Ph.D. Title Proposal
on
Lab-On-Chip for Water Quality Monitoring

Submitted in partial fulfillment of the requirement
for the award of the Degree of

Doctor of Philosophy
in
Electronics Engineering

by

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under the guidance of

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PROPOSAL FOR TOPIC APPROVAL TO BE SUBMITTED TO THE UNIVERSITY OF MUMBAI FOR THE DEGREE OF **Ph.D. (TECHNOLOGY)** IN THE SUBJECT OF **ELECTRONICS ENGINEERING.**

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Statement by the Candidate

I wish to state that the work embodied in this synopsis titled "Lab-On-Chip for Water Qualtiy Monitoring" forms my own contribution to the work carried out under the guidance of Dr. S. S. Rathod at the Sardar Patel Institute of Technology. I declare that this written submission represents my ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission.

(Candidate Signature)

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Introduction

According to WHO, 3.4 million people losses life annually due to Water Borne Diseases. Contaminated water is responsible for diseases like Chlorella, Cryptosporidium, Diarrheal, Dysentry, Giardiasis, Hepatitis E, Typhoid fever, etc. Contributors to the Waterborne diseases include single exposure to the Microbiological bodies (Bacterias, Pathogens, and Viruses, etc.) or long term exposure to the chemicals (Nitrates, Arsenic, Fluorides, etc.). In 2017, WHO proposed a framework for Safe Drinking water which includes preventive measures and risk-based management. The framework composed health-based targets established by competent health authorities and systems of independent survillance [1]. The prediction of water quality depends on the measurement of chemical and microbiological parameters. Most of the Sensors available for measurement of Chemical parameters and Microbiological parameters are costly as well as require significant time for result prediction which restricts fast growth of Local surveillance bodies. This work aims to develop low-cost Water quality measurement sensors to accelerate the formation and growth of Local Surveillance and Prediction of water quality at the consumer side. Population Growth, emission of Greenhouse gases, frequent climatic changes and Urbanization have imparted a significant stress on the natural resources of water. Agriculture runoff including pesticides and fertilizers from large farms, disposal of Industrial waste and livestock waste, soil erosion, poor construction, and uncontrolled deforestation leads to serious degradation of the Surface-water as well as Groundwater. The Frequent climatic changes and Natural events such as Volcanic eruptions, Natural minerals had negatively impacted the quality of the Ground water [2]. Water is a necessary entity for many purposes that include Agriculture, Industrial consumption and drinking, among others. Water needs to be clean and must meet precise water quality requirements(such as dissolved oxygen and pH levels) for proper vegetation growth and crop yield [3]. Clean water is a critical resource for the survival of all humans. Drinking water utilities are facing new challenges of real-time monitoring due to increased attention towards accidental or deliberate contamination, aging infrastructure, limited water resources and prevention of the Diseases outbreaks [4].

Conventional methods of the Water Quality measurement involve collection of the sample from the field under study and testing sample at Laboratory where measurement facilities are available. Such methods are no longer considered efficient due to high labor and transportation cost, long time to measure parameters. Therefore a strong need arises to develop a real-time system to predict the water quality in less amount of time. Water quality is predicted by measuring Chemical and Microbiological parameters. The Chemical parameters suggested by US Environmental Protection Agency(USEPA) for predicting water quality includes measurement of Turbidity(TU), Oxidation Reduction Potential(ORP), Electrical Conductivity(EC) and pH [4]. Recent reports on groundwater quality published by Central Ground Water Board indicate the Salinity value greater than 10000 mS/cm making water highly portable. Also, higher proportion of the Flouride ($> 1.5mg/l$), Arsenic ($> 0.01mg/l$), Iron ($> 1.0mg/l$) and Nitrates ($> 45mg/l$) are observed in various states of India. This leads to an increase in the death as well as Waterborne Diseases count in the population directly dependent on the Groundwater for daily needs [5].

Chemical Measurement techniques have developed to such an extent that precise measurements can be made for all the parameters as specified by WHO, ESPA but considering microbiological parameter measurement are both costlier as well as time consuming [6]. Microbiological Measurement includes the detection of the pathogens, Bacteria, and Viruses responsible for the health problems in the Humans, Animals, and plants. Viruses are the smallest form of microorganism capable of causing diseases whereas bacteria are typically single-cell organisms responsible for severe health issues. Both Bacteria and Viruses count in the Water are regulated by EPA's Maximum containment levels(MCLs) criteria. Mingxiao et al., designed a system to detect bacteria in water including a micropore arrays Micro-

electromechanical Systems (MEMS) based bacteria filter and a nanowire forest silver Surface-enhanced Raman scattering (SERS) silicon-based sensor. The developed sensor eliminates the need for Fluorescent as well as the Culturing technique thereby drastically reducing the time to predict the result [7]. Weiyang et al., developed a dual-channel bacteria-based biosensor for sensitive and reliable monitoring of toxic substances in water using microbial fuel cell (MFC) technology as a biosensor for the detection of water toxicity. The usage of small-scale MFC biosensor produced favorable conditions for high sensitivity by reducing the internal resistance and increasing mass transfer in the micro-sized chamber [8]. Jeniffer et. al., developed a methodology for the Escherichia Coli (E. coli) detection in drinking water through alternative instrumental methods such as E-nose and E-tongue. The results obtained through the developed method are validated with the Membrane Filter Technique (MFT) and the measurement discrimination was made through PCA, reaching 99.4% of variance with the E-tongue. Similarly, a 97.6% variance was obtained for the bacteria discrimination with the E-nose [9]. Antonio et. al., presents a preliminary study concerning the problem of the static optimal sensor placement of a wireless biosensor network in a water distribution network for real-time detection of bacterial contamination. An optimal sensor placement strategy is proposed, which maximizes the probability of detection considering a limited number of sensors while ensuring a connected communication topology [10]. Kruthika developed a low-cost, disposable, monolithic chip integrating bacteria enrichment using passivated-electrode insulator-based dielectrophoresis (DEP) and capacitively-coupled bioimpedance sensing. This integrated chip enables real-time detection of small populations of bacteria in water. The platform operates by selectively concentrating bacteria through DEP forces produced by tunable AC electric fields. Following enrichment and release, bioimpedance measurements are taken concurrently at multiple frequencies in a focusing region [11].
Aziz et. al., developed a slotted rectangular patch antenna to determine the relationship between dielectric constant of different types of water with the life of E. coli bacteria in all water and analyze them [12]. Ping et. al., proposed a quantum dot(QD) based semi-automatic system for the detection of pathogenic bacteria in drinking water. It combined QDs imaging technique (with advantages of higher fluorescence intensity and longer fluorescent signal, multiple color choices, tolerant to reaction environment, et al.) with a fast filtration system, and enabled the semi-automatic detection process [13]. Ninad et. al., developed a purification system using a proportional-integral-derivative (PID) controller at a water storage tank in metropolitan cities, which helps in controlling pH of water, clarity, and presence of microorganisms in water [14].

Research Hypothesis

The Bacteria detection by sensing Ionic Current to predict the presence of the Bacteria in the microfluidic channel. The detection of the Bacteria will be done by utilizing Electrophoresis Technique to Separate bacteria at a different distance in the Microfluidic channel according to the different diameters. The Microfluidic Channel and Electronic System will be integrated by adopting the Heterogeneous Lab-On-Chip Technology.

Aims & Objective

- Development of the Sensor capable of predicting bacteria count based on ionic current measurement.
- Development of the simulation model for Sensor to test separation of the Bacteria's according to diameter using Electrophoresis.
- Development of the Simulation Model of the Electric circuit for Measurement of the Ionic current.
- Use of Heterogeneous Technology for Lab-On-Chip device fabrication.
- Development of the Electric circuit for measurement of the ionic current in nA to μA range.
- Development of the Portable Casing for Microfluidic device.
- Measurement of response of the fabricated device and calibration of the sensor with industry grade sensor.

Materials & Methods

Lab-On-Chip System incorporates MIcrofluidic as well as VLSI Technology on the same system to efficiently implement all the subsystems required for the Implementation of the Biological System. This includes the on-chip Microfluidic input channel, Reaction chamber to perform complex reaction between the input and reagents, signal conditioning circuit, Digital readout or Biomarkers, and Drainage System. This reduces the cost of detection by replicating Laboratory functions onto the Single Chip. Lab-on-Chip technology is classified into two types according to the method of the fabrication of the device. Homogeneous Lab-On-Chip uses Single VLSI technology to implement Signal conditioning, Digital readout, and PDMS technology to formed microfluidic channels.Heterogeneous Lab-On-Chip technology utilizes PDMS Technology to formed Microfluidic channel and electronic devices which may belong to VLSI technology or any other technology. This greatly reduces the fabrication cost of the prototype and observe the results.
The Modeling of the Lab-On-Chip will be done in the Multiphysics FEM Software such as COMSOL to test hypothesis and also to compute necessary parameters required to achieve Electrophoresis, Electroporation at Millimeter to Micrometer channel. Since the Single bacteria, current ranges in Nanoampere ranges it is mandatory to amplify the signal to the extent such that it can be easily detected by Analog to Digital Converter. The Circuit is simulated to set the necessary gain as well as to remove line frequency noise in the Circuit Simulator Software such as Multisim. The Value of the current obtained after the modeling of the Bacteria cell and Microfluidic channel are taken as input the Circuit Simulator to choose minimum gain for the Circuit. The Circuit will be designed for both the Micrometer and Millimeter channel and analysis will be done to determine the Limit of detection while utilizing the Heterogeneous Lab-On-Chip System.
The optimized solution from the simulated circuit, as well as the Modeled system, will be implemented utilizing PDMS microfluidic Technology and Electronic systems. The final step is the Integration of the Electronic System and Microfluidic device and tests the sample. The result obtained from the fabricated device will be compared to the Standard Industrial Equipment and WHO standards to test the Hypothesis.

Expected Results/Outcomes

- Sensor Capable of predicting Water quality on the basis of the measurement Ionic current of Microorganism.
- Sensor capable of real time monitoring.
- Reduction in the reagents Volume by utilising Millimeter channel
- Reduction in time of prediciton by sensing real time Ionic current.
- Separation of Bacteria using Electrophoresis.

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