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Microcontroller-based ion meter application utilizing real-time data acquisition system

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ABSTRACT

In this work, detection of lead (II) ions with automatic recording and data logging system for ions based on electrochemical analysis using an ion-selective electrode and wireless communication technology in surface water are presented. The new system automatically reports lead (II) ions value, time and date in real-time. Results displays in the cellphone of a pre-determined user to a computer system for data banking and further analysis. The system consists of two main parts, a remote monitoring station, and a receiver. The monitoring station acquires the required data, and send the data to the pre-determined cellphone user or computer system in the form of short message services (SMS) using the Global Systems for Mobile communications (GSM technology). It then transmits the data using the GSM network through local telecommunications and infrastructure. The system can work correctly no matter the distance from remote stations and to the receiver. The function of the receiver (cellphone or computer) is to receive, display and databank the information. The information downloaded to the computer systems for data banking and further analysis. The comparison of the results between the results of the new system and the commercial ion water resulted in an R-squared of 0.99. The testing results obtained were compared with the corresponding reference analysis. The combination of these new technologies makes this approach more affordable and can be implemented by any persons even with little technical.

1. Introduction

The traditional way of heavy metal ions detection and analysis are usually performed in the laboratory (Bansod et al., 2017; Kumar et al., 2017). It requires a tedious and expensive process. Although lab-based ion detection is more accurate compared to portable and real-time methods, provision of spatial-temporal data are not usually meet by this conventional method and could not define the evolution of the required parameters (Lv et al., 2017). For conventional or laboratory analysis, during storage and transportation sample may experience contamination that can affect its original chemical compositions due to various chemical, biological and physical processes between sampling time and laboratory analysis. On the other hand, handheld/portable methods perform data gathering at the location of interest, provide ways to overcome a significant problem facing the laboratory method, especially on how to preserve the water sample's original condition during sampling and transportation and handling. It lacks the real-time and online which could give stakeholders enough lead time to mitigate or take some measures to lessen if not prevent disaster if an accident happened.

Various literature pointed out the advantages of remote monitoring compared with the conventional laboratory analysis and portable sensors like elimination or addition of contaminants due to improper sample transportation and handling, reduction of total cost due to automation (less human intervention), data-driven and real-time analysis, fast determination of pollutants which could give enough lead time for some mitigation activities to lessen if not eradicate damages (Chen et al., 2018; Li et al., 2018; Lin et al., 2016). Also, it can obtain more spatial-temporal information of the area of interest (Christidis et al., 2007) and the chance of conducting data gathering in areas which possess great danger and challenging to access like swallow rivers, deep lakes and garbage-filled lagoons and canal (Lillehoj et al., 2013).

Recently, there has been increased research and projects to design and implement online and real-time water quality monitoring (Rowe et al., 2011; Yantasee et al., 2007). This automation ranges from partial automation (automated sensing but manual in data recording and reporting to a full automation in which from calibration to reporting are all real-time and automated. A combination of automated and continuous flow analyzers, electrochemical sensors and wireless sensor network (WSN) for real-time or automated measurements of water quality were much documented in Sibal and Espino (2018). With these, the new development of new electrodes, more powerful microcontroller and high performance transceivers permits gradual solving of previous problems the drift and inconsistency Dimeski et al., (2010).

Electrochemistry opens up various quantitative methods for the detection of essential analytes for various utilization like health, the laboratory analysis, water quality detection, and monitoring, and environmental monitoring (Bruins, 2015; Campos et al., 2012; Nantaphol et al., 2019; Szunerits and Boukherroub, 2018). Most of its uses confined to the laboratories and manned by highly technical skills personnel which make it expensive for a broader utilization. Increase in population, industrialization and climate change alter the landscape of the way people monitor specific environment and analytes. It needs a simple and inexpensive method that can be applied in the field and could provide a real-time and accurate result, especially in areas where the laboratory is limited or non-existing. These advantages are much more appreciated if it added with internet

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technology, using mobile technology from which technical expertise can forgo while data logging and reporting can be much improved. With the availability of new techniques, technologies and systems, are expected to be in low-cost, simple to operate, and as independent of infrastructure as possible in doing an electrochemical task while retaining its accuracy.

In this research, a low-cost, handheld device that performs ion concentration detection to determine the presence or absence of lead (II), simple to operate and can provide real-time status of lead. For the transmission of information, we utilized the most common and widely used technology of SMS using GSM technology and local telecommunications company's infrastructure. This method guarantees that it is compatible with both low-end and smart cellphone which will function as a receiver to display the results.

The demonstration of systems accuracy and capabilities performed by comparing the performance to a commercial lead (II) tester while retaining preliminary activities like calibration, mixing of solutions and samples and the stirring of the mixed samples. We then test the device for infield testing of water quality by detection of lead (II). We also demonstrate the transmission of the results (lead level) over from a particular place to a pre-identified cellphone number for automated recording system and data logging.

2. Methods and materials

The new system is composed of three parts: the data acquisition part which composed of the ion-selective electrode (ISE) for lead (II) and the interface and conditioning circuits; the controller and its peripherals; and the data transmission unit.

The output signals of the ISE which are normally weak (millivolts / milliampere) take amplification, conditioning and conversion from Analog to Digital (ADC) before transmission to the microcontroller using I2C protocol take place.

The controller using the microcontroller operates the whole system. It controls, direct and link all necessary component of the system in performing the assigned task. It receives the signal from the sensor (potential difference), preprocess it and backup this data thru a built-in Secure Digital (SD) card in a comma-separated values (CSV) format before transmitting them to the intended users using GSM technology. With these scheme, the users have an instant access of the actual situation of the lead concentrations in the area of interest. Fig. 1 shows the overall system of the proposed Lead (II) ions automated detection and data acquisition system. A lithium-ion battery of 3450 mAH, 3.7V specifications provides the energy supply.

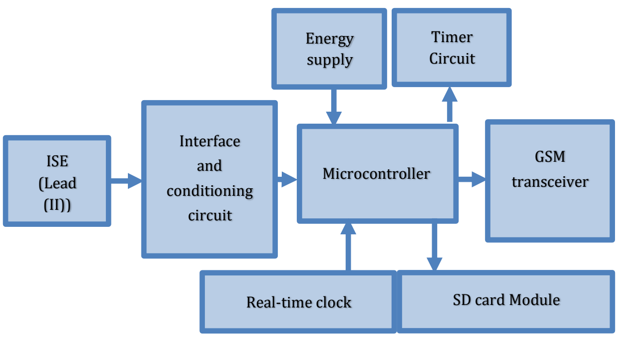

Fig. 1: The overall diagram of the new system.

2.1. Data acquisition unit

Data acquisition unit comprises of an ISE for lead (II) and the interface/conditioning circuit. The ISE is a solid state, combination cell electrode. It utilizes the potentiometric methods in determining the level of lead (II) ions in the area. The newly acquired value will be transmitted to the interface and conditioning circuit and processed so that compatibility with the microcontroller attained.

Interface with the conditioning circuit is a customized circuitry based on previous projects if pH and cyanide detection. Enhancement implemented to fit to the microcontroller voltage level requirement. Analog-to-digital conversion also implemented in the interface circuit. A solid state, an ion-selective electrode (ISE) used for the determination of lead (II) level. The output of the ISE is a signal which is a potential difference due to changes in the sample's ion activity.

2.2. Microcontroller

The fast progression of electronic devices and data acquisition system pave the way research and implementation of numerous potent, useful and cost-efficient tools and peripherals offering a feasible answers to the challenging issues and problems of detection and monitoring applications. A number of an online monitoring system using an open-source and architecture microcontroller made available in advanced countries but with a specific area and focus (Adamo et al., 2015; Zulhani and Abdullah, 2009).

Measurement of ionic strength also attracts much research, and some are based on the commercial portable ion meter described in Rowe et al. (2011). Three electrodes ion meter, commonly name half-cell electrodes made an early impact on ion monitoring. Microcontrollers enjoyed wider utilization among the majority of projects and research because of their flexibility, cost-efficiency in comparison with other systems and projects.

Cost-efficient, and high-performance Arduino Atmega 2560 is chosen as the main controller. The platform powered by an open-source Arduino Integrated Development Environment (IDE), which is compatible with other components of the system. Features, specifications and capabilities include enough number of analog and digital input pins which could cater to other type of sensors and future expansion. It has also capability to use various connection technology like Universal Asynchronous Receiver/Transmitter (UART), Serial Peripheral Interface (SPI) and Inter-integrated Circuit (I2C) for compatibility with other sensors and peripherals. Shown in Fig. 2 is the microcontroller and some important pin diagram. Its compatibility, capability to connect with other within and outside the system and easy to program using IDE makes the system as one of the most suit after microcontroller nowadays.

Fig. 2: The microcontroller and its pin layout.

2.3. Data transmission unit

Data transmission is an important part in the data recording process which could affect data integrity and accuracy. Any addition or subtraction of signals during transmission led to erroneous data. This wireless transmission permits the transfer of information from the actual area where the system operates to the intended users - a cellphone or a computer system with GSM transceiver. This wireless transfer of data is a significant problem in the early stages of real-time ion monitoring systems. One of them had to manually download the data from the handheld ion meter, while others use an unreliable method or costly hardware.

Current technologies like satellite, radio, GSM, GPRS, Bluetooth and infrared are used to transmit data from one location to another. Coverage wise, satellite offers the best solution, but comes with a very high cost. Most of the other methods has its own disadvantage for utilization in data transmission for WQM data which includes: permit to operate radio is tedious and time consuming, Bluetooth and infrared have limited distance of transmission while most of the common people does not know GPRS. This leaves us with GSM being the mostly subscribe technology as the technology of choice.

Given the advantage of GSM, this project utilizes the GSM technology to send data to the preprogram cellphone user or directly to the computer systems with the database. The applicability of this system is highlighted when the area of interest is remote places and the only means of communication is only thru the GSM network. Economic considerations are the reason for selecting the Short Messaging Signaling (SMS) format. SMS is paging service using the GSM capability to send alphanumeric data. Because of advancement of technologies, SMS became the cheapest electronics communication and much lower compared to voice communications.

The telecommunications company (Telcos) utilizes the standard 900 and 1800MHz frequencies to send and receive mobile data. GSM transceivers is responsible in converting digital signal to analog signal as minimum requirements for near to perfect transmission. GSM technology also transmit SMS or text.

2.4. Software design

The Arduino microcontroller used Arduino IDE for customize programming which brings several advantages in comparison with traditional programming language and tools, including flexibility, low memory specifications, and ease of customized software development. The microcontroller directs all activities of the sensor node. All other electronics component of the sensor node is connected to the microcontroller like the interface and conditioning circuit, timer, the energy management circuit, SD card (for data backup), GSM transceiver module.

In this study, a simple software design that allows the seamless flow of information from reading of the ISE to the long distance transmission activities. Arduino IDE used to develop most of the application due to its compatibility with other peripherals and component within the sensor node.

The program gets the value from the ISE, conditioned it, and converted the signal from analog to digital signal. The microcontroller reads the newly AD converted signal values, pre-process, and convert it to millivolt (mV) value ready for transmission. Systems flowchart for the whole data gathering shown in Fig. 3. The actual time of sensing is added at the microcontroller pre-processing stage respectively.

Part of programming is to create a CSV file as data backup mechanism, containing lead (II) values, time and date of sensing. For energy saving, sensing interval is selected based on the requirements of the user like 30mins. Some developed algorithms designed to save more energy.

2.5. Preparation of water samples

The focus of study is the detection of Lead (II) ions, the transmission of data to the intended receiver (cellphone or computer system) and ultimately the visual display of lead (II) status of an aquatic area or water samples. Preparation of water samples and its corresponding chemical reagents, the mixing of samples with the ionic strength adjuster and the process are not directly part of the research process. The process for this system starts upon the immersion of ISE to the water sample or aquatic area.

2.6. Chemical apparatus, electronics components, and software

A portable ion meter (Mettler-Toledo -USA) serves as a reference method to validate the accuracy of the new system. It employed a combination ion-selective electrode (ISE) for the lead (II) ions from (Mettler Toledo) used both for a portable ion meter (as a reference) and for the new system. The ISE is a solid state, combination type, lead (II) electrodes. This type of ISE is more convenient to use compared to the three electrodes for the half cell type of electrode (Pungor et al., 1978).

The primary purpose of the interface circuit is to link microcontroller and ISE and condition the signal generated from the ISE as an input signal to the microcontroller. It is a customized circuit which consists of instrumentation (Philips, Japan) and operational amplifier from (Motorola of US). The microcontroller is an Arduino Mega 2560 (Arduino, Italy). Wireless communication transmitter and receiver (transceiver) is a GSM/GPRS module from Arduino (Italy). The system relies on battery as a power source with a lithium-ion battery (Panasonic, Japan) as the preferred battery type for its high energy capacity. It also has a timer circuit for its energy management, battery booster circuit and data backup circuitry (SD Card). The results generated from the new system sent to a pre-defined cellphone (any cellphone type) using any GSM technology like 2G, 3G, and 4G.

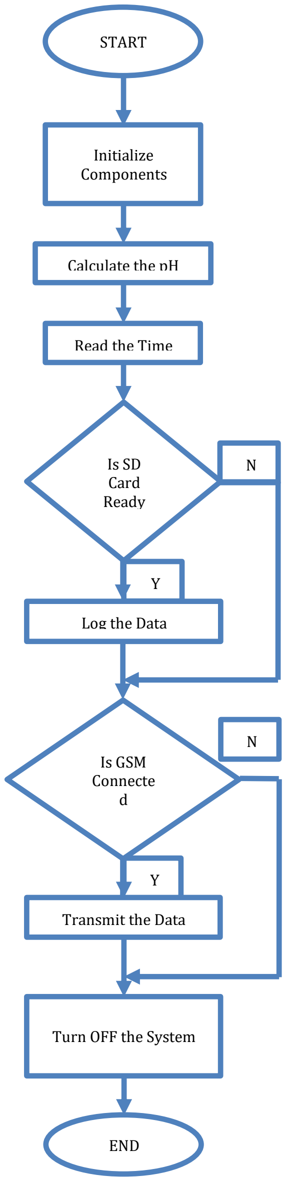

Fig. 3: Flowchart for reading the value.

Arduino integrated development environment (IDE) is the software used for the development of the systems programs like pre-processing of a signal using Nernst equation and conversion of a signal from Analog-Digital and vice versa. Microsoft Excel

VBA programming used to download data from cellphone and SD Card to a computer system for data banking and additional processing for other utilization.

3. Results and discussion

Fig. 4 displays a performance comparison between the new system and a commercial ion meter using the same solutions and ISE used. An R-squared of 0.9986 depicts the accuracy of the new systems against the commercial ion meter. Electrochemical fluctuations primarily caused differences between the commercial device and the new system during measurements.

3.1. Detection of lead (II)

Lead is among the most common toxic heavy metals found in water supplies. Trace amounts of lead can be detected by potentiometric analysis. The potentiometric response of the new system calibrated using standard solutions of sodium and then applied that calibration to a water control samples as shown in Fig. 4.

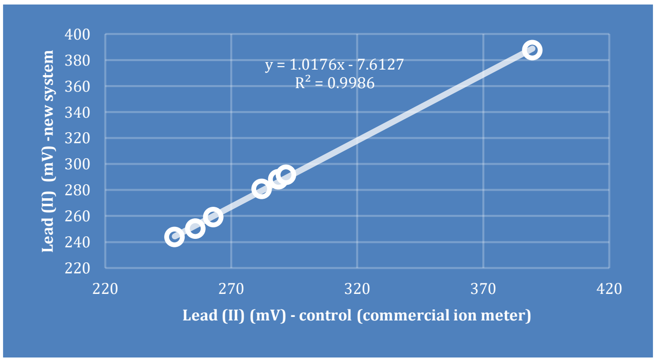

Fig. 4: Potentiometric measurement of lead (II) ions in water samples.

3.2. Discussion

Detection of analytes like lead (II) using the electrochemical method is an alternative method to perform simple and on-site testing of the presence and absence of lead (II) ions. This method took advantage of the established good features of an ISE: signals are not affected by the turbidity and lighting of the tested water samples or the presence of a small particle. Also, the output of an ISE (current or voltage) can be easily converted to usable output which makes it easier to databank, the process or transmitted to another location using wireless communication.

Some research conducted demonstrated the utilization of a low-cost potentiostat made from commercial components to do lead (II) detection. However, these devices are designed to operate offline; thus an extra effort and human resources must be performed to download the results to the computer and copy it to the USB or send the data thru the internet.

The common problem of field-based lead (II) ions and in any heavy metal ion detection are the challenge on how to automate the recording and data logging. Designing a technology or method for easy and cost-efficient that will encourage more stakeholder's utilization makes this endeavor more challenging. Based on these challenge, the target for this research were: that the new systems deliver excellent performance, easy to operate, low-cost in terms of materials and software, and can perform automation in data recording.

During testing, the system shows and display the following: it is capable of performing lead (II) detection with accurate analyses; it can be operated by minimally trained users, it is a low cost system (the new system cost is only 100 US dollar while the commercial ion meter cost range is 800-1500 USD); acquire, process, and transmit data automatically. Aside from this, it can also apply both in a laboratory setup or in the field (subject to manual calibration and mixing of the sample) and most importantly, the results can be displayed anywhere and anytime using text messaging (SMS).

It also demonstrated the electro-analytical capabilities and automated data acquisition capabilities of the new system. The new system used potentiometric analysis to provide a comparable limit of detection to other portable electrochemical detectors for lead (II) and GSM-SMS technology for automated data acquisition and reporting system which indicates that more users (from simply concerned citizen to low-income local government units like towns and communities) can use this new device to perform in-situ monitoring of water quality.

The design of the new system can also be utilized with pH and other ionic concentration-based analytes. The utilization of Arduino based microcontroller makes it easy to fit the system to other physicochemical analysis with a little tweak of programming. Also, with the integrated development environment (IDE) as the programming tool for research, it makes it simple to reprogram the device to alter, add other parameters and functions and recipient of the data and information.

Finally, by using GSM technology through SMS techniques, it ensures that the system is compatible with cellphone- the most widely utilized technology. With its compatibility with the earlier type of cellphones (text and voice only-2G technology) to smartphones (4G), it ensures wider adaption and implementation. It only utilizes SMS or text messages which do not require any phone-based applications (commonly called Apps) to operate. This approach widens the adaptability chances of the system, especially in the resource poor areas.

4. Conclusion

In this work, the design and actual application of a microcontroller-based ion meter with automatic recording and data logging system realized. It is a low-cost, custom built, with high detection accuracy for lead (II) ion determination systems. Most of its parts are available in the local and online market making its production easier. It has an open-source software which makes the system more flexible and cost-efficient. Open-source software and customization features allows future enhancement and modifications without significant changes both in hardware and software. Other than the interface circuit, the system can be assembled and operated by a non-technical person. Its total cost is much lower than the commercial ion meter. It can be simply utilized in the determination and recording of toxic lead (II) ions by the researcher, government agency and other stakeholders who want to monitor the water quality.

The system uses an ion-selective electrode, microcontroller and GSM transceiver which is acceptable to ordinary people. Design of the interface and conditioning circuit which can be easily reconstructed for mass production. It does not require any highly technical skills or electrochemical knowhow to operate.

Our system met the two major requirements of the water quality monitoring system, in the term of accuracy and easy to use. It tried to avoid if not addressed most of the problems in the implementation of the lead (II) detection. Stakeholders have access to the collected data remotely through the tested and matured GSM technology, thus an assurance of reliability and timeliness in delivering the data to the intended users.

The developed real-time lead (II) detection and automated data acquisition and reporting system was used to detect and report to the stakeholders' true status of the investigated water surface area. It was tested both in laboratory and field setup under diverse conditions, and it provided accurate results which was validated in comparison with the commercial ion meter.

The obtained results of the new system, lead (II) detection and reporting systems were adequate and ready for larger and bigger WQMS implementation. Automation of on-site preparation both for the solutions and mixing process is the next agenda of the authors. The next focus is on improving the robustness of the sensor and for a longer duration of sensor deployment.

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