer Corporation, Bourne (MA), USA; Fig. 2), which was placed in the bathroom of the participant and collected room occupancy data.

The watch (Fig. 1) was worn by participants on the wrist of the preferred arm during the complete study period. It recorded the summed magnitude of its inbuilt three-axis accelerometer with a sampling rate of 8 Hz. It also recorded ambient luminance by an inbuilt light sensor with a sampling interval of 30 s. Both activity and luminance data were provided by an internal algorithm on an arbitrary linear scale between zero and 1000 in steps of one. Furthermore, the watch provided a button (Fig. 1) that can be used by the wearer to place a marker in the data. Participants were asked to use this button to indicate the beginning and end of their bedtimes.

Figure 1. The Somnowatch plus that was worn by study participants. The light sensor (upper left) and the button that can be used to place a marker in the recorded data (center) are also visible.

The room occupancy sensor (Fig. 2) was placed by the study coordinator in a convenient location in the bathroom before the beginning of the recording period of 14 nights. It recorded room occupancy over the complete recording period with a sampling interval of 10 s. The sensor data were provided by an internal algorithm as the percentage of each sampling interval that the room was occupied in steps of ten percent.

Figure 2. The HOBO UX90-005M Room Occupancy/Light Logger that was used during the study.

The complete ambulatory system was picked up from study participants by the study coordinator after the completion of the recording period. Data were then downloaded from both components using commercially available software. We used the software Domino light (SOMNOmedics) for the watch, and the software HOBOware Lite (Onset Computer Corporation) for the room occupancy sensor. The extracted .csv files were stored for further processing.

B. Study Details

The ongoing study was in confirmation with the declaration of Helsinki and was approved by the Ethics Committee of the University Hospital Erlangen, Germany (Re-No. 106_13 B). Participants were acquired by urology experts (of the University Hospital Erlangen and several participating registered urologists in private practice) that assured that inclusion criteria were met. The inclusion criteria were a diagnosed benign prostrate syndrome and a resulting average number of nighttime micturition of two or greater. This ensured a sufficient number of events during the study.

The study was explained to participants and they subsequently signed informed written consent. For a quantification of symptoms prior to measurement, the participant had to fill in an IPSS questionnaire. Further, it was noted whether other persons also used the toilet during the nighttime and whether the participant slept alone.

Besides the ambulatory sensor system, a micturition protocol for each night was handed out to participants. The protocol had to be filled in by the participant and indicated the times they had to micturate during the nighttime. We specifically asked participants to fill in the protocol as objectively and as soon after bedtime as possible. This protocol was the basis for algorithm evaluation.

Up to now, we collected data from six participants (Tab. I) using the described study protocol. Only data from twelve nights was available for participant four, as this participant underwent prostate surgery the morning after night twelve.

TABLE I. INFORMATION ABOUT PARTICIPANTS.

Subject	Age	Pre-study nighttime micturition	IPSS score
1	67	2	6
2	60	3-4	14
3	76	4	15
4	66	5	28
5	67	3	22
6	57	3	16

C. Data Processing

In order to prevent misdetections, the data from the two components of the ambulatory sensor system had to be fused. Neither component could detect nighttime micturition alone. The data from the watch could show activities due to several reasons (e.g., fitful sleep, leaving the bed for reasons other than to micturate). The data from the room occupancy could show activities due to persons other than the participant entering the bathroom.

Before sensor data fusion for nighttime micturition quantification, we identified start and end of bedtime. First, the start of bedtime was identified. If a marker was placed by the participant, the exact time of the marker was used. If no marker was present, the starting time of the first period of at least twenty minutes of activity and luminance values below the empirically defined threshold value ten was used. Then, the end of bedtime was identified. If a marker was placed, the exact time of the marker was used. If no marker was present, the starting time of the first period of least sixty minutes of activity and luminance values above the threshold value ten

was used. The time between these markers was the basis for nighttime micturition quantification [7]. Only the data between these markers were used for subsequent processing.

For nighttime micturition quantification, we fused the sensor information of the watch and the occupancy sensor in three steps. First, the data of the room occupancy sensor was searched. Candidate nighttime micturitions were identified, if the room occupancy sensor showed values above 10 % in a sliding window of length 60 s. Second, these candidate time slots were compared with the activity and luminance data of the watch. If activity and luminance values higher than ten were found, the candidate was counted as a nighttime micturition. Third, for a more detailed analysis, the start and end of a toilet visit was identified. The first instant of activity values above ten after a period of 10 s of consecutive activity values below ten was defined as start of the toilet visit. Analogously, the last instant of activity values above ten before a period of 10 s of consecutive activity values below ten was defined as end of the toilet visit. This procedure is exemplified in Fig. 3.

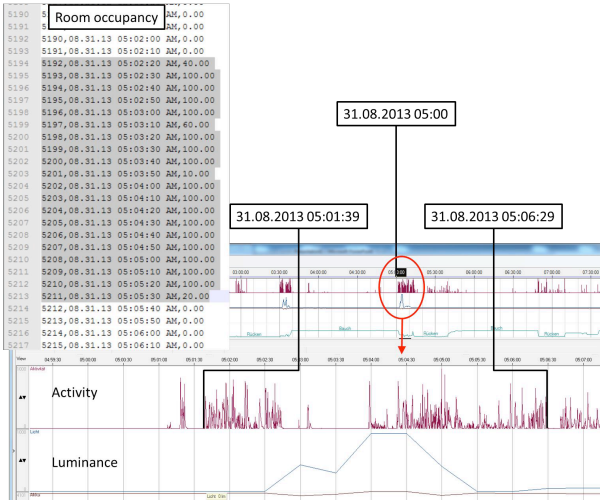

Figure 3. Example for a night-time micturition. The participant noted a micturition at 05:05:00. The room occupancy data (upper left part) identifies a time slot between 05:02:20 and 05:05:30. Connected activity clusters in the watch data (lower central part) around this time slot with a luminance change within this time slot yield to a labeling between 05:01:39 and 05:06:29.

D. Evaluation

The quantities of the automatic data processing described above were compared with the entries in the micturition protocol.

III. Results

Tab. II shows the number of sensor-detected micturitions for each night and each participant as compared with the entries in the micturition protocol.

Tab. III shows the mean absolute deviation of the number of sensor-detected micturitions for each participant as compared with the entries in the micturition protocol. The mean absolute deviation over all participants and all nights was 0.32.

Tab. IV shows the average number of nighttime micturitions as entered in the protocol and as detected by the sensor system, and the deviation between the values. The mean absolute value of all deviation was 3.8 %.

TABLE II. Number of nighttime micturitions as entered in the protocol (left number) and signed deviation as detected by the ambulatory sensor system (right number).

Night number	Participant number					
	1	2	3	4	5	6
1	2–1	1±0	5±0	5±0	3±0	4±0
2	2–1	1±0	3±0	5±0	3±0	3±0
3	2–1	1±0	4±0	5–1	2±0	3–1
4	2+1	2±0	5±0	6–1	3–2	2+1
5	2–1	1±0	4±0	6±0	2±0	4±0
6	2±0	3±0	4±0	5±0	2±0	4±0
7	0±0	1+1	4±0	3+1	2+1	3–1
8	2±0	2±0	6±0	3±0	2±0	2±0
9	1+2	3±0	4±0	5±0	2+1	3±0
10	1±0	0±0	5±0	3–1	2±0	4±0
11	0±0	2±0	7–1	6–2	2–1	1±0
12	2±0	1±0	4±0	4–1	2±0	3±0
13	2+1	1±0	6–1	-	3±0	2±0
14	0±0	1±0	3±0	-	2±0	3±0

TABLE III. Mean absolute deviation (MAD) of the number of nighttime micturitions as detected by the ambulatory sensor system in absolute numbers and percentage.

	Participant number					
	1	2	3	4	5	6
MAD	0.57 40.0 %	0.07 5.0 %	0.14 3.1 %	0.58 10.7 %	0.36 15.6 %	0.21 7.3 %

TABLE IV. Average number of nighttime micturitions as entered in the protocol (ANP), average number of nighttime micturitions as detected by the ambulatory sensor system (ANS), and deviation (DEV) between the two values.

	Participant number					
	1	2	3	4	5	6
ANP	1.43	1.43	4.56	4.67	2.29	2.93
ANS	1.43	1.50	4.43	4.25	2.21	2.86
DEV	0.0 %	4.9 %	–2.9 %	–9.0 %	–3.5 %	–2.4 %

IV. Discussion

In this paper, we proposed a sensor-based system for ambulatory quantification of nighttime micturition frequency and evaluated its accuracy. The results showed that the system is accurate, with an average misdetection rate of 0.32 and a mean absolute deviation of 3.8 % when comparing the average number of nighttime micturitions. Especially a precise quantification of nighttime micturitions over a longer study period is important for nocturia assessment [7]. Our proposed system is accurate in this respect, which is why it has the potential to be used as an objective ambulatory assessment tool for nocturia diagnosis and treatment.

Anecdotally, we can already report results from such a nocturia treatment assessment. In our ongoing study, some of the participants were subject to medication treatment in order to reduce the nighttime micturition frequency. One example is participant six, who took the drug “Prostagutt Forte 160/120” (Dr. Willmar Schwabe GmbH & Co. KG, Ettlingen, Germany) two times a day (in the morning and

evening), starting before night six. As can be seen from Tab. II, the trend in the nighttime micturition frequency is towards less frequent toilet visits after start of medication intake (average number of nighttime micturitions before night six is 3.20, average number of nighttime micturitions after night six is 2.63). More of these objective treatment assessment results can be expected after completion of our study.

The current study setup and analysis procedure exhibits several possibilities for improvement. First, the number of participants needs to be higher in order to make a more substantial evaluation of the proposed system possible. Second, the algorithm for start and end of bedtime and of a toilet visit can be substantially improved by making use of automatic pattern recognition methodology as it was for example presented in [15]. We will aim at improving these aspects in the future work in our ongoing study.

One definite disadvantage of the study that was presented in this paper is the employment of a micturition protocol. As already stated in the introduction, questionnaires for self-reporting suffer from compliance, embarrassment and subjective bias [8]. It can be speculated that some of the misdetections shown in Tab. II are actually errors in the self-report. However, the application of a micturition protocol was the only available means for providing ground truth information. The application of video cameras or human observers is not feasible in this particularly private home monitoring scenario. We are quite positive that, by using an unobtrusive room occupancy sensor, we could propose a system that meets the privacy requirements of its users. None of our study participants reported otherwise.

In summary, our proposed system is unobtrusive, non-stigmatizing, and works with minimal interaction by the patient. Since it provides accurate quantities of nighttime micturition, we conclude that its application in ambulatory assessment of nocturia is feasible. The system can therefore be used as an assessment tool for nocturia diagnosis and treatment. Treatments could be both drug administration and surgical procedures. In the case of drug administration, the system could be used to fine tune dosages, in the case of surgical procedures, the system could be used to monitor post-surgery development to assess surgical effectiveness. Overall, the system has the potential to deliver accurate and objective values for defining treatment and measuring therapeutic and medication success in nocturia.

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