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Study of an ESP32-Based Biomedical Instrument for Digital Urine Detection and Local Monitoring in a Hydrophyte Composite Textile Medium

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ABSTRACT

This paper presents a new biomedical digital instrument for urinary volume acquisition in a hydrophile composite textile medium. The considered textile media consists of composite internal and external layers (cotton and Luffa cylindrical fabrics respectively). Under a control voltage E, the unary sensor transforms the cumulative urine volume Q inside the diaper into output voltage Us(Q). Then, third order polynomial models of Us(Q) and Q(Us) are analytically computed from samples of real data, using Matlab/CFtool. In addition, both analog signal E(t) and Us(Q(t)) are applied to analog-to-digital conversion pins of the ESP32 system-on-chip, for further digital processing needs. Furthermore, a digital processing flowchart of an Arduino/C++ application sketch is provided. As an implication, acquired digital samples of voltage Us(Q) are used to compute the corresponding cumulative urine volume Q(Us) to sent to Arduino virtual plotter for real time monitoring in ml unit. On the other hand, rigorous comparative studies show that analog waveforms of Q(t) and Us(t) captured by a storage oscilloscope and their corresponding digital signals as visualized on Arduino virtual monitor, are identical. These relevant results have been useful for the validation of the proposed biomedical digital instrument, to be extended in future research works in order to build a new generations of low cost and high quality smart diapers.

Key words: Biomedical instrument, ESP32, hydrophilic composite textile, urinary volume acquisition, Matlab/CFtool, Arduino USB virtual monitor

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1. INTRODUCTION

Unary absorption diapers are widely used through the world in any population class, e.g., babies, women, elders and numerous persons affected by urinary incontinence. A few type of hyper absorbing diapers may cause skin cancer when wearing them for long time wetness period [1]. In order to ever come this problem, it is necessary to frequently change the diaper if is very wet. However, when and how can a person recognize a very wet diaper without looking or touching inside? This relevant question has motivated the apparition of diapers equipped with yellow bands, having the ability to turn into red under over wetting states [2]. Even in this case, a person who is far from the diaper wearer cannot observed any change in the diaper color state.

Fortunately, most modern diapers are smart products, i.e., they are equipped with embedded unary sensors, allowing to automatically detect the urine volume Q inside the diaper, and then sent an alert signal to the wearer, if Q achieves a given overflow threshold. In most cases, the alert system is extensible to target remote persons via wireless transmission technology.

Ideally speaking, any modern microcontroller can be used for both digital signal processing tasks and wireless transmission transactions. However, a suitable choice of a microchip might yield lower building cost and better operational performance as it will be seen later in section II of this paper.

In these aforementioned cases, the urinary sensor is designed according to an equivalent physical quantity to be captured as image of the urine volume inside the diaper. As an implication, widely used equivalent physical quantity considered in existing urine sensors are: electric resistance ([3], [4], [5]), electric capacitance [6], thermal change [7], photo electronics [8], pressure [9], and wetness ([10], [11]).

However, most of these equivalent physical quantities require greedy realization and real time processing costs. In other to overcome these practical difficulties, a new urine sensor initiated and well tested in [12], is founded on the *output voltage image* resulting from the electric effect of the cumulative urine inside the diaper. Therefore, the main aim of this paper is to use that simple urine sensor, as a basic module for the development of a pioneering urinary digital detection device in smart diapers. The remaining sections of this paper deals with research material and method, results and discussions, and conclusion.

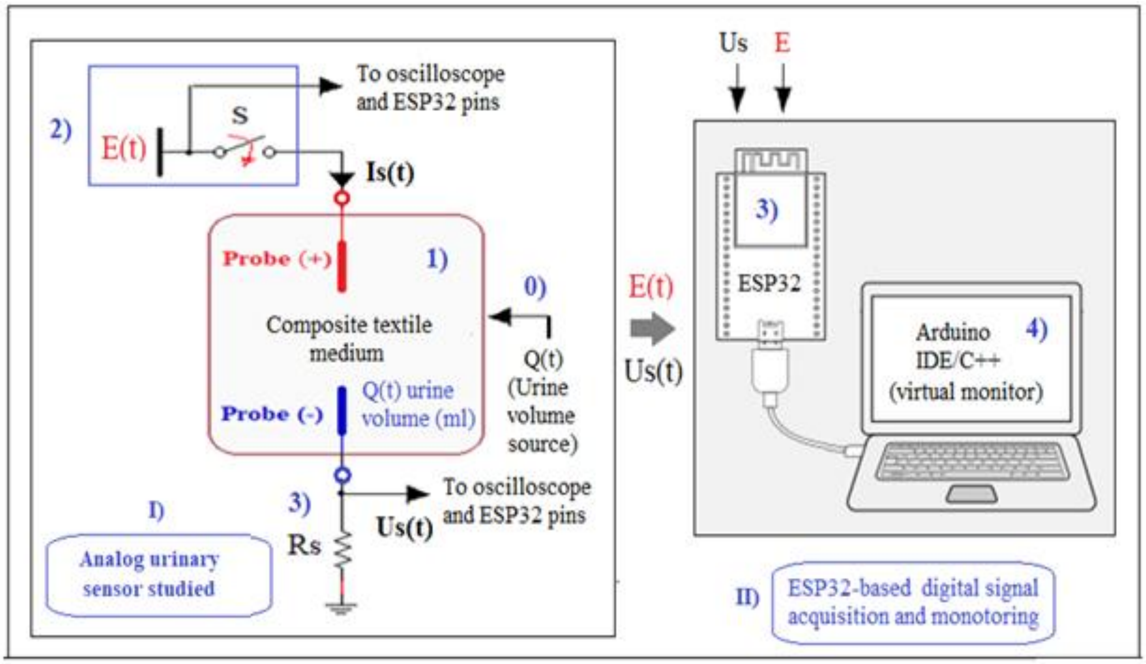


Fig. 1 Block diagram of the ESP32-Based urinary digital detection instrument

2. TOOLS AND METHOD

The block diagram of the urinary digital detection instrument initiated in this paper is presented in Fig. 1. It consists of two main parts I and II.

Recall on urinary sensor

Given the urinary sensor architecture and its operating principle, it is worth noting that:

- Qu(t) stands for the cumulative urine volume inside the composite textile medium at time t, with initial condition Qu(t) = 0 if the whole textile medium is absolutely dry, and the switch *S* associated to the supply voltage E(t) is closed;
- Is(t) is the electric current resulting from the conductive effect of the wet textile medium containing an urine volume Qu(t);
- Us(t) is the voltage image of Qu(t), which is a simple output signal to be detected and processed.
- The general operating law between Us(t) and Qu(t) is modelled by an electrodynamic differential equation, or by a first order lead/lag transfer function, with a short transient time period; equivalently;
- The static model Qu(t) = g(Us(t)) can be easily built at design time from combined experimental and analytical methods;
- E(t) is a DC electric supply voltage of the sensor. It is not always a constant, since it is usually a battery, involving over time voltage decreasing;
- The resistance Rs = 10 kΩ is quite suitable.

Fig. 2 presents a sample of real analog signals displayed on the oscilloscope screen for an experimental step response of the analog urinary sensor.Note that the transient time is less than a second. Then, it is shown how a static model Us(Q) or

Q(Us) equivalently, can be analytically computed from associated experimental data using Matlab*cftool* (curve fitting tool).

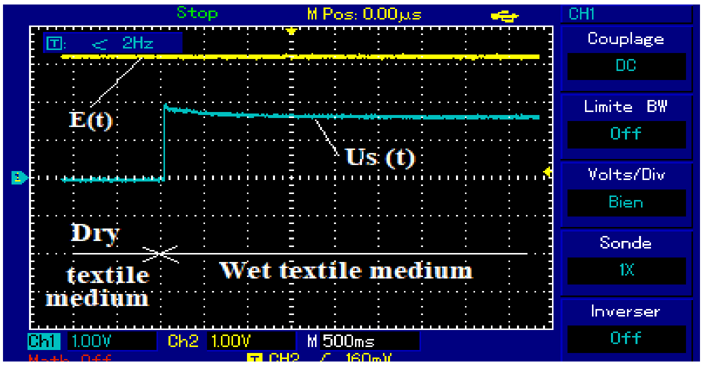


Fig. 2 Sample of analog signals E(t) and Us(t) for the urinary sensor (under Q = 40 ml).

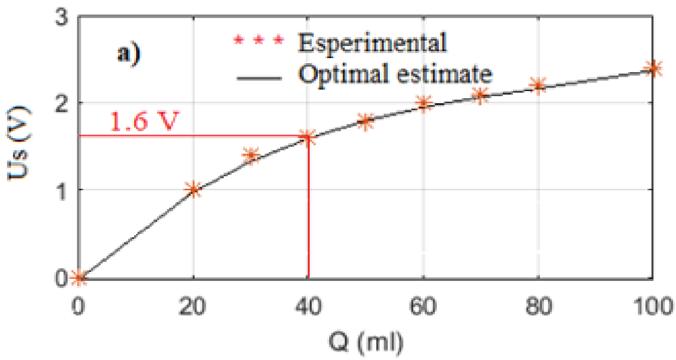


Fig. 3 Static model of Us(Q) developped in [14].

ESP32-based digital signal acquisition and monitorig

The ESP32 in Fig. 3 (part II), is a latest SOC (system-on-chip) device from *Espressif* Manufacturer. Compared to most SOC devices, it offers lower size, lower cost, higher degree of pins reconfigurations, higher types of standard instrumentation bus (I^2S, I^2C, USB),build-in Bluetooth (4.2 version, BLE types and Wifi (802.11, 2.2 to 2.5 GHz) modules, dual processing core, and a wider set of free tutorials for IoT development technology, etc. In addition, its driver for Arduino IDE-C++ programming is quite free. Therefore, it is the best choice for the development of IoT (Internet of Things) devices. opportunities.

Fig. 4 ESP32

In Fig. 6 (part II), a Laptop computer is connected to the ESP32 via an USB port. It can be used at both development time and real time signal processing. Assuming that an Arduino IDE-C++ is preinstalled, then the Laptop is used at development time for programing, compiling and downloading the target C++ program to the ESP32 application memory. In real time, it is used as a virtual plotting monitor of real data samples {E(kT0), Us(kT0)} received from the ESP32 via a USB cable, where T0 is the sampling period, k being the sample index.

The flochart of the target Arduino C++ application is presented in Fig. 5, and Fig. 6 shows the workbench image used experimental and testing needs.

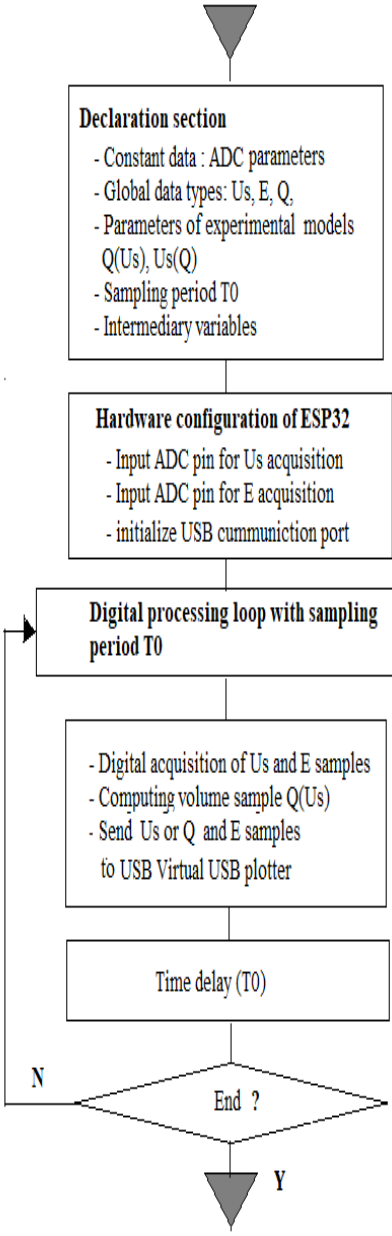
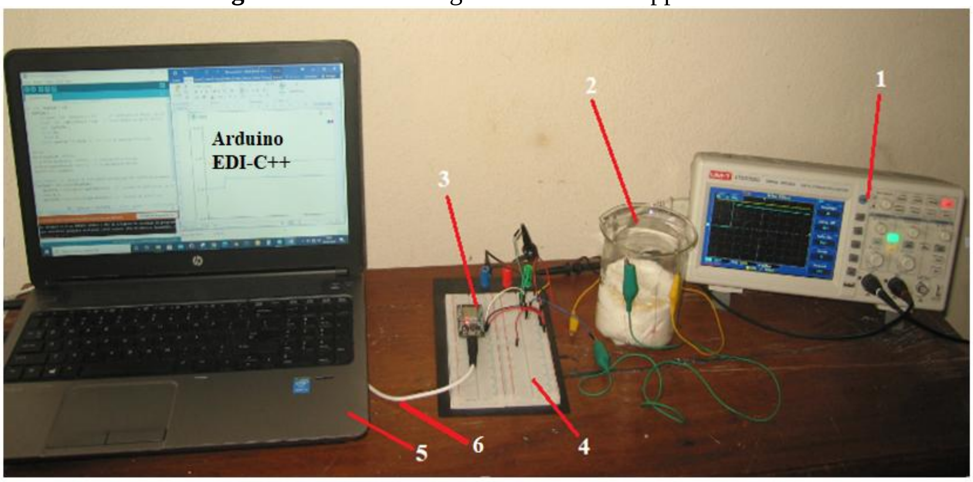


Fig. 5 Flowchart of target Arduino C++ application

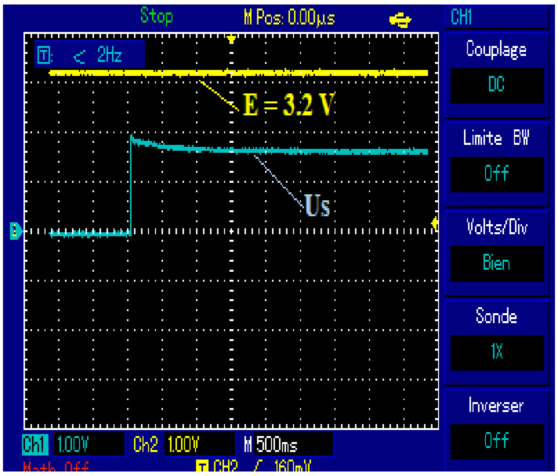


1 - Oscilloscope 2 - Composite textile medium 3 - ESP32 4 - Testing board 5 - Laptop PC 6 - USB cable

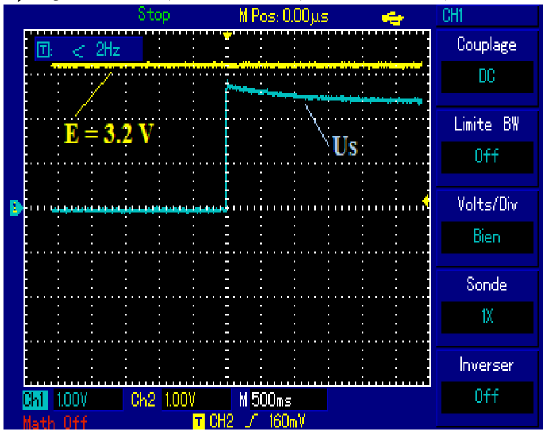
Fig. 6 Workbench of a the proposed ESB32-based digital instrument for urinary data acquisition from a textile medium

Oscilloscope (analog signals)

a)Qu = 40 ml, Us =1.6 V, Usm=2 V, Tr = 1s

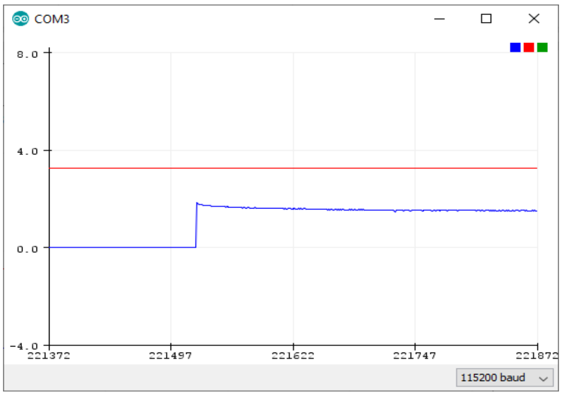


b) Qu =100 ml, Us = 2.4 V, Usm=2.6 V, Tr = 2 s



USB virtual Plotter (Digital signals)

c) Qu = 40 ml, Us =1.6 V, Usm=2 V, Tr = 1s



d) Qu =100 ml, Us = 2.4 V, Usm=2.6 V, Tr = 2 s

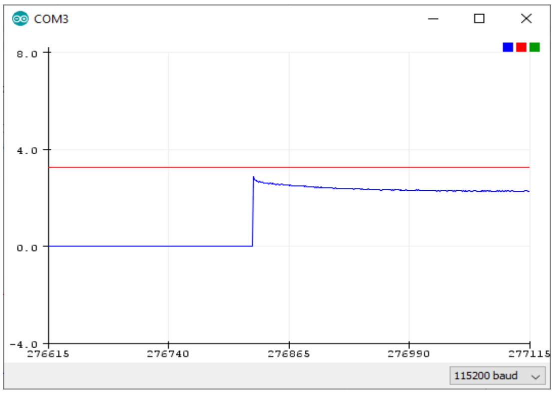


Fig. 7 Sample of signals (E(t), Us(t)) and their corresponding digital waveforms

Table -1 Characteristic of Workbench modules

No	Type	Model	Qualities
1	Oscilloscope	UTD2052CL	50 MHz, 500 MS/s, storage memory, USB connector for graphics saving
2	Composite textile medium	Cotton and Luffa layers	Sweetness, high urine absorption capacity
3	SOC device	WROOM32	IoT technology
4	Testing board	White	-
5	Laptop PC	DELL	2.40 GHz, Win 10
6	Android cable	USB	115000 bauds
7	Arduino	IDE-C++	1.8.12

The technical characteristics of the workbench modules presented in Fig. 6 are provided in Table 1. On the order hand, it is worth noting that:

- The total sampling period T (ms) of the ESP32-based digital processing loop, is a sum of times due to sequential tasks (i.e. digital computing Td, USB communication Tc, and downstream delay T0 (or sampling period equivalently).
- The target C++ application embedded into ESP32 application, offers 216 Ko memory size according to the C++ compiler specifications, and the adopted sampling period is T0 = 10 ms.
- In each real time digital processing loop, available sampled signals are sent to Arduino virtual monitor via an Android USB cable for textual or graphical visualization.

3. RESULTS AND DISCUSSIONS

However, each result presented in Fig. 7 deals with the step response over time of the composite textile medium for a fixed absorbed urine volume Q (ml). In smart diapers design, the static models between urine volume Q and its corresponding output image (i.e. Us in our case) is more relevant, for signal acquisition and processing tasks. In this paper, the static analytical laws Us(Q) and Q(Us) are established in Matlab/Cftool framework from their experimental data, according to third order polynomial shapes (1) and (2) respectively.

In Fig. 8, the graphs of experimental data and related analytical least square estimates are plotter for the sake of better visual comparison. As straightforward results, the direct urine absorption law (1) describes a static input-output model of the urine volume sensor, while its reverse function given by (2) is needed in the executable application program, for reliable reconstruction needs of the associated urine volume Q (ml) to be sent to a virtual terminal monitor. Of course, the urine volume samples Q (in ml) are physically more realistic than their related voltage samples Us (in volt).

$$Us(Q) = p_1 Q^3 + p_2 Q^2 + p_3 Q + p_4 \quad (1)$$

with

$$\text{p1} = 2.625\text{e} - 06, \quad \text{p2} = -0.0006439$$
$$\text{p3} = 0.0621, \quad \text{p4} = 0.002241$$

and

$$Q(Us) = q_1 (Us)^3 + q_1 (Us)^2 + q_3 Us + q_4 \quad (2)$$

with

q1 =10.87, q2 =-21.64
q3 =30.97, q4 = -0.03052

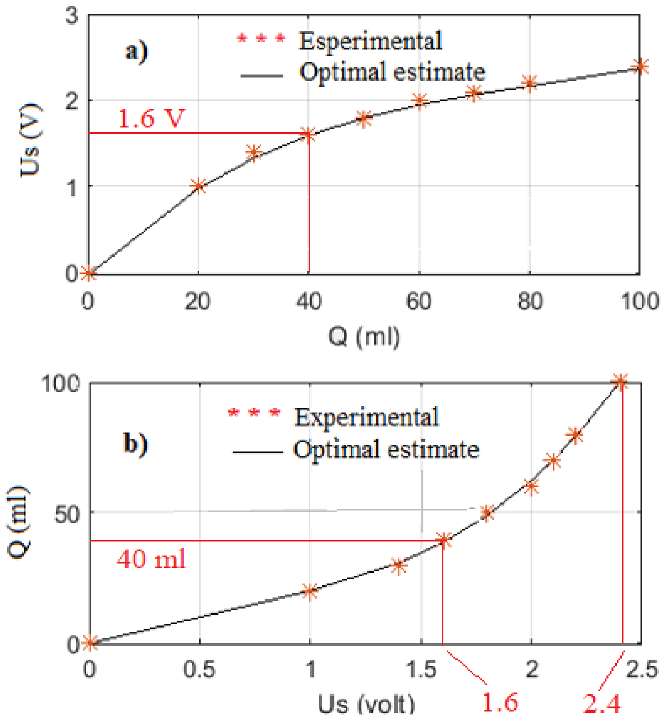


Fig. 8 Third order polynomial models of Us(Q) and Q(Us)

Fig. 9 shows how digital values of an arbitrary urine volume (e.g. Q = 65 ml), can be easily displayed on Arduino virtual USB plotter. Minor fluctuations observed might result to combined effects of both urinary diffusion noise through the urine absorbing medium, and to a suboptimal choice of the sampling period T0 = 10 ms. However, a simple first order IIR (infinite impulse response) filter can be used is necessary, to cancel these aforementioned noisy effects.

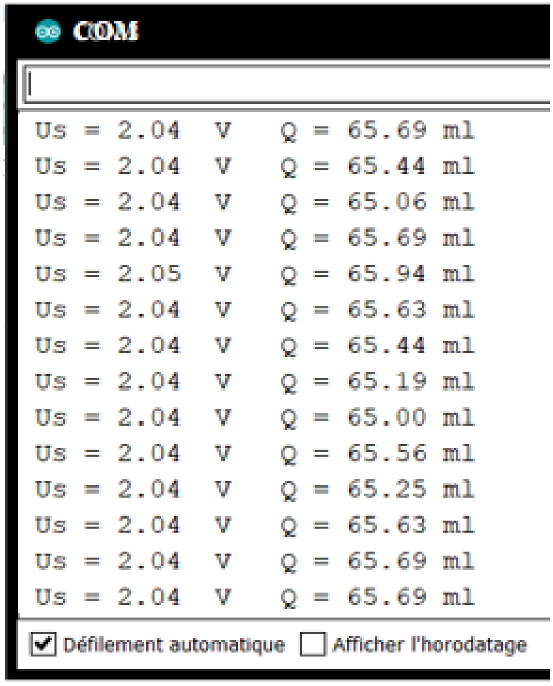


Fig. 9 Us and Q values in Arduino USB virtual monitor

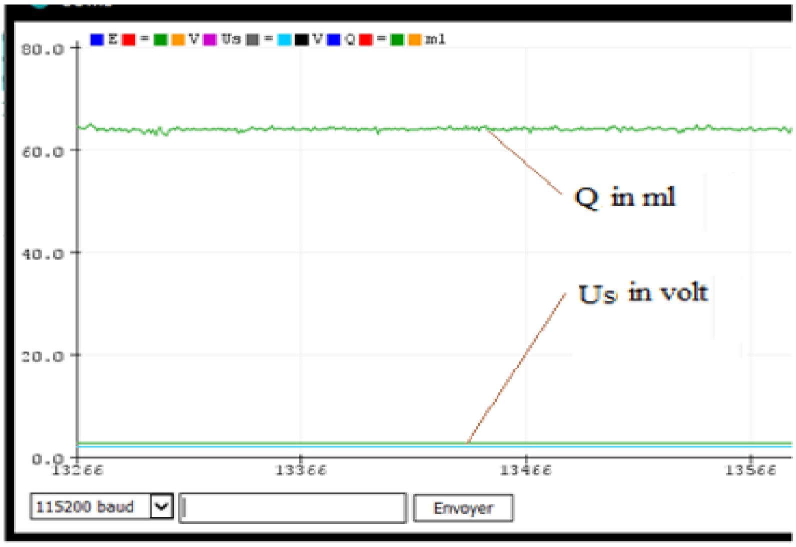


Fig. 10 Graphs of involved digital signals on Arduino virtual plotter

In Fig. 10, the graphs of digital signals U(n) and Qs(n) are visualized on Arduino USB virtual plotter, where n being the index of sampled data, within the integer range $13266 \leq n \leq 13566$ with length 300 samples.

Finally, the most relevant scientific merit of this paper, has been to develop and build a first pioneering well tested prototyping biomedical digital instrument, from a simple analog urinary sensor.

4. CONCLUSION

This research paper has outlined a pioneering class of biomedical instruments, for digital acquisition and local monitoring of cumulative urinary volume, inside a multilayer composite textile medium. The proposed class of ESP32-based digital instruments, are structurally simple while offering high operating flexibility and quality. Therefore, their extension in future works as new types of low cost and high quality wireless biomedical instruments, might create attractive business opportunities for smart diapers researchers and manufacturers.

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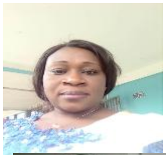
BRIEF BIOGRAPHY OF AUTHORS



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