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PAPER

Implementation of a Prototype of an Electronic Device for Measuring Lead Calculation in Blood

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ABSTRACT

Lead, a vital but dangerous industrial metal, poses serious health risks. Exposure, especially in mining and industrial areas, has led to alarming statistics; in Mexico, 21.8% of children have elevated blood lead levels, while in Cuba, 58% of exposed workers exhibit signs of poisoning. In Huacho, Peru, 71.4% of the population has high levels of lead, attributable to the mining industry. Globally, lead is estimated to contribute to 0.6% of the disease burden and cause approximately 143,000 deaths annually, with more than 600,000 children under the age of five dying from it. Traditional methods are expensive and time-consuming. That is why a low-cost portable device is proposed, developed with technology such as Matlab and Arduino, which uses anodic voltammetry to measure blood lead concentrations. Although requiring improvements, this device has the potential to significantly improve the monitoring and prevention of lead-related diseases, providing accurate and rapid results to protect public health where the reading of the presence of lead in the blood was achieved.

KEYWORDS

contamination, detection, electronic device, lead exposure, health prevention

1 INTRODUCTION

Lead is a heavy metal with a grayish hue, malleable, and relatively abundant in the earth's crust that is widely used in the industrial field due to its high density and ability to resist corrosion, making it a valuable material in various applications such as the manufacture of batteries, paints, soldering, and conduits [1].

According to current criteria set by the World Health Organization (WHO), a blood lead level equal to or greater than five micrograms per deciliter (µg/dL) in children and adults is considered to be a cause for concern and may indicate lead exposure. Also, there is no safe level of lead in the blood. Even mild exposures can have adverse health consequences, especially on children's neurological development [2].

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Lead exposure is estimated to cause approximately 143,000 deaths each year and contributes to 0.6% of the global burden of disease. In addition, more than 600,000 children under the age of five dies as a result of lead exposure, a number that is increasing due to the lack of preventive policies [3]. These figures underscore the urgency of addressing this problem effectively [4], implementing policies and preventive actions to reduce exposure to this toxic metal and protect the health of the population.

In Mexican localities with a population of less than 100,000 inhabitants, there is an alarming prevalence of 21.8% of elevated lead levels in children aged one to four years [5]. This data reveals a troubling situation that requires immediate attention and effective measures to address lead exposure in this specific population.

In Cuba, it has been identified that 58% of workers exposed to lead exhibited levels that indicate poisoning [6]. The high proportion of affected workers highlights the importance of implementing preventive measures in occupational settings to safeguard workers' health and minimize the risks associated with lead exposure.

In Huacho, Peru, 71.4% of the population has high levels of lead in the blood, attributable to the mining industry [7]. This activity, while contributing to state revenues, also generates pollution and health risks from heavy metals such as lead. Similarly, in mining regions such as Cerro de Pasco and La Oroya, mining and metallurgical activities have caused serious pollution [8].

The intersection between medicine and electronic engineering has made it possible to address medical challenges in innovative ways [9], leveraging technological advancements to improve both the diagnosis and treatment of various medical conditions. This multidisciplinary approach has led to the creation of wearable devices and embedded systems that can perform accurate analysis in real-time, thus facilitating early detection and timely intervention [10].

Accurate and timely detection of elevated blood lead levels is crucial to preventing disease and maintaining public health [11]. However, conventional methods can be costly, require specialized equipment, and take time to deliver results, limiting access, especially in communities with limited or remote resources. Innovative approaches that are more accessible, inexpensive, and efficient, but just as accurate and reliable, are required to overcome these barriers and ensure effective detection of lead in the blood.

At the national level, Vega et al. [12] mention that led contamination affects both youth and adults, being more common in adults due to exposure to paints with high levels. However, this contamination also affects children, who, by putting objects in their mouths, can easily expose themselves. In the port of Callao, where there is industrial activity, pollution mainly affects children under the age of six who live nearby.

According to Castro and Sobrado's [13] research, blood samples were taken from 40 schoolchildren at the Agustino to analyze their lead level through atomic absorption. This process emits light towards the analyte to measure the amount absorbed, inferring greater absorption at higher concentrations of the element. Reagents such as ammonium phosphate and nitric acid were used. The results showed an average of 2.88ug/dL of lead in the blood, with a minimum of 1.14ug/dL and a maximum of 15.3ug/dL. Sex did not influence the lead levels found. This study highlights the importance of monitoring lead exposure in residential communities.

On the other hand, the global situation described by Shao et al. indicates that in 2012, the Center for Disease Control and Prevention (CDC) [14] reduced the safe level of lead in children aged one to five years from 10µg/dL to 5µg/dL in the U.S. The Onondaga County Health Department (OCHD) reported a follow-up in Syracuse, NY. It collected data on gender, race, and place of birth for 83,000 children in 2011, with nearly half in need of medical care.

Similarly, Carrel et al. [15] states that lead levels in pregnant women can affect the neonate neurologically and cognitively as it passes through the placenta.

Levels between five and10ug/dL are more harmful than those below 5ug/dL. Levels above 5ug/dL were found in dried blood stains from newborns from Lowa, despite living in less polluted rural areas. Coupled plasma mass spectrometry determined the lead level in 0.3ml samples, considering various parameters. The Wilcoxon-Mann-Whitney and chi-square tests were used to compare levels between zones.

Modern engineering and the use of computational tools such as Matlab offer an opportunity to efficiently detect lead in the blood. Anodic voltammetry, with data processing, enables integrated systems for accurate and non-invasive measurements [16]. These portable and affordable devices are adaptable in different medical settings, improving access to screening. This project seeks to design a device to detect lead in blood, reducing related diseases and promoting public health. Integrating medicine, engineering, and computing, a complete solution is sought to improve the quality of life.

2 METHODOLOGY

The steps to achieve the project objective have been carefully sequenced for optimal progress. The initial stage will involve an extensive search for relevant scientific literature and data, focusing on identifying the most suitable electrochemical method for mercury detection. Once the method is selected, preliminary tests will be conducted using liquids with similar properties to blood to generate response curves and assess the method's reliability. Following these trials, the selected method will be applied to actual blood samples for thorough characterization and validation. Upon obtaining the experimental data, a comprehensive table will be compiled, summarizing the results across all liquid samples tested. To enhance data analysis, an algorithm will be developed in MATLAB, allowing for the visualization of the individual behavior of each sample. This algorithm will facilitate a deeper understanding of the electrochemical response and improve the accuracy of the detection method.

2.1 Definition of terms

Anodic voltammetry. It is a procedure that detects metals in liquids, being fast and accurate. It requires electrodes and an electronic circuit to send data to a computer. It is measured in PPM and can test small amounts of water for contamination [17].

The choice of this technique over other electrochemical methods is based on its simplicity and effectiveness, in addition to the fact that its attributes are ideal for the elaboration of the electronic device in this analysis.

Matlab. Comprehensive development platform that facilitates the performance of highly complex computational calculations. In this program, you will find valuable engineering tools such as image processing, statistical analysis, wireless communications, and the ability to convert algorithms to C or C++ and HDL code for use in embedded devices, among other resources [18].

Matlab stands out for having a unified interface for data analysis, simulation, and graphical representation. It also offers a wide range of functions, intuitive syntax, ease of use, and versatility.

Arduino platform. It is an open-source platform made up of hardware, in this case an Arduino Nano board, equipped with a microcontroller from the Atmel family known as the Atmega 328P. The Arduino board enables a variety of actions on the output ports, suitable for voltametric processes of current exchange between anodes and cathodes described in Table 1, which are essential for signal processing in the microcontroller [19].

Arduino has significant advantages in being cross-platform, affordable, having a simple and accessible programming environment, as well as being open source and having understandable hardware.

Table 1. Platform Arduino description

Specification	Details
Microcontroller	ATmega328P
Operating Voltage	5V
Digital I/O Pins	14 (6 PWM)
Analog Input Pins	8
Flash Memory	32 KB (2 KB used by bootloader)
Clock Speed	16 MHz
Dimensions	18 × 45 mm

2.2 Block diagram

This tool shows concepts (see Figure 1), variables, or stages of the research process and is useful for identifying the relationships between the investigated variables and visualizing their interaction [20].

The scheme of the operation of the electronic equipment begins with the acquisition of data by means of electrodes connected to the sample and the Arduino nano, which receives the signal through its analog pin [19]. The data is then graphed to characterize the sample, visualized on a computer, where it is processed by an algorithm in Matlab [18].

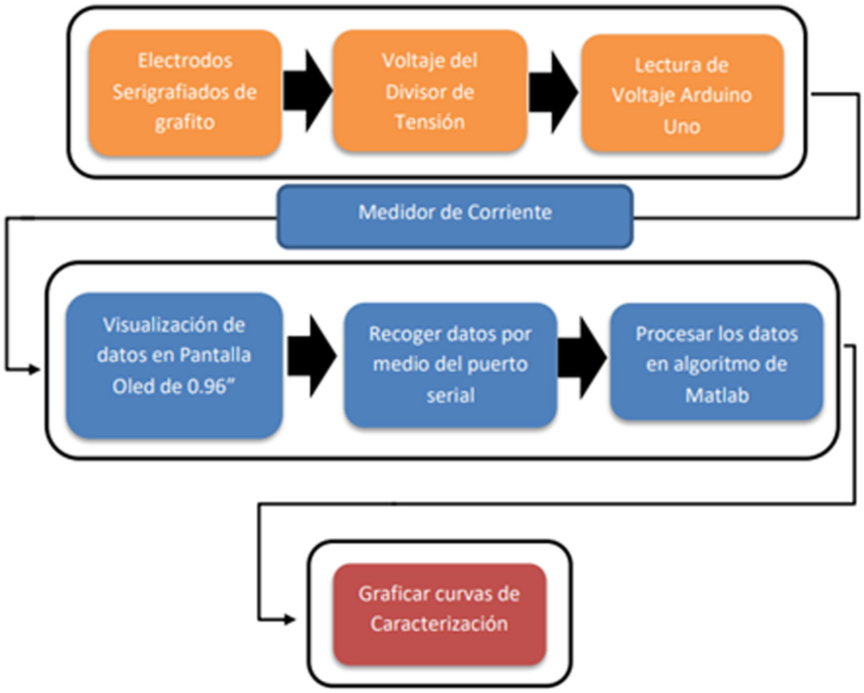

Fig. 1. Diagram of performance blocks

Graphite screen printed electrodes. They are devices used in various electrochemical and biosensor uses. These electrodes are composed of a conductive substrate, typically carbon, on which a thin layer of carbon paste is deposited that houses the active electrode [21]. This screen printing technique will facilitate the creation of electrodes with particular designs and exact shapes, making them highly adaptable and versatile for the purpose of research.

Voltage divider voltage. It consists of a circuit made up of two resistors connected in series between two points, with a voltage source applied at the input of the splitter.

Ohm's law and Kirchhoff's law of voltages are used to determine the voltage of the voltage divider. These regulations state that the voltage at each divider resistor is proportional to its resistance with respect to the resistance of the entire circuit [22]. The voltage by means of one of the resistors in the voltage divider will be calculated with the following formula:

$$V_{Ri} = V_{in} \times \frac{R_i}{R_1 + R_2}$$

Inasmuch:
V_{Ri} = Voltage through resistance R_i
V_{in} = Input voltage to voltage divider
R_i = Resistance at the voltage divider i
R_1 and R_2 = Total resistances of the voltage divider

Arduino uno voltage reading. This procedure involves measuring the voltage on one of your analog pins using the built-in analog-to-digital converter (ADC). The ADC converts the analog voltage into an actionable digital representation.

The Arduino Uno has a 10-bit ADC, which allows the voltage to be represented in 1024 levels (2^10). The default voltage reference is 5V, encompassing measurements from 0 to 5V.

To read the voltage on an analog pin, analog read (pin) is used. This returns a value between 0 and 1023, representing the voltage on a scale of 0 to 5V [23].

$$\text{Voltage} = \text{referencia\_de\_voltaje}\left(\frac{lectura\_ADC}{1023}\right)$$

Data display on 0.96" OLED display. The graphical interface serves multiple functions in the circuit, from displaying messages at the start and during data collection to displaying voltage and current values, along with the output of the built-in digital-to-analog converter (DAC), with a resolution of 10 bits (0–1024). This value of the DAC will ensure accurate voltage measurements at A0. In addition, the OLED 128×64 display will record the elapsed time during sampling, facilitating voltage vs. time analysis, and display the project name along with real-time values at the start and end of the test [24].

I collect data via the serial port. The Arduino Uno's serial port plays a crucial role in enabling real-time data collection at 6800 baud, sending it to an external device. This feature will be instrumental in visualizing and analyzing study data, simplifying comprehensive monitoring and evaluation of the circuit and its components.

Data processing in Matlab algorithm. The process in Matlab will be adapted according to the data and objectives, and then process, clean, and prepare them. Subsequently, they will be analyzed, including statistical calculations and predictive modeling, making use of visualization tools to represent the data graphically. After the analysis, the results will be interpreted, identifying trends or patterns, and presented in a clear and concise manner through graphs, tables, or reports.

3 RESULTS

In this section, we will present the main results found during the development of the device capable of quantifying and detecting lead using the anodic voltammetry method. During this process, different parameters were evaluated to optimize the accuracy and sensitivity of the device.

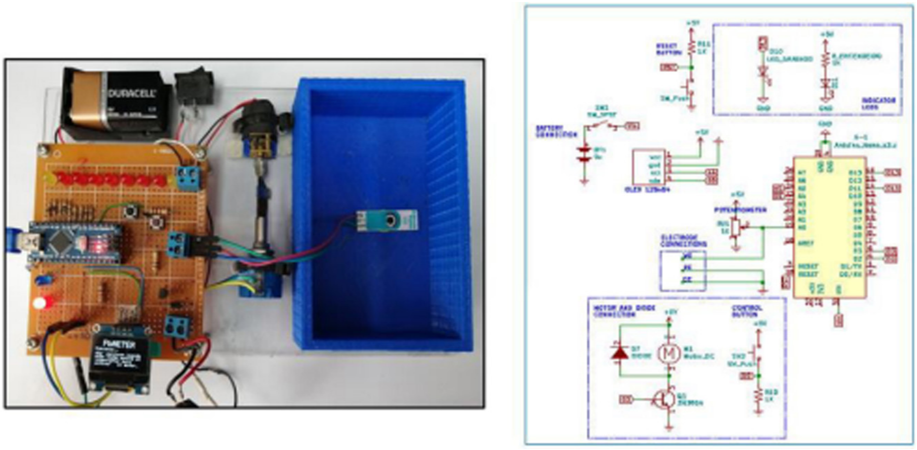

Fig. 2. Schematic diagram and prototyping

Figure 2 shows version 3 of the device, with hardware and software improvements. Arduino Uno was replaced by Arduino Nano, more compact but just as functional. Now, the device performs a voltage sweep from 0 to 2.5v, with 50mv increments, controlled by a geared motor and a multi-turn potentiometer for greater accuracy. This version was subjected to additional tests to confirm its correct functioning and sensitivity in electrochemical processes such as Redox, comparing the results with a PalmSens device.

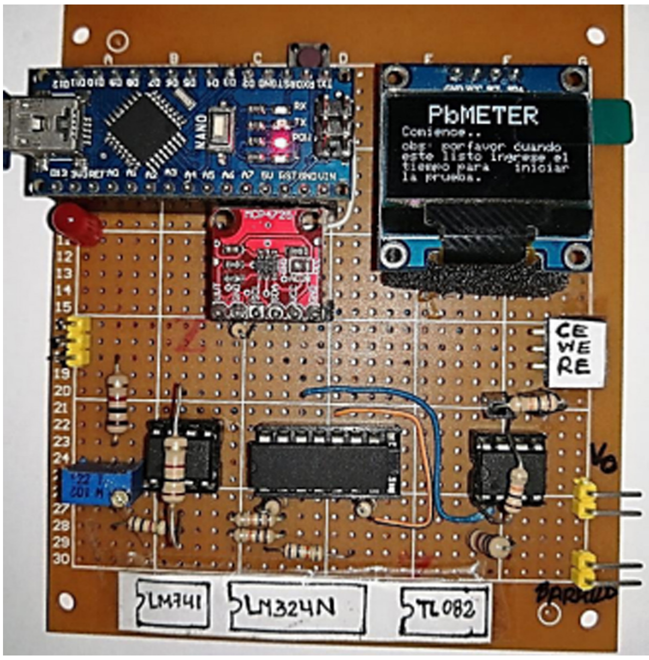

Fig. 3. Assembly and final circuit

Figure 3 presents the final circuit of the PbMETER device used in tests with standard lead concentrations to evaluate current in electrochemical tests. A symmetrical digital source was used in the lab to fix the voltages and allow for voltage sweeping. An external power supply with series batteries with a virtual ground was added to replicate the voltages without a digital source. Major components, such as amplifiers, Arduino and DACs, plug into sockets for ease of maintenance and modularity.

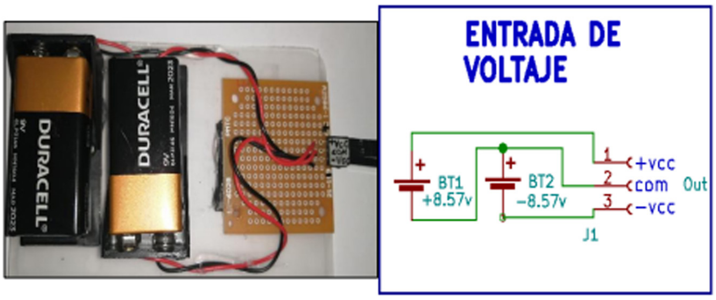

Fig. 4. Power circuit

Figure 4 shows the schematic and the plate welded on a perforated Bakelite of the PbMETER circuit. This requires an external source configured as a symmetrical source to power the complete circuit and generate the voltage sweep from –790mv to 280mv. The outputs of this source are +VDC, com, and –VDC, connected to the voltage input of the main board in the same order. The batteries in the image can be replaced by rechargeable batteries, although this would increase the cost of the final product, which is characterized by being energy-efficient and easily portable.

3.1 Unification of results

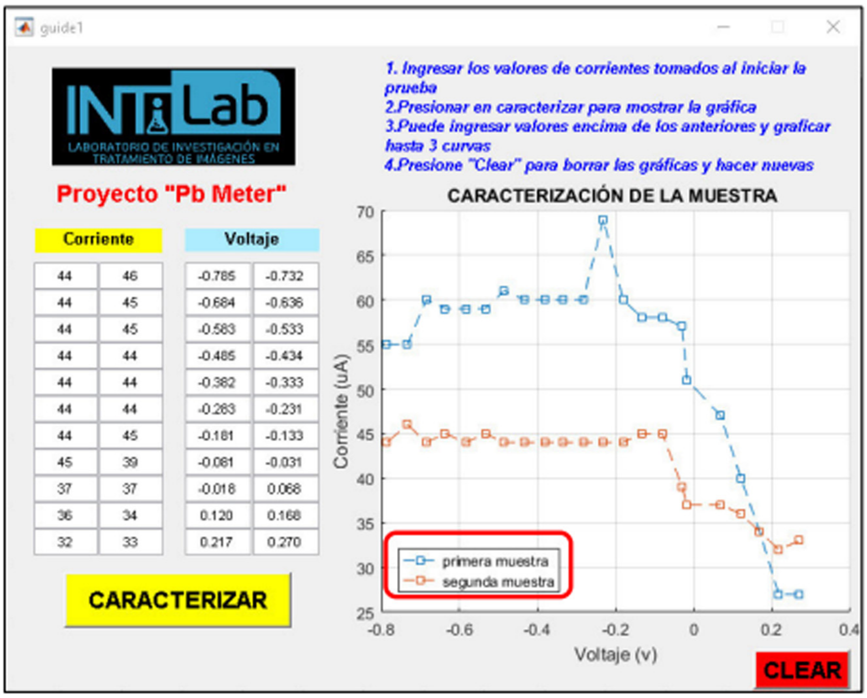

Fig. 5. Program in Matlab

Figure 5 shows the characterization of two standard lead samples at 100 ppm. The first was treated for 10 minutes at –1.5 V, the second for five minutes. The sweep from –790 mV to 300 mV, reveals current peaks of 69uA and 45uA, respectively. Both specimens were plotted together and labeled for identification.

4 DISCUSSION AND CONCLUSIONS

The creation of an innovative device, employing the Arduino platform together with Matlab and the anodic voltammetry technique, allows for the effective detection of lead in the blood. However, the electronic development faced challenges due to necessary modifications of the original methodology, adapting to the specific voltametric technique mentioned.

A notable limitation in the results is the use of an external power supply configured as a symmetrical source for the operation of the PbMETER device. Although functional in laboratory environments, this reliance on a non-autonomous external power supply represents a disadvantage in practical applications requiring portability. While the use of rechargeable batteries is suggested as a solution, this option would increase the cost of the device, which could compromise its accessibility and feasibility in scenarios where low cost and portability are key factors.

In addition, the power supply was simplified by using two batteries connected in series, creating a "virtual land" at the midpoint of the 9V batteries [12]. On the other hand, it was observed that the op-amps generated a significant noise signal during the measurements. This drawback was mitigated [13] by applying filtering techniques through the libraries available in MATLAB, thus improving the quality of the captured signals. Finally, thanks to these adjustments, Matlab's software was able to accurately [14] replicate the results obtained by the PALMSense potentiostat, demonstrating the efficiency and accuracy of the developed system.

It is concluded that a low-cost, easy-to-use portable electronic device has been developed, capable of taking rapid measurements of blood lead concentrations to alert people with elevated toxic levels early. In addition, a functional graphical user interface (GUI) has been created, which interprets and displays the data in characterization curves for better understanding, being portable and compatible with resource-limited PCs. Although it is the first prototype, areas for improvement to increase its functionality are recognized. However, it highlights its ability to perform outpatient tests, which differentiates it from more sophisticated devices that require specialized equipment in health centers.

Future improvements to the device could focus on reducing costs and enhancing portability by integrating rechargeable batteries without increasing expenses. Additionally, optimizing sensitivity and accuracy through advanced filtering or improved signal processing in Matlab would refine lead detection. Expanding tests to diverse populations and environmental conditions would further validate the device's robustness and adaptability for broader use.

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