Innovations in Uroflowmetry: Ergonomic, Cost-Effective, and AI-Powered Solutions for Sustainable Healthcare

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Abstract. Lower Urinary Tract Symptoms (LUTS) affect 40% of male adults over the age of 40, with this percentage increasing as they age. These symptoms impact quality of life and require frequent evaluations in clinical settings. However, access to timely diagnostic tests may be limited, delaying detection and appropriate treatment. To address this issue, a home uroflowmetry was developed to assess and monitor urinary flow from home. This device integrates advanced biosignal processing techniques, offering an innovative and accessible methodology for collecting and analyzing urodynamic data. In addition to enabling continuous monitoring, the tool provides preliminary diagnoses, enhancing autonomous management of urological health and optimizing clinical decision-making.

Keywords: Uroflowmeter, Lower Urinary Tract Symptoms, Diagnosis, Prevention.

1 Introduction

Symptoms of the Lower Urinary Tract (LUTS) encompass a set of clinical manifestations that significantly affect the male population, especially men over the age of 40. These alterations are primarily characterized by three types of manifestations: bladder storage issues, changes in urination, and post-micturition symptoms [1].

Among the most common pathologies associated with LUTS is benign prostatic hyperplasia (BPH), a condition affecting 50% of men over 60 in Mexico [2], characterized by the non-cancerous growth of the prostate, which causes obstruction in urinary flow. Prostate cancer, the second leading cause of cancer-related death in Mexican men, can also initially manifest with LUTS. Additionally, conditions affecting the urethra, such as stenosis or inflammatory processes, contribute to obstructive symptoms [3].

The timely diagnosis and management of LUTS are crucial, as up to 30% of untreated cases develop significant complications within five years, including recurrent urinary tract infections, stone formation, and progressive renal function deterioration

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[4]. A complete urodynamic evaluation, considered the gold standard for diagnosis, requires specialized equipment with costs ranging from $40,000 to $180,000 MXN, in addition to highly trained personnel [5]. This economic barrier, coupled with the invasive nature of certain diagnostic procedures, contributes to approximately 45% of patients delaying their medical evaluation, postponing the diagnosis and treatment of underlying conditions such as benign prostatic hyperplasia (BPH) [6].

The objective of this research was to examine the challenges currently faced by the healthcare sector in diagnosing Lower Urinary Tract Symptoms, and how the current diagnostic mechanisms present specific issues. To this end, a search was conducted for various products on the market, as well as developing technologies, to identify flaws and potential innovations in diagnostic equipment. The analysis helped pinpoint crucial areas where innovations are needed and provided insight into how these improvements can enhance the healthcare system. As part of the analysis, a proposed solution to the identified flaws in diagnostic equipment is presented, along with how they can be implemented in a medium-level device. In this context, the integration of innovative technologies emerges as a promising solution to develop more accessible and less invasive diagnostic tools.

1.1 Problem Statement

The current problem of Lower Urinary Tract Symptoms (LUTS) is exacerbated by multiple interconnected factors. Limited access to specialized tests, with waiting times that can exceed six months in public health systems, is combined with a low culture of prevention, where 67% of men consider urinary symptoms as a normal part of aging [7]. These figures describe the U.S. population; however, this trend is repeated globally due to the taboo surrounding discomfort related to the genital area.

In addition to the low culture of prevention, some of the current diagnostic methods are invasive (urethral catheterization), which causes reluctance to undergo these procedures, with records showing that approximately 40% of patients avoid periodic evaluations [8]. It is important to note that this percentage of patients is found in those over 50 years of age, the target population for the timely diagnosis and management of LUTS. This suggests an increased urgency regarding the methodologies implemented for this purpose[9].

It is imperative to transform the current diagnostic paradigm by eliminating access barriers and improving accuracy in monitoring urinary function. This improvement focuses on integrating an affordable home device with advanced data processing algorithms for the early detection of urological alterations and continuous patient monitoring.

2 Literature Review

This literature review overviews the different methods used in the market for the construction of a uroflowmeter, as well as the current use of new technologies such as Machine Learning in the development of a diagnosis based on the data acquired by the device.

2.1 Operation and Mechanism of Uroflowmeters in Clinical Practice

Currently, the construction of the mechanism for a uroflowmeter is based on four main operating mechanisms for sample collection [10]. The first recorded uroflowmetry instrument is attributed to Rehfisch in 1897; this device operated based on the principle of air displacement [11]. However, the most used mechanisms on the market today are Weight Transducers, Rotating Disks, Capacitance Transducers, and Volume-based systems.

Weight Transducer Flowmeter
This type of uroflowmeter involves weighing the voided urine, thereby measuring the volume of urine expelled. It also calculates the urine flow rate by differentiation with respect to time. This operating principle is also known as the Gravimetric Principle [12].

This type of uroflowmeter is the most widely used on the market due to its ease of construction. Additionally, it offers the advantage of precise measurement of the evacuated volume. However, it has several disadvantages due to its operating principle, including a slow response time, the density of the urine affecting the results, and any external impact or movement potentially causing artifacts [13].

Rotating-disc Flowmeter
The uroflowmeter involves a spinning disc onto which the urine falls. The disc is kept rotating at a constant speed by a servomotor, despite variations in urine flow rate; the weight of the urine tends to slow the disc's rotation. The additional power required to maintain a constant rotation is proportional to the urine flow rate [12].
This type of uroflowmeter offers advantages such as precise flow measurement and a fast response time, thanks to the Momentum Flux Principle. However, its disadvantages include the interpretation of traces, as artifacts can arise from the "wag effect." Additionally, results are affected by urine density, and the device is difficult to clean [13].

Capacitance Flowmeter
This uroflowmeter uses the Bimetallic Strip principle, where the electrical capacitance of a dipstick, mounted in the chamber, changes as the height of the urine column in a standard-sized container varies [12].

Its advantages include lower construction costs and the presence of mechanical components. However, the urine density must be set, and it is prone to artifacts caused by external impacts [13].

2.2 Analyzing Uroflowmetry Curves with Machine Learning

The analysis of uroflowmetry curves has significantly evolved since the introduction of the first mechanical uroflowmeter by Drake in 1948 [15], becoming a fundamental diagnostic tool in modern urological practice. This non-invasive technique provides crucial quantitative information about the function of the lower urinary tract, allowing for the detection and monitoring of various urological pathologies [16].

The standardization of measurement parameters by the International Continence Society (ICS) has established a universal reference framework for interpreting uroflowmetry studies [17]. The key parameters include maximum flow (Qmax), average flow (Qave), flow time, and total volume, with Qmax being particularly relevant in the evaluation of lower urinary tract obstructions, with reference values established for both genders.

Schafer et al. [18] systematized the morphological analysis of flow curves, identifying characteristic patterns including the normal bell-shaped pattern, the intermittent pattern associated with neurological dysfunctions, the flat pattern indicative of severe obstructions, and the asymmetric pattern suggesting anatomical or functional alterations. This morphological classification continues to be the basis of current clinical analysis.

The incorporation of computerized techniques has revolutionized the analysis of uroflowmetry curves. Spectral analysis using Fourier transform, developed by Yang et al. [19], allows the decomposition of curves into their frequency components, facilitating the identification of subtle pathological patterns and the elimination of artifacts. Advances in machine learning, such as artificial neural networks, have achieved accuracies above 90% in the automatic classification of patterns [20].

Kumar et al. [21] implemented support vector machine algorithms, which have significantly improved discrimination between normal and pathological patterns, while Wang et al. [22] demonstrated the effectiveness of random forests in the multiparametric analysis of flow curves. These advances in artificial intelligence have enabled a more objective and reproducible evaluation of uroflowmetry studies.

Modern real-time analysis systems, described by Park et al. [23], have introduced instantaneous data processing during the study, enabling early artifact detection and dynamic parameter adjustment. Integration with complete urodynamic studies, investigated by Yamanishi et al. [24], has significantly improved the understanding of micturition pathophysiology and diagnostic accuracy.

Current trends in the field are moving towards the development of portable monitoring systems, the implementation of more sophisticated artificial intelligence algorithms, and integration with telemedicine platforms. These advances promise to improve the accessibility and diagnostic accuracy of uroflowmetry studies, enabling more continuous and personalized monitoring of patients with lower urinary tract pathologies.

3 Methodology

Currently, in the healthcare market, the diagnosis of Lower Urinary Tract Symptoms is carried out using a series of methodologies focused on Urodynamics, with Uroflujometry being the main non-invasive diagnostic method due to its simplicity. However, the execution of this study has various external factors that affect the results and the accessibility of this procedure.

To create a potential solution to the diagnostic problem of Lower Urinary Tract Symptoms, we analyzed the main issues that these face, considering the economic accessibility of the study, the social paradigm surrounding diseases related to the genital area, the process of conducting the study both methodologically and functionally, and the delay in the use of new technologies in the equipment.

Ergonomics: Challenges in the Design of Uroflujometry Equipment

These devices typically require patients to urinate in a specific position, which is not always comfortable or suitable for everyone. The shape of the urine funnel, for example, may not fit the anatomy of all patients, leading to discomfort and affecting the accuracy of the measurement. Additionally, the incorrect shape of the funnel can cause splash accidents [25].

Moreover, the environment in which the test is performed also influences the patient's experience. Many patients feel anxious when having to undergo a test related to urination, due to the perception of invasiveness and the associated shame. This phenomenon, known as "white coat syndrome," can interfere with the proper execution of the procedure and, therefore, the results obtained. Anxiety and discomfort can also result in a decrease in the quality of the data collected, affecting the effectiveness of the diagnosis [26].

Costs: A Barrier to Accessing Uroflujometry

The cost of a uroflujometry test and the price of uroflujometry equipment represent a significant barrier for many patients, especially in regions with limited resources. Current devices, although effective, are expensive in terms of both acquisition and maintenance. Additionally, the tests must be performed in specialized facilities, which further increases the expenses associated with the procedure. This economic factor limits access to timely diagnoses, leading many people not to undergo the necessary tests or to receive a delayed diagnosis [6].

Use of New Technologies: Artificial Intelligence and the Revolution in Diagnostics

In the field of uroflujometry, the incorporation of new technologies like artificial intelligence (AI) has begun to make a significant difference in diagnostics. However, its adoption is still limited, mainly due to the lack of proper infrastructure and the conservatism of some sectors of medicine. AI has the potential to improve the accuracy of urinary flow measurements, enabling faster and less invasive diagnoses [27].

Moreover, AI could help analyze large volumes of patient data, allowing the identification of patterns that might otherwise go unnoticed. The use of advanced technologies could also facilitate the development of smaller, more accessible, and efficient devices, reducing the need for expensive equipment and enhancing the patient’s experience.

Future of Uroflujometry: Home Use Devices and Continuous Monitoring

The future of uroflujometry could be marked by the creation of home-use devices, which would allow patients to perform tests in the comfort of their own home. These devices could integrate with mobile applications, enabling more continuous and accessible monitoring of urological conditions [28].

In conclusion, the challenges faced by uroflujometry in terms of ergonomics, costs, social context, and the adoption of new technologies are numerous, but they also present opportunities for improvement. As medicine progresses, the implementation of innovative technologies could transform the patient's experience and make diagnoses more accessible and accurate.

4 Results

As a result of the analysis of the current issues in uroflowmetry diagnosis, our goal is to develop a comprehensive biomedical system for uroflowmetry that includes the creation of a device with an ergonomic and durable casing to ensure accuracy in measuring urine volume and flow without interference, the development of an advanced algorithm for data processing that allows the identification of patterns indicative of lower urinary tract disorders, and the implementation of programming tools to generate clear and understandable graphical reports for patients.

FlowCare for U is a male uroflowmeter prototype designed as a home-based tool for the detection of Lower Urinary Tract Symptoms (LUTS), providing continuous monitoring and offering information that gives an integrated context of the patient and reliable clinical data. The first part is based on the weight measurement principle using piezoelectric transducers, highly sensitive sensors to mechanical distortions, while the second part involves the processing of the biosignal to obtain clinically relevant data, creating an easily accessible and understandable graphical report for users/patients, and the classification of this data through artificial intelligence for the potential early detection of pathologies primarily related to the prostate and the male urinary tract.

This proposed idea can be seen in Fig. 1, which presents a representation of the ongoing development of the FlowCare device. Currently, the development of this solution is still in progress; however, the research conducted on the current issues has enabled the creation of this prototype. Each stage carried out throughout the development of this proposed solution is detailed in the following points:

Phase 1: Literature Review

In the first stage, a comprehensive search of existing studies was conducted to identify key points, their significance, and their relationship with men's sexual, functional, and reproductive health.

As a result, the current issue in detecting Lower Urinary Tract Symptoms (LUTS) was identified, as well as how these symptoms are linked to more severe urinary conditions in adult men [29]

Additionally, a literature review was conducted on innovations in the field of medical devices for LUTS diagnosis, revealing various products aimed at home-based screening but at excessively high prices for the target audience.

The conclusion of this research led to establishing the objectives and components that would be integrated into the final prototype, aiming to develop a comprehensive and holistic project that fulfills its purpose as an easy-to-use medical device.

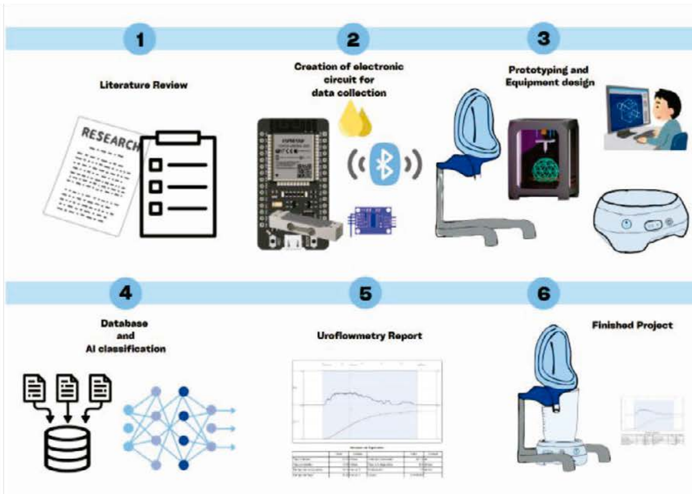

Fig. 1 Visual representation of the development flow of the FlowCare For U device, designed for the early detection of Lower Urinary Tract Symptoms (LUTS) from home. This process encompasses the review of literature to observe what has already been recorded, the creation of a low-cost circuit for data collection, the design of the prototype, the integration of AI for early diagnosis, and the completion of the device along with the patient's status report.

Phase 2: Circuit

The second part of the project involved designing the electronic circuit for data acquisition, specifically measuring the patient's urine flow. This circuit consists of three key components:

1. **ESP32 Microcontroller** – Responsible for collecting and processing sensor data.
2. **Load Cell** – Measures variations in urine flow using strain gauges, based on the Wheatstone bridge configuration. The selected load cell has a 5 kg limit and generates a small voltage signal when deformed by an applied load.
3. **HX711 Module** – Amplifies and converts the analog signal from the load cell into a digital format using a 24-bit ADC. It then transmits the data to the ESP32 via a two-wire serial interface (Clock and Data), ensuring precise weight readings.

For wireless communication, the ESP32 was configured as a Bluetooth device, allowing real-time data transmission to a mobile device or computer. Depending on the application, Bluetooth Low Energy (BLE) or Serial Bluetooth (SPP) was used, enabling users to receive, visualize, and analyze the data through a compatible app or software.

Phase 3: Prototyping

The uroflowmeter was composed of several parts that together function as the hardware. First, it was designed with an ergonomic approach for personalized home use, requiring no technical knowledge and being easy to clean for the user. This design was 3D-printed to achieve the goal of being a low-cost device.

This process focused on a support structure for capturing urination with two objectives: preventing splashing accidents during urination and ensuring that the flow correctly falls into the collection cup. Additionally, during this prototyping stage, efforts were made to create a small and user-friendly uroflowmeter, considering its intended home use.

Phase 4: Database and AI Clasification

Once the data was acquired and transmitted via the Bluetooth communication protocol, it was processed and conditioned to quantify the six most important values of our curves, according to the ICS.

In addition to being processed to obtain these values, the data was fed into an AI system that classified it to provide a possible diagnosis of the patient's lower urinary tract health.

The AI is train using a database previously provided by a urologist. With the goal of improving urological diagnostic equipment, the specialist contributed a dataset of adult male patients who had consulted him for abnormalities in their natural urination patterns.

This AI system was developed using an algorithm capable of classifying patient data for the detection of potential pathologies related to the urinary tract and prostate.

Phase 5: Uroflowmetry Report

The goal is to generate a report for each urination, allowing the user to visualize both the processing and their flow and volume curves, as well as the six key metrics obtained from these graphs. Additionally, the report will include a diagnosis of their Lower Urinary Tract condition, enabling personalized monitoring.

Phase 6:

Thus, with the completion of the project methodology design and the prototyping of four deliverables, the system includes: the uroflowmeter ready for measuring changes in urine flow, the support structure along with the collection urinal to ensure accident-free collection without altering the flow, a collection cup, and a final report on the patient's urination.

5 Discussion

The current landscape of diagnosing Lower Urinary Tract Symptoms (LUTS) reveals several significant barriers that hinder early detection and treatment. As highlighted in the introduction, LUTS is a common issue among adult men, especially those over 40, and often points to underlying conditions such as benign prostatic hyperplasia (BPH) and prostate cancer. However, the traditional diagnostic methods, including urodynamics, face challenges such as cost, invasiveness, and accessibility, which delay timely diagnosis and treatment. These barriers ultimately lead to worsening health conditions and increased healthcare costs due to the development of complications.

One of the main findings of this study is the identification of the limitations in current diagnostic devices. While uroflowmetry remains a widely used non-invasive diagnostic tool, the mechanisms of existing uroflowmeters often suffer from inaccuracies due to external interference, ergonomic limitations, and high costs. Additionally, many patients are deterred from undergoing the necessary tests because of anxiety, discomfort, and the perceived invasiveness of certain procedures. The low cultural awareness of the importance of preventing urinary disorders further exacerbates these challenges, with a significant proportion of men regarding urinary symptoms as a normal part of aging, thus avoiding seeking medical attention until symptoms become severe.

Given these issues, the proposed home-use uroflowmeter presents a novel solution that addresses multiple aspects of the diagnostic process. The integration of a user-friendly, low-cost device that allows for continuous monitoring of urinary flow represents a significant improvement over traditional method. By enabling patients to collect their own data at home, the device not only enhances convenience and comfort but also reduces the stigma often associated with clinical visits for urinary health.

Moreover, the incorporation of advanced technologies such as artificial intelligence (AI) holds the potential to revolutionize how uroflowmetry data is analyzed. The application of machine learning algorithms to identify patterns indicative of urinary tract disorders offers the advantage of higher diagnostic accuracy and objectivity. The development of AI-based systems for early detection allows for quicker and more accurate identification of potential issues, reducing the need for costly and invasive procedures in the future. In addition to improving diagnostic speed, AI can also help identify at-risk individuals earlier, enabling preventive care that reduces the likelihood of complications such as recurrent infections or kidney damage.

In conclusion, this research highlights the need for innovation in the diagnostic tools available for LUTS. The integration of home-use devices with AI for data analysis presents a transformative opportunity to overcome existing barriers such as cost, accessibility, and patient reluctance. By addressing these challenges, this solution could pave the way for a more efficient, affordable, and patient-centered approach to managing urinary tract health. Ultimately, this innovation will contribute to a more proactive healthcare model that emphasizes prevention, early detection, and continuous monitoring, benefiting both patients and healthcare systems alike.

6 Conclusion

Through the search for improvements in the diagnostic processes of Lower Urinary Tract Symptoms, this study allows us to develop a possible solution to the current problems in the healthcare sector, specifically in the urology field.

According to our research, innovation in medical diagnosis can lead to improvements in patient care, cost savings in both diagnosis and the consequences of later-diagnosed diseases, as well as enhanced management of the data obtained from each diagnostic study.

Furthermore, it was discovered that the current development of new technologies, such as Machine Learning for issuing a potential diagnosis, presents a huge opportunity for implementation in new devices. The study also shows that this potential diagnostic aid is being developed through multiple modalities for analyzing the data, whether through the analysis of the curves formed or simply by the uroflowmeter parameters collected by the device.

Finally, the proposed solution will not only optimize the diagnostic process, reducing detection times through the creation of a culture of urinary disease prevention and the development of a clinical history related to the patient's urination, but it would also reduce costs associated with managing complications. In doing so, a more efficient, accessible, and preventive care model is promoted, aligned with the current needs of the healthcare system.

7 References

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