Portable Potentiostat for Electrochemical Biosensors using STM32 Microcontroller

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Abstract- **A potentiostat is an electronic device that is used in various electrochemical studies. Electrochemistry is the study of electricity and its relationship with chemical reactions. Electrochemical studies like cyclic voltammetry, square wave voltammetry, and other amperometric studies are carried out on a potentiostat. In voltammetry, potentiostat controls an electrochemical cell where the applied potential is varied and corresponding current readings are found which are related to chemical reactions. These findings help to study electrochemical behavior and study redox reactions occurring at the surface of the electrode. A conventional potentiostat is sophisticated equipment and also priced high. The low-cost portable potentiostat can be designed using a microcontroller and operational amplifiers. STM32 Nucleo-144 board has been used in the construction of potentiostat, it is a 32-bit microcontroller that uses ARM architecture for its operation. It has a 12-bit wide Digital to Analog Converter (DAC) and Analog to Digital Converter (ADC). The principles of DAC and ADC along with the functions of operational amplifiers like summing amplification and current to voltage conversion can be utilized in the design of potentiostat. A varying potential is applied to the working electrode and the current changes in the counter electrode are recorded. STM32 is used because of its high operating speed and wide resolution. The obtained results were found to be on par with the conventional type. Low cost, portability, and usability are advantages of the microcontroller-based potentiostat.**

Keywords- Electronic device, Electrochemistry, Voltammetry, Point-of-care testing

1. INTRODUCTION

Biosensors are used for various biological applications like drug determination, environmental gas sensors, food quality, etc. Biosensors working is based on sensing the bio-recognition elements in the sample. They react with the analyte and generate a signal, then the transducer converts the received signal into an electrical signal. The electrical signal can be processed digitally and presented to the user [1]. Biosensors are of different types based on their working principle and can be classified as optical, electrochemical, mass-based, chromatography, and various other methods [2]. Each method has its characteristics in which electrochemical methods are used widely in biosensors due to their simple operating technique, portability, cost-effectiveness, and fast response time [3].

An electrochemical biosensor usually consists of a three-electrode cell; A working electrode made up of conducting material, a counter electrode with an inert metal, and a reference electrode to present reference voltage are the three electrodes employed in an electrochemical cell. They work by generating voltage or current due to the chemical reactions happening in the cell [4]. Electrochemical biosensors are the most used sssand promising biosensor technology as they are the most sensitive among other techniques [5].

Electrochemical chemical studies help us in understanding redox reactions, electron transfer kinetics, and quantitative determinations of compounds present. Cyclic voltammetry is a common electrochemical technique used.

The potentiostat is an analytical instrument used in electrochemical studies. It is connected to an electrochemical cell. A potentiostat can be designed by a microcontroller. In electrochemical studies, a potentiostat is an integral part to carry out the experiments. There is a need for the development of low-cost and point-of-care (POC) diagnosis by electrochemical biosensor which has the advantage of portability and is much desired. There are few works reported based on microcontroller-based potentiostat and it has certain advantages and disadvantages over others [6]- [9].

Digital to Analog converter(DAC) and Analog to Digital Converter(ADC) is performed by the microcontroller in potentiostat operation [10], [11]. STM32 Nucleo F746ZG is a 144-pin board that acts as a central processing unit(CPU). It is a 32-bit wide microcontroller made by the ARM architecture. It is provided with a 12-bit wide DAC and ADC [12], [13].

Operational amplifiers are an important part of potentiostat which are used to perform signal processing operations. They are much helpful in amplification and conversion processes required in the operation of a potentiostat. The output can be read through personal computers using multiple

software like a serial plotter, excel, and origin, and the output is displayed as a graph.
Ascorbic acid (Vitamin C) is commonly used as a therapeutic agent in health care. It helps in curing scurvy by boosting the immune system of the human body [14]. The detection of ascorbic acid using an electrochemical procedure will serve its purpose in pharmaceutical applications [15], [16].

2. MATERIALS AND METHOD

2.1 Materials
STM32F746ZG microcontroller, an electrochemical cell with electrodes, operational amplifiers, resistors, capacitors, power source, wires, and cables. Chemicals used are potassium dihydrogen phosphate, hydrochloric acid, and ascorbic acid (vitamin C). Double distilled water is used wherever needed.

2.2 Sample preparation
Phosphate Buffer Solution(PBS) is prepared by dissolving potassium dihydrogen phosphate in DD water and pH is adjusted to 2.0 by adding HCL. The ascorbic acid stock solution of 0.1M is freshly prepared and a 300 µM concentration is used for cyclic voltammetry [17].

2.3 Electrochemical studies
Conventional potentiostat and microcontroller-based potentiostat are used for electrochemical analysis. OrigaFlex - OGF01A potentiostat and the designed potentiostat are used for the same. The glassy carbon electrode(GCE) is the working electrode, the saturated calomel electrode acts as a reference, and the platinum wire electrode is employed as a counter electrode. Electrodes are well cleaned with alumina powder and distilled water. Electrodes are sonicated and used.

2.4 Electronic circuit

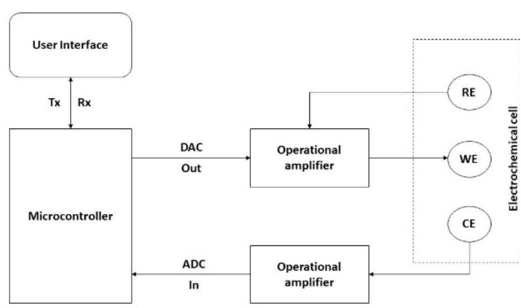

Fig. 1 Electronic block diagram of a potentiostat

The microcontroller here is the focal point of the circuit. 12bit DAC signal is fed into operational amplifiers where the potential window of potentiostat is decided by a summing amplification and reference voltage is compared with the applied voltage as a comparator function. The corresponding voltage will be passed to the working electrode and due to chemical reactions in electrolytes, the current in the counter electrode will vary. The current changes in the counter electrode will be converted into a voltage using a trans-impedance amplifier. Then the varying voltages will be fed into the analog input channel of the microcontroller where the ADC operation is performed. The processed data will be transferred to the user interface for displaying the results to the user in the graphical format.

3. RESULTS

3.1 Cyclic voltammetry of bare GCE in PBS
Cyclic Voltammetry is carried out for PBS 2.0 pH in the bare GCE and scans are carried out in 50 mV/S. From the graph, we can find there is no presence of peaks in PBS.

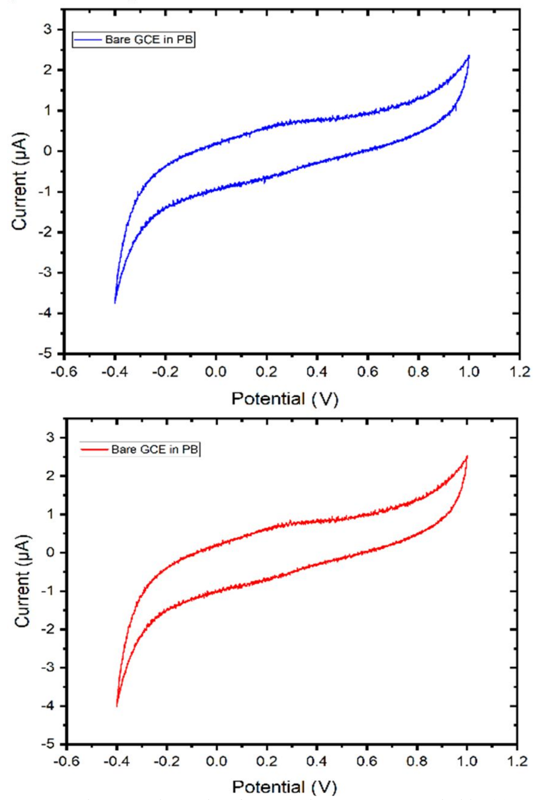

Fig. 2 Voltammetric study of PBS in bare GCE recorded in (a) microcontroller potentiostat (top) and (b)conventional potentiostat (bottom)

Fig.2 (a) represents the voltammogram recorded by the microcontroller-based potentiostat. The scans are carried out in bare GCE with PBS. Fig.2 (b) represents the voltammogram recorded in the conventional potentiostat of the PBS in the bare GCE. From the graphs, it is clear the electrodes works in their capacity and the absence of the sharp peaks in both oxidation and reduction side as a PBS will not involve in the reactions.

3.2 Cyclic voltammetry of ascorbic acid solution

Ascorbic acid of 300µM concentration is added to the PBS solution. Then the solution is stirred in the presence of a magnetic stirrer to get an even mixture.

The reaction occurring in the solution can be given as:

$$C_6H_8O_6 \rightarrow C_6H_6O_6 + 2H^+ + 2e^- \quad (1)$$

The oxidation occurring at the electrode is irreversible one to dehydroascorbic acid.

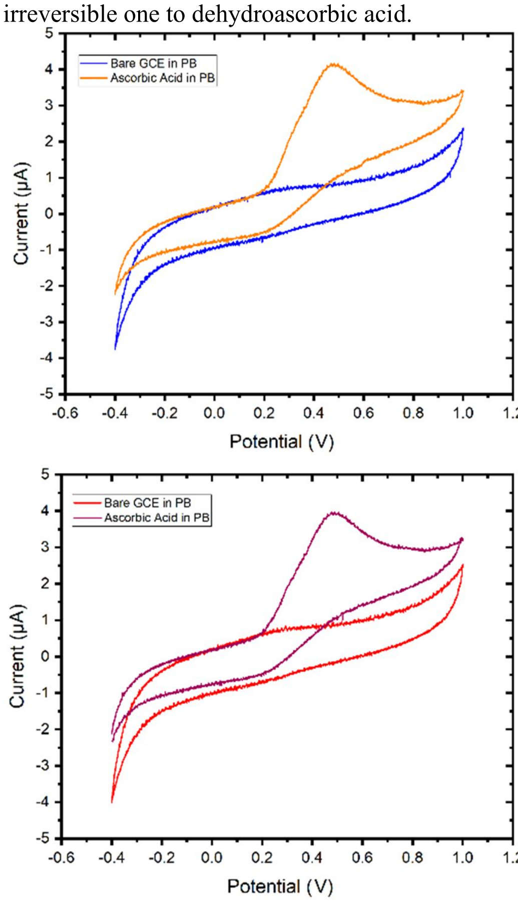

Fig. 3 Voltammetric study of ascorbic acid in bare GCE recorded in (a) microcontroller potentiostat (top) and (b)conventional potentiostat (bottom)

Fig.3 (a) represents the voltammogram of ascorbic acid in the microcontroller potentiostat. Voltammogram gives the peak current (I_{pa})at 3.9 µA. Fig.3 (b) represents the voltammogram of ascorbic acid in the conventional potentiostat. From the voltammogram, the peak current I_{pa} is found at 4.1 µA. The scans are carried out in 50 mV/s in the potential range of -0.4V to 1.0V. From both the potentiostat, the presence of oxidation peaks corresponds to the potential at 0.47V (470 mV) helps us in the quantitative determination of ascorbic acid. The peaks currents show the ascorbic acid detection capabilities of the electrode.

3.3 Comparative study between conventional and microcontroller potentiostat

Cyclic voltammetry of ascorbic acid is carried out simultaneously in both the potentiostat. From figure 4, both the graphs coincide with each other with very few current variations. A microcontroller-based potentiostat is efficient and can be replaced with a conventional type.

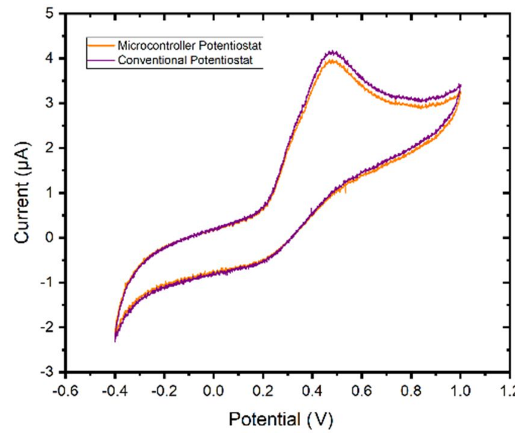

Fig. 4: Comparative study of ascorbic acid determination in bare GCE by microcontroller potentiostat and conventional potentiostat.

4. CONCLUSION

Cost-effective and portable potentiostat using microcontroller design helps in reducing the dependence of conventional potentiostat. From the results and comparative study, it is clear that the microcontroller-based potentiostat matches the performance of the conventional one. It can be used as an electrochemical biosensor for various biological applications with admissible efficiency.

5. ACKNOWLEDGEMENT

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