Revolutionizing Patient Care: An Autonomous System for Supervision of Diuresis Measurement Using the Internet of Things in Medical Devices

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***Abstract*— This work proposes the development of an Autonomous System for Supervision of Diuresis Measurement (ASSDm) in medical devices to monitor patients. The system aims to minimize human interaction, allowing for the interpretation and dissemination of urine measurement information. By utilizing Electronic Instrumentation techniques and exploring IoT-based data communications, the ASSDm has the potential to provide autonomous and non-invasive electronic surveillance in monitoring urine accumulation in collection bags. This proposal introduces a new concept of remote sensing signal processing in medical devices, as revealed by the obtained results.**

***Keywords*— Biomedicine, Urine Collection, IoT electromedical, Medical Communication Systems.**

Fig. 1. Urine Collection Bag Attached to the Bed in a Hospital Setting

I. Introduction

In today's age of technology, new solutions are constantly being developed to improve the quality of medical care and make the job easier for healthcare professionals. One of these solutions is the use of electronic devices connected to the internet, known as the Internet of Things (IoT). Therefore, this project will explore the application of IoT, offering a significant differential over traditional methods of patient monitoring.

This proposal enables a new, more connected approach and facilitates the interpretation of specific clinical situations. By utilizing IoT, the proposed system is able of collecting, analyzing, and share a wide variety of measurements at a frequency higher than those performed by humans, enabling a more efficient and accurate monitoring of the patient by healthcare professionals [1], [2].

The medical procedures that allow the constant elimination of urine through dripping are common practices in healthcare [3], [4]. Therefore, the use of a collecting bag equipped with an anti-reflux valve and a drainage tap at the bottom is necessary to assist in the emptying of urine throughout the day. This bag accumulates the patient's urine during the treatment.

In Figure 1, a general overview of its usage in a hospital setting is shown.

The main activity of healthcare professionals, which involves the collection of urine, is the analysis of the patient's fluid balance, where the loss of fluids is determined through urine collection. This monitoring is done manually, usually in a time interval of 24 hours [3], [4]. This process requires healthcare professionals to physically move and go to each patient's bed who are undergoing the procedure to measure the accumulated urine collection [5].

In this context, the healthcare professional individually reads each patient, checking the amount of fluid accumulated in the urine collection bag. This measurement is obtained by observing the volumetric gradation indicated on the urine collection bag or with the aid of a graduated cylinder [6]. Finally, the fluid balance calculation is performed manually, considering the difference between the amount of fluid the patient receives and the amount of fluid expelled through urine [4].

Thus, the manual monitoring of procedures in determining fluid balance introduces a demand to healthcare professionals, often generating rework and constituting an additional burden to these professionals. An example is the archiving of this information for electronic recording purposes. In many cases, this recording activity can consume a significant volume of hours of the health professional, taking him away from his specific functions of action.

As a result, this article highlights three primary contributions:

- The work proposes the development of ASSDm, an autonomous system based on the Internet of Things applied to medical devices, aiming to introduce a new autonomous method for monitoring urine accumulation in the collecting bag.
- The proposal of ASSDm is to utilize techniques of

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Electronic Instrumentation and sensing through the use of load cells to infer and disseminate relevant information about urine measurement, providing electronic, autonomous, and non-invasive surveillance, reducing the need for human interaction during the supervision and recording process.

- The approach introduces a new concept for the monitoring urine measurement procedures in patients, exploring the resources of IoT to contribute to discussions on the potential applications of connected autonomous medical devices, with the aim of enhancing efficiency and precision in healthcare.

The rest of the text is organized into the following sections. Section 2 discusses implementation aspects on the Measurement Platform. Section 3 describes the results of the evaluation of ASSDm from the perspective of a functional prototype. Section 4 Proof-of-Concept Evaluation Discussions and directions for future research. Section 5 presents the conclusions.

II. Implemented Aspects in the Measurement Platform

On the process of measuring the accumulated urinary liquid volumes in the urine collection bag, an industrial strain gauge sensor, specifically a load cell, was used as the basis.

Therefore, the electrical signal output of the strain gauge corresponds to voltage values related to the strength of the weight of the urine collecting bag. The difference between the voltage outputs was used to define the urinary fluid volume profile.

It is important to highlight that the use of load cells for obtaining liquid volumes in the healthcare field is a widely adopted practice [7].

In this way, a mechanical-electronic-computational system was developed, utilizing the strain gauge sensor as the measurement method. This designed physical system allowed the collection of information about accumulation of liquid in the urine collection bag. These pieces of information were shared through remote servers, enabling for shared access, as discussed in the following subsections.

A. Mechanical Aspect

The design of the measurement platform, ASSDm, was designed considering the normative requirements that specify sets of rules for functional behaviors and the physical characteristics related to safety and performance requirements of electromedical equipment [8].

Hence, ASSDm is an instrumentation system that enables the acquisition of data on the liquid accumulation in the urine collection bag by measuring the expelled liquid quantity from the patient. This acquisition was achieved through the implementation of a sensing method within the urine collection bag. The designed proof-of-concept system, as depicted in Figure 2, encompasses the medical device urine collection bag (comprising tubes and the urine accumulation reservoir), the strain gauge sensor, and the developed hardware and firmware.

The measurement platform presented in Figure 2 was developed in three stages: (i) the construction of a mechanical

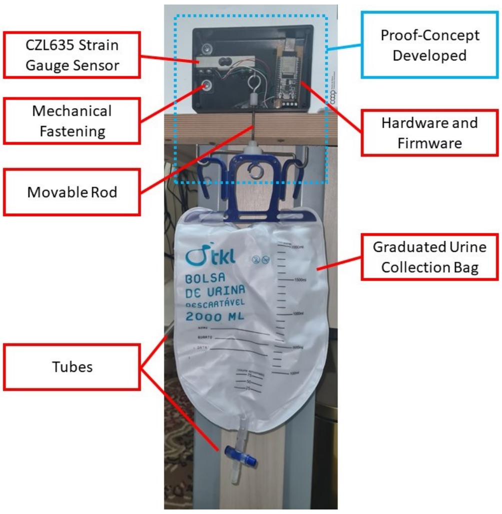

Fig. 2. ASSDm: Platform Designed for Measuring Urine Volume Accumulation in the Collection Bag.

system capable of withstanding continuous measurement and a weight force exceeding the maximum accumulation limit of 2 liters without damaging the structure; (ii) the development of a suitable electronic system for data acquisition, pre-processing of the electrical signal, and data logging; (iii) the programming of the firmware to create a supervisory management system and remote sharing of the stored data.

B. Electronic Aspects

During the development of the prototype as a proof of concept for the ASSDm device, an electronic design was developed, which consists of an electrical circuit board, also known as a *Printed Circuit Board* (PCB), specifically tailored to meet the project's requirements.

Therefore, the main considerations regarding the developed PCB are as follows: (i) electrical safety for medical applications according to the IEC 60601 [8] standard; (ii) sensing capability to perform electrical measurements; (iii) enable communication with the internet; and (iv) compact size.

In Figure 3, the electrical features that are part of the PCB design are presented. It should be noted that this hardware, along with the firmware, comprises the ASSDm Measurement Platform item, illustrated in Figure 2.

During the development of the PCB, the ESP32 microcontroller was chosen due to its widespread use in the field of electronics and embedded systems, primarily because of the following characteristics: (i) versatility; (ii) low power consumption; (iii) availability of a wide range of libraries; (iv) cost-effectiveness; (v) support for various digital communication interfaces between sensors and the internet; and (vi) documentation provided by the scientific community in IoT applications [9], [10].

It is important to remember that the measurement system employs the use of a load cell, which measures the weight force at the anchor point from which all electrical data is inferred. The load cell has the electrical characteristic of changing its electrical resistance based on the applied load.

Thus, it is possible to read the electrical signals that, properly characterized, can be processed to correlate with the volume of fluid accumulated in the urine collection bag.

In the electrical connection between the $CZL635$ load cell and the $ESP32$ microcontroller, the electronic component $HX711$ was used. The $HX711$ is an amplifier and analog-to-digital signal converter chosen for its features, including: (i) 24 bit resolution; (ii) measurement accuracy; (iii) linearization; (iv) SPI (*Serial Peripheral Interface*) digital communication interface; (v) low noise; and (vi) stability [11].

In Figure 3 a), the electrical schematic designed for the functional prototype of the proof of concept is shown. In Figure 3 b), the developed printed circuit board (PCB) is presented with the connection of the $HX711$ component. In Figure 3 c), the same PCB is shown with the connection of the $ESP32$ microcontroller on top of the $HX711$ component. Finally, Figure 3 d) displays the image of the $CZL635$ load cell sensor.

The design of the PCB considered mainly the aspect of compact size, with the objective of adding aspect of a functional prototype that would cause the least physical impact in the hospital environment. It is enclosed in an insulating material, using engineering polymers, which ensures Class 2 electrical isolation. These physical characteristics can be observed in Figure 2, highlighted as the "Proof-of-Concept Developed". Please note that the figure labels and descriptions may vary based on your specific article format and style.

C. Firmware Aspects

The measurement system firmware was developed in MicroPython under ESP32. The choice of MicroPython is justified by it being an open-source implementation of the Python programming language that has been optimized to run on microcontrollers and embedded systems [10].

The main functions of the firmware implemented in ASSDm are as follows: (i) configure the hardware; (ii) manage the data collection from the sensor; (iii) share the data with a cloud server; and (iv) synchronize events over time using the *Network Time Protocol* (NTP) for time synchronization.

It is important to highlight that the NTP protocol allows for the synchronization of the device's clocks in a network based on reliable time references [12]. This temporal synchronism is crucial in establishing the rate of fluid loss from the patient. Accurate time measurement enables the precise calculation of fluid balance through synchronized electronic recording based on world time, ensuring the accuracy of the collection moment and eliminating the reliance on manual registration in the patient's medical records system.

D. Software Aspects

The chosen cloud service, *ThingSpeak*, should be capable of connecting the prototype to the internet through the ESP32, utilizing IoT communication protocols. Several essential aspects were considered in the selection of ThingSpeak, with the aim of: (i) ensuring an efficient system; (ii) providing an *open-source* IoT platform; (iii) offering reliability and ease of use in information sharing; and (iv) allowing access from various computing devices.

The application of the *ThingSpeak* software highlights the following key IoT features: (i) an intuitive user interface; (ii) compatibility with various devices and operating systems, including iOS, Android, Windows, and MacOS; (iii) data security and privacy, with compliance to privacy regulations and standards; and (iv) the use of the *Message Queuing Telemetry Transport* (MQTT) protocol, known for its lightweight message handling and subscription-based approach [13].

It is important to note that the use of the MQTT protocol is suitable for communication between Internet of Things (IoT) devices with limited bandwidth resources [13].

By considering these aspects during the software design, it is possible to create an efficient and reliable application to utilize *ThingSpeak* for measuring the accumulated volume of liquid in the urine collection bag. These aspects ensure usability, data security, and privacy, providing a valuable tool for patient monitoring and care.

In addition, *ThingSpeak* offers advanced data storage and analysis features. By sending the data to the cloud, it can be accessed at any time and from anywhere, making it easy for healthcare professionals to follow up remotely. The platform also enables data visualization through customizable graphs and widgets, making it easier to interpret the data and identify relevant trends or patterns.

Therefore, the use of *ThingSpeak* for sending data of the measurements of urine accumulation in the collection bag to the cloud presents solid justifications, including continuous and accurate measurements, remote access to data, and patient data security. This innovative approach contributes to more efficient monitoring, improving care and quality of life for patients with conditions related to renal function.

III. Results

The analysis of the results was made in the perspective of evaluating the proof of concept, with analysis of this ASSDm Measurement Platform conceived. Having as an outcome, if it has utility of a functional prototype for which it is intended.

Thus, it was revealed that the use of ASSDm enables more efficient and accurate monitoring of patients' urine output. The integration of IoT technology into the ASSDm device allows for automatic data collection and real-time monitoring, enabling a greater number of data points to be collected. This, in turn, provides a more comprehensive and detailed assessment of the patients' clinical condition. The following sections describe and present the results obtained through this approach.

In order to collect data on the accumulation of urine volume in the collection bag, a simulated liquid flow rate was introduced drop by drop into the urine collection bag over a period of 30 minutes. This liquid flow rate resulted in the flow behaviors depicted in Figures 4 and 6.

Table I displays information sent to the cloud: [Time] collection time, [ID] reading number, [R-Urine] weight, and [V-URine] accumulated volume.

The information regarding the profiles of accumulated urine volume in the collection bag can be accessed on multiple

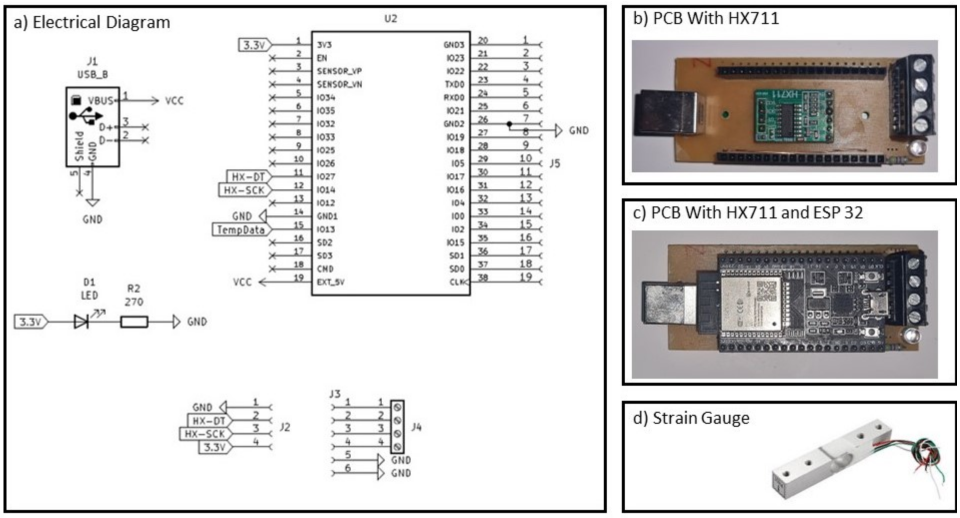

Fig. 3. ASSDm: Hardware Developed for the Measurement System.

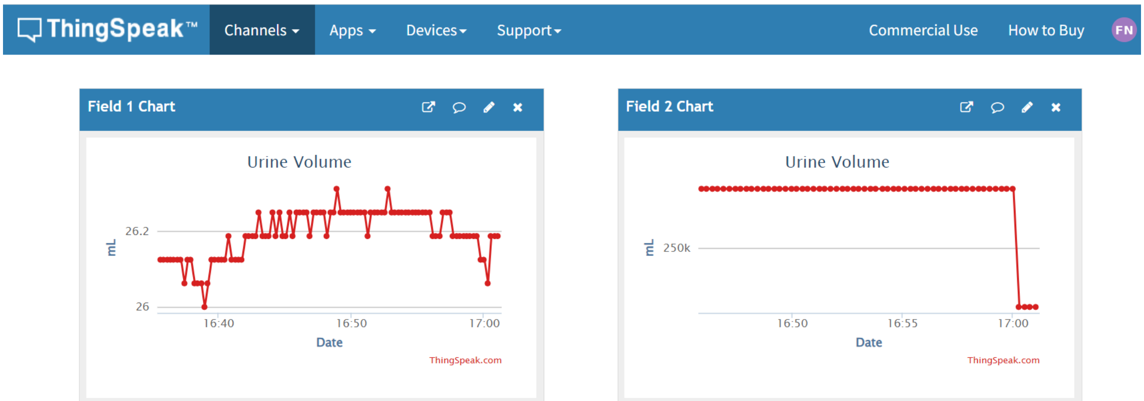

Fig. 4. Visualization of Graphs on a Computer Screen ("Volume da Urina" is portuguese for "Urine Volume")

TABLE I
SENT MESSAGES THINGSPEAK

Time	ID	R-Urine	V-Urine
2022-12-16 19:35:39 UTC	97268	26.125	223
2022-12-16 19:35:54 UTC	97269	27.542	224

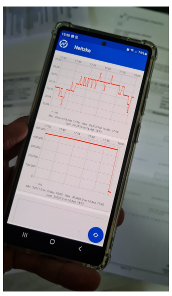

Fig. 5. Visualization of the graphs on a mobile device screen.

computing devices. In this regard, Figures 4 and 5 illustrate these measurements of the accumulated urine volume in the collection bag in two situations: (i) Figure 4 on a fixed device, such as a computer, and (ii) Figure 5 on a mobile device, such as a smartphone. These graphs allow for remote observation of information about Urine Volume in function of Time.

In Figure 6, a screen capture of the smartphone is shown, providing a more detailed view of the simulation depicting the accumulation of urine volume in the collection bag. The upper image in Figure 6 illustrates the variation in volume per minute, while the lower image represents the total accumulated urine volume. This highlights the potential contribution of the ASSDm device.

Therefore, with the results obtained through the simulation, it is possible to validate the functionality of the prototype as a functional proof of concept capable of providing a greater amount of information about urine measurement compared to conventional methods that collect data at larger time intervals [4], [5]. Obtaining accurate and continuous information allows for a more effective monitoring of renal function, enabling the early detection of significant changes and the appropriate clinical decision-making.

Thus, the capacity of ASSDm to provide a range of detailed information that contributes to clinical and epidemiological research has been evaluated. With more accurate and comprehensive data, researchers can conduct more in-depth analyses and identify relevant patterns or trends [4], [5].

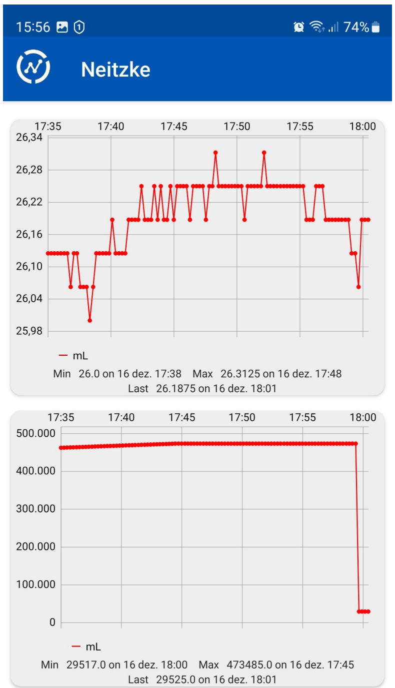

Fig. 6. Visualization of the graphs, screenshot of the mobile device screen.

IV. Proof-of-Concept Evaluation Discussions

The application of the Autonomous System for Supervision of Diuresis Measurement (ASSDm) has demonstrated promising results in utilizing IoT resources in Medical Devices. This innovative tool has the ability to provide accurate and continuous information about the volume of urine accumulated in a collection bag, overcoming the limitations of traditional manual records.

The ASSDm can significantly contribute to the workflow of healthcare professionals by eliminating the need for manual collection and measurement at each patient's bedside. In hospitals that lack any form of automation in urine measurement systems, healthcare professionals often have to interrupt their activities constantly to perform diuresis measurements. This process consumes considerable time and effort.

However, with the possibility of implementing the ASSDm, data collection is automated and performed continuously, allowing healthcare professionals to focus on other essential clinical tasks. This not only optimizes workflow efficiency but also reduces the workload of healthcare professionals, enabling them to dedicate more time to direct patient care and provide higher quality assistance.

Although the Autonomous System for Supervision of Diuresis Measurement (ASSDm) has shown promising results, there are still opportunities for future research and improvements.

As future work, the following key discussions can be considered: (i) Expansion of ASSDm applicability: Investigating the adaptation and effectiveness of ASSDm in different clinical settings can expand its impact and benefits in medical practice; (ii) Integration with Electronic Health Record (EHR) systems: A potential expansion of ASSDm is the integration with Electronic Health Record systems, allowing the diuresis measurement data to be automatically recorded in patients' medical records; (iii) Development of advanced algorithms: ASSDm can benefit from the development of advanced data processing algorithms and machine learning techniques; (iv) Evaluation of clinical effectiveness: It is essential to conduct clinical studies to evaluate the effectiveness of ASSDm in terms of accuracy, reliability, and impact on clinical decision-making; (v) Data security and privacy: The use of Internet-connected devices and continuous data collection require special attention to the security and privacy of information.

V. Conclusions

In summary, the Autonomous System for Diuresis Measurement Supervision (ASSDm) represents a significant innovation in diuresis monitoring. This tool has the potential to provide more efficient and continuous tracking of accumulated urine volume, compared to traditional measurements, benefiting both patients and healthcare professionals. The integration of the ASSDm with the Internet of Things (IoT) in the context of Signal Processing has shown its potential applicability. In the future, the ASSDm can leverage interconnectivity to become a ubiquitous system, enhancing health and stimulating scientific research. With the imminent advancements in technologies beyond 5G, emphasizing the importance of this technological leap for health.

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