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IoT-based Monitoring Model for Pre-Cognitive Impairment using pH Level as Analyte

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Abstract

World Health Organization (WHO) reports show rapidly increasing death rates brought about by chronic illnesses. This scenario calls for possible remedies and interventions to minimize such occurrences. A possible avenue of addressing this is the provision of an immediate monitoring system using an application to determine pH levels which can keep track of an individual's vital signs even in a remote area. The pH transducers transform the pH value into a current signal which is connected to a current controlled voltage source circuit that generates a potential difference. Also, this project utilizes a customized Field Programmable Gate Array (FPGA)-based IoT architecture which uses a low-cost, low power and secure communication infrastructure called as Long-Range Wide Area Network (LoRaWAN). This research aims to develop a diverse and productive research program in IoT, Long Range (LoRa) implementations and an FPGA-based system which can monitor the vital signs of a patient to eventually facilitate the needed immediate medical attention and service; and to utilize LoRa for a subscription-free and long-range bio-telemetry to healthcare providers. The study provides for different human activities and identified pH levels in their sweat. Each pH level sample produces a variance of the current signal. This research project entails to benefit both the patients as to consciousness of their physical well-being, equipping them to handle themselves prior receiving of medical attention; and for clinical practitioners for an immediate facility or signal to keep tract of patients' physical condition.

Keywords: Analyte, cognitive impairment, IoT, pH level, pH transducer

I. INTRODUCTION

Research has shown that approximately about 2000 people die every month due to being not mindful of their health [1-4]. Workload apparently appears to be one of the key factors. Due to the bulk of work demands, individuals rarely have time for themselves. Hence, as they do take their state of health for granted, they unknowingly develop chronic illnesses. Moreover, the everyday life stressors adds-on to the condition. Numerous studies on stress likewise proved of its significant impact to one's state of well-being. Stress has been proven to have deterrent effect in certain brain areas which could then lead to a lasting injury. Stress affects several of our memory functions and even the cognitive functioning of the brain [5-6]. Another crucial concern is on age. The inverse relationship of aging with our cognitive functioning is a given fact. As age increases, cognitive functioning declines. Taken as a whole, stress, age and cognitive impairment are interrelated. Fig. 1, shows a typical condition of an aging person and the possibility of the development of Alzheimer disease (AD), which is a weakening in cognitive function [7-8].

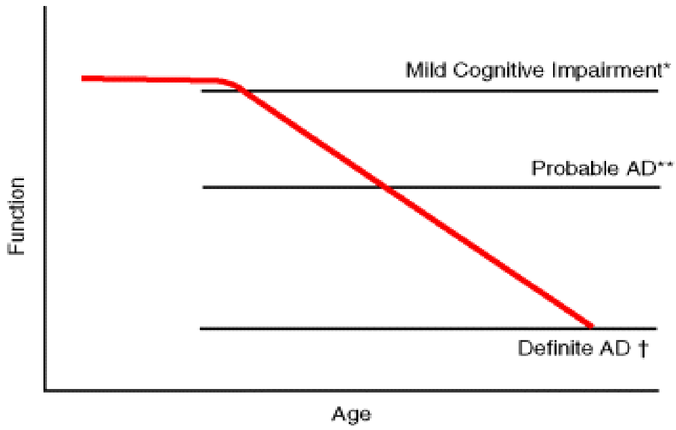

Fig. 1. A hypothetical change in the function of an individual as they age.

As to the normal process, determining and ensuring one's state of health is obtained through undergoing the appropriate medical procedure and diagnosis. Such preliminaries are vital in identifying if a person is suffering from an illness or disease [9-10]. The information required for diagnosis is typically collected from a patients' medical history together with the generated result of subjected physical examination [11]. Considering the given processes, it will usually take some time for the result to come out and to inform patient's about their condition. Given the fast pace of medical technology, and with advancements in the technology of diagnostics, examination cannot be limited alone to physical examination. Biological fluids are also potential source to be analyzed in a clinical laboratory to aid in the diagnosis of the patient's condition. The diagnosis can be facilitated through the help of biosensors. In the biosensor clinical diagnosis, the drawn information can be collected from either a living or a deceased patient. By which, the medical diagnosis using this biosensor becomes a source of vital information. The objective of this paper is to come up with a rapid mode of biochemical and bio-molecular diagnostic/analysis methods of patient's condition. Likewise, this research project aims to increase the individual's level of awareness as to one's state of health and to optimize the growing world of technology in the field of health care. Through a biosensor, certain substance or analyte with high specificity can be readily detected. The analyte's concentration (aqueous solution) is measured by biosensors. It is commonly proportional to an electrical signal produced by a biosensor in terms of its range of measurement [12-13].

The biosensor extends its relevance not just only in the analysis of biological media but also for process control in the food and chemical industry [14]. It has proven its benefits in the healthcare field for the diagnostic and monitoring of illnesses as well. Moreover, this device is founded on a definite biological/chemical recognition component in associating with a transducer/s for information processing. The possible development in the biosensor industry field is remarkably increasing and the emergence of biosensor market is also expected to rise in the coming years. Biosensors in general have been applied to a wide variety of areas including in medicine, pharmaceuticals, the environment, food, and even the security and defense field [15]. The current improvements in the field of bioelectronics and biotechnology have given modes which are able to capably transduce biological information by means of real-time and label-free electronic devices. This advancement has directed to the enhancement of biological sensing platforms in signifying its capability in the screening of biological samples and point-of-care use.

The potential hydrogen (pH) level in any aqueous substance measures how acidic it is., hence, anything below 7 indicates an acidic solution, while above 7 specifies its alkalinity. Studies show that sweat samples raise their merits to compare to other biofluids as biomarkers for different diseases [16]. Also, the induction of perspiration is an exceptional case, contrasting with other biofluids which are directly gathered. Obtaining an ample volume of sweat can be obtained by exercise and stress, however, in cold conditions, sweat reduces [16-17]. Therefore, sweat is a vital source of information which is a non-invasive, ergonomic, and rich source of analytes thus, can serve for continuous access to electrochemical sensing [18]. This research aims to develop a diverse and productive research program in the existing pH transducer as biosensors which can monitor the vital signs of a patient and can provide immediate medical service using pH level as analyte.

The rest of this paper is organized as follows: Section II is the discussion of related works to the proposed monitoring model such as different biosensors, and their techniques for health monitoring applications and description of Long Range (LoRa) implementation; Section III presents and describes the proposed mode; framework and explains the implementation details; Experimental setup and results and implementations are provided in Section IV; lastly Section V concludes the paper and recommended study for future works.

II. REVIEW OF RELATED WORKS

This section presents some related which are applicable to the proposed work. This includes different biosensors and their techniques for health monitoring applications.

A. Development of Biosensors

A biosensor is a device that detects a substance or analyte with high specificity. Glucose, lactate, glutamine, and glutamate are some example of analytes [19-20]. Most biosensors are designed for the concentration of an analyte in an aqueous solution as a sensor, and it adheres its purpose as a transducer to produce an electrical signal, and normally proportional to the analyte's concentration in its measuring range. Table 1 shows the three main parts of how a biosensor works. The enzyme, which identifies and responds with the target analyte producing a chemical signal [21]; the sensory organ and transducer, which produces a physical signal; and the output can be fed to an amplifier system, which conditions and intensifies the signal like the functionality of the ion-sensitive field effect transistor (ISFET) [22]. The process of analyzing the complex biological substance can be done by these biosensors. The recognition of a huge volume of compounds has great significance in scientific research. Moreover, it is indispensable in the healthcare applications for the diagnosis and monitoring of illnesses [23].

Several research developments in the bioelectronics and biotechnology fields have developed technologies which are able to capably transduce both in biological and engineering events. The advancement has directed to the development of different biological sensing platforms [14]. Below are some of the development around the world of biosensors.

A collaborative project of the Institute of Bioscience and Technology of Cranfield University and Pelikan Technologies in Palo Alto, USA, developed the Medisense home blood, glucose monitor. It was the world's most effective biosensor so far [14, 24]. The device is fully integrated with painless blood sampling and glucose measurement. In Lund University, they have created an emerging area in the bioelectrochemical field. They provide research development in the determination procedures founded on the spectroelectrochemical method [14, 25]. The design of these biosensors is concentrated on the detection of chemically-modified starch and cellulose. And, they are aimed on examining heterogeneous and intraprotein electron-transfer of ligninolytic enzymes for the construction of amperometric biosensors. In Japan, they have noteworthy research effort in biosensors technology. The study is based on the first microbial biosensor [14]. Likewise, many biosensors for biochemical oxygen demand (BOD), cyanide, detergents, dioxin, plankton, phosphate were developed [26-27].

The company Bayer AG, a healthcare and medical products provider has developed glucometer tools for testing of glucose in the blood and diagnosing of hepatitis A virus patients through an in-vitro immunoassay system [14, 28]. Roche Diagnostics AG, also a medical products provider, patented a product named "Amperometric biosensor test strip" for analyzing blood samples [14, 29].

The key features of the development of the different biosensors above are economical, convenient to use, and elicits rapid testing results that can be used for a specific application. Moreover, in the future, these biosensors are a definite potential, especially in the healthcare application in the Internet of Things (IoT) era, where Big Data compromises their information contents.

B. Biosensor architecture

Figure 2 shows the typical architecture of a biosensor. The bioreceptors that normally bind the analytes to the interface element which is called as the transducer. This transducer element can be an electrode of fiber optic type that specifically converts the analyte into an electronic signal. The amplifier conditions, filter and even amplify the converted electronic signal. Finally, a computer-based system or any FPGA module, and a dedicated software transform the output signal to meaningful information which can be applied to a large variety of applications.

Table 1. The typical topology of a Biosensor

input		**sensory organ/conversion**		**output**
Example substances	analytes	receptor	transducers/sensors	signals
1. sweat	lactate/lactic acid	chemoreceptor	pH	current
	urea/carbamide	chemoreceptor	Ion selective electrode (ISE)	voltage
2. saliva	electrolyte solution	chemoreceptor	electrolyte-insulator-semiconductor (EIS)	current
	mucus	chemoreceptor	polymer/ piezoelectric	sound/vibration/ pressure

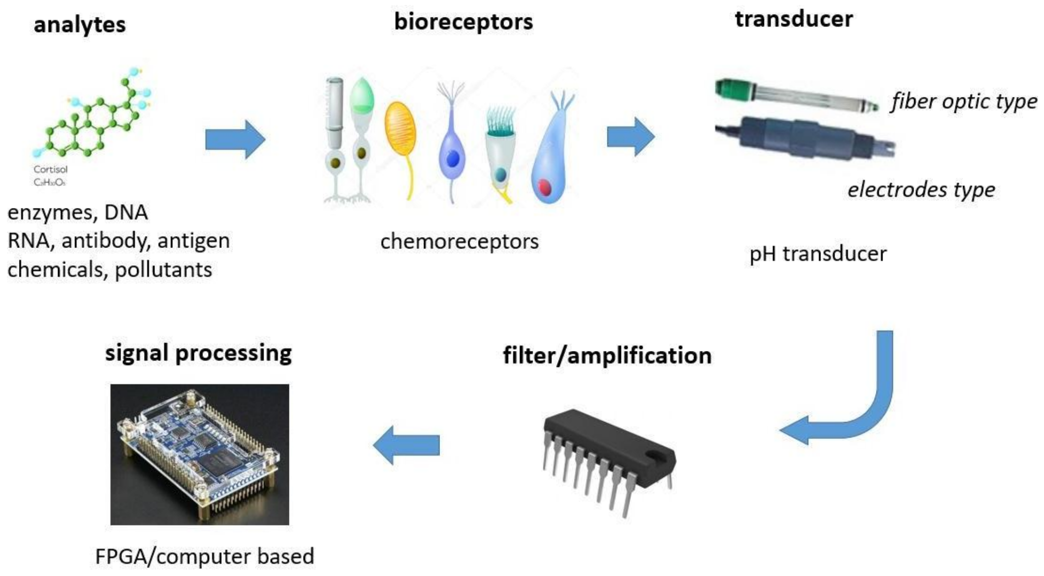

Fig. 2. The general architecture of a Biosensor.

C. Internet of Things/Long Range implementation

The global communication network is now on a most important evolution, making a more useful and expanded network approach especially in mobile networks. Also, with an increasing demand for Internet of Things (IoT) applications [30-32], IoT will deliver a key transformation by producing a relaxed, flexible and mechanized setting for end users. The internet of things is projected to carry variety in intelligent transport systems, smart home automation, remote maintenance, and industrial automation, etc. Since IoT is an emerging technology that has the capability to interconnect the available input data resources and possible output applications together. A technology like Low Power Wide Area Network (LPWAN) [33] can be applied with further evolving and appropriate systems for technologies implemented through IoT.

One overall goal of this study is to develop a customized system for patients with chronic illnesses utilizing the potential of both Long Range (LoRa) [34-38] and IoT technologies. This research program aims to have a mobile medical examination system using IoT and LoRa technology which could link medical databases, doctors, and patients allowing a smooth speedy medical treatment. This proposed scheme makes an IoT-based healthcare project for people who give them all the individual info about their health using their mobile and can monitor all their historical health data. This serves as a life-saving device as it provides warning signals of potential health disorders.

The Long Range (LoRa) technology is a low-power wireless transmission protocol for joining IoT devices at the edge to a network. This technology will serve as a gateway for the servers/cloud which permits users to gather nonstop data, and to analyze for possible applications to provide an enhanced consumer experience. The IoT applications can maximize the potential of sensors linked to a LoRa device to check and trace assets, determine resource consumption, check temperature, pressure, pollution level and other environmental variables, and recognize fires or definite sounds. Moreover, this technology is applied in applications like in automobiles, industrial equipment, and smart home networks.

D. Field Programmable Gate Array

Using an FPGA like the iCE40 UltraPlus [39] lets users to execute a LoRa-compliant device, because an FPGA-based design is suited to this requirement, and appropriate for many applications [40]. It also permits for link to different kinds of sensors via flexible I/Os, and fixed peripheral blocks. Moreover, reference designs like machine learning/artificial intelligence can be utilized to design a smart edge tool. It has various specifications like LoRa-compliant device which uses RISC-V processor and accelerators. It can also link to several types of sensors. Moreover, if implemented, reconfiguration through machine learning IP can be included to gather and evaluate data from several sensors such as sound, image, pulse rate sensors. Applications with voice/sound processing such as window cracking, fire alarm, etc. is also possible. Moreover, an FPGA-based system can be designed to implement a stand-alone scheme dedicated to health monitoring. It is capable of emergency medical services that can collect patient's medical information to give immediate support of help in real time scenario with low power consumption.

E. Related works

Reference [41] proposed an ECG monitoring model that utilizes an android application. This framework depends on ECG sensor, microcontroller, and android innovation. However, in using ECG electrodes, it typically requires a wet sensor which the use of a conductive gel to increase conductivity between skin and electrodes. In similar research work in [42], presented a healthcare scheme for patient's heart rate and body temperature. Also, it uses a web server and an Android app to monitor these patients' vital signs, but the information from these two vital signs is not enough to consider if a certain patient has an illness or diseases because it needs to verify by the medical experts.

Reference [43] developed a speed-controlled rehabilitation treadmill (BitAid) which helps patients in their after-stroke rehabilitation. The BitAid utilized a BITalino Kit which consists of sensors that can test ECG. It can also measure the electrodermal activity (EDA) and electromyogram (EMG). Through an accelerometer, it can determine the balance. Meanwhile, reference [44] designed a system that determines certain circulatory diseases such as coronary occlusion, congestive heart failure, and congenital heart disease through images of patients' fingernails. Reference [45] developed a system that monitors the amount of glucose in blood based on capacitance method through Artificial Raindrop Algorithm. Reference [46] constructed a module that detects body of a human whether standing or moving. The said module utilizes a shutter, Fresnel lens, and a pyroelectric infrared (PIR) device.

In reference [47], though an effective patient's healthcare monitoring system utilizing both the IoT, and RFID technology, which collected patient's information from heartbeat pulses. Another IoT-based system [48] which discusses the task of gathering and loading the data in the IoT platform, it provides a real-time reading of data. As mentioned, its complexity in data analysis and the sequentially storing of data represents its drawback.

III. PROPOSED MONITORING MODEL

A. pH transducer

The pH transducers convert a pH measured value directly to an electrical current signal. The selected pH transducer is HI 8614N pH transducer which functions from -2 to +16 pH measurement range. Its pH electrode's cable has a 10-meter maximum length. It proportionally converts the input pH signal into a 4-20 mA signal which can be read by digital interfaces, regulators, and indicators.

B. Current to voltage converter (IVC)

Fig. 3 shows the two-stage current to voltage converter circuit. This circuit will produce a voltage which is proportional to the given current and based on reference [49].

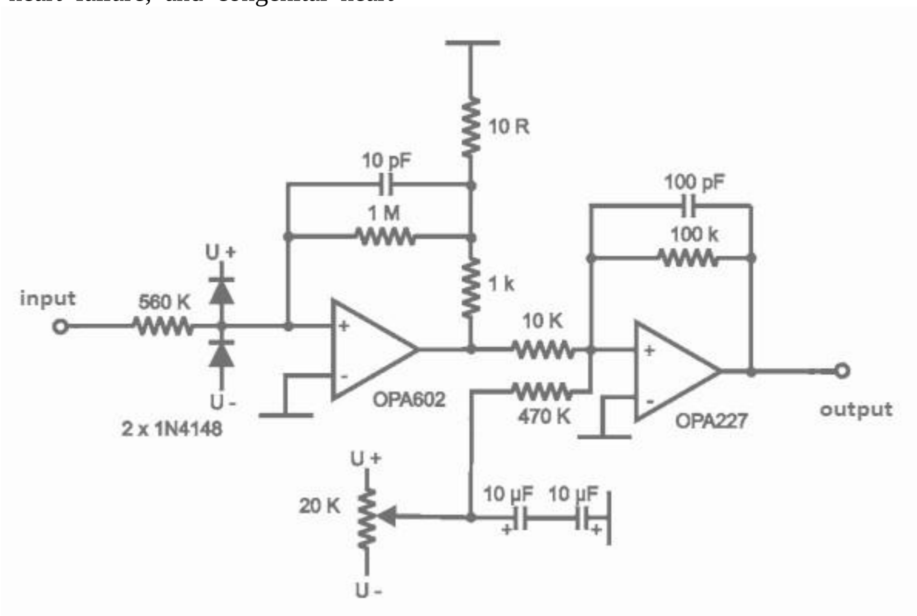

Fig. 3. Circuit diagram of the current to voltage converter.

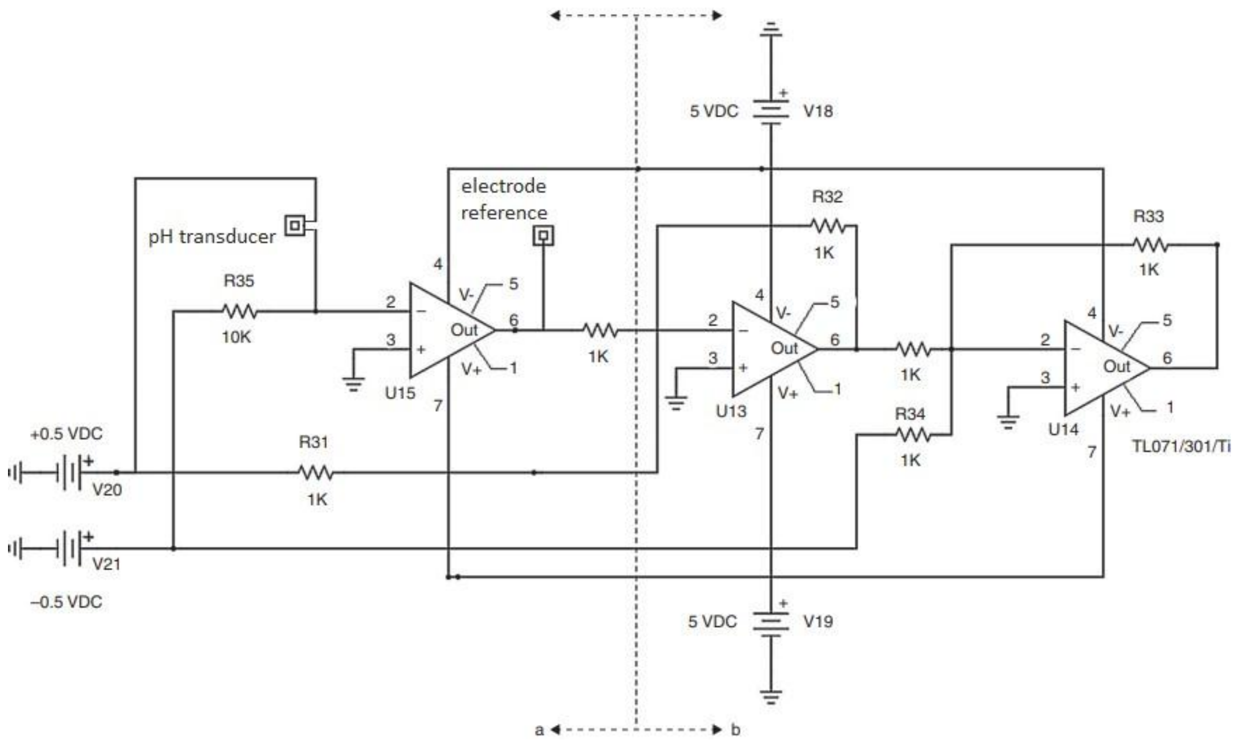

Fig. 4. Conditioning Circuit.

C. Conditioning Circuit

The conditioning circuit is shown in Fig. 4 which includes circuits for pH transducer biasing and based on the Valdes-Perezgasga circuit [50]. Its function is to condition, filter and amplify the converted electronic signal.

D. Proposed System

Fig. 5 shows the overall proposed system which is applicable for any biosensors even for wearable IoT. A software interface for data visualization was included. The block diagram of the Lattice iCe40 FPGA is shown in Fig. 6.

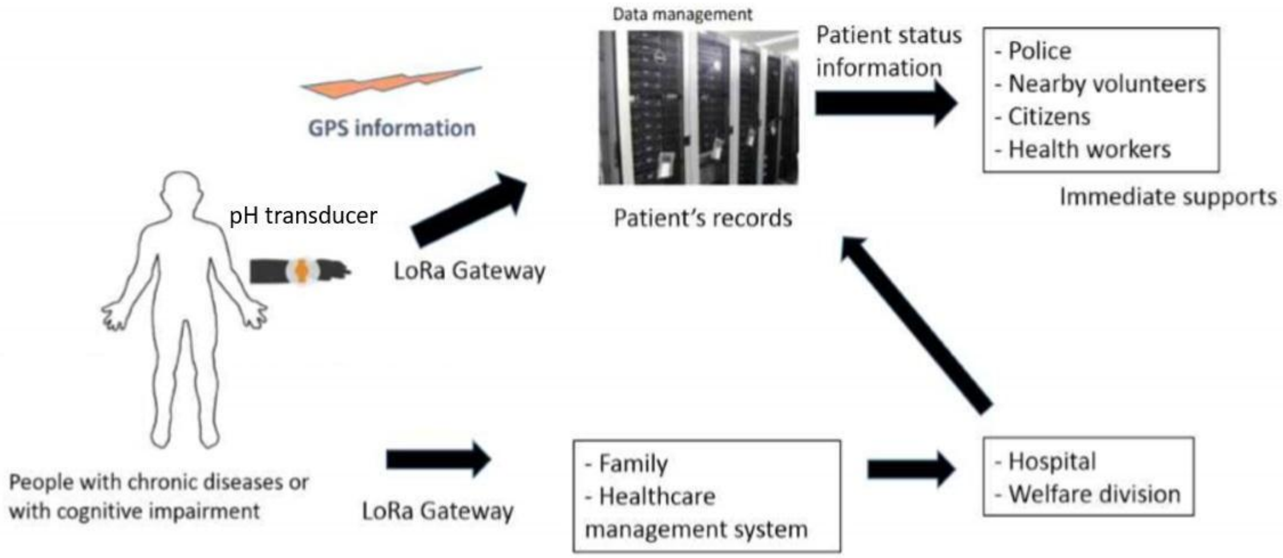

Fig. 5. Over-all proposed system

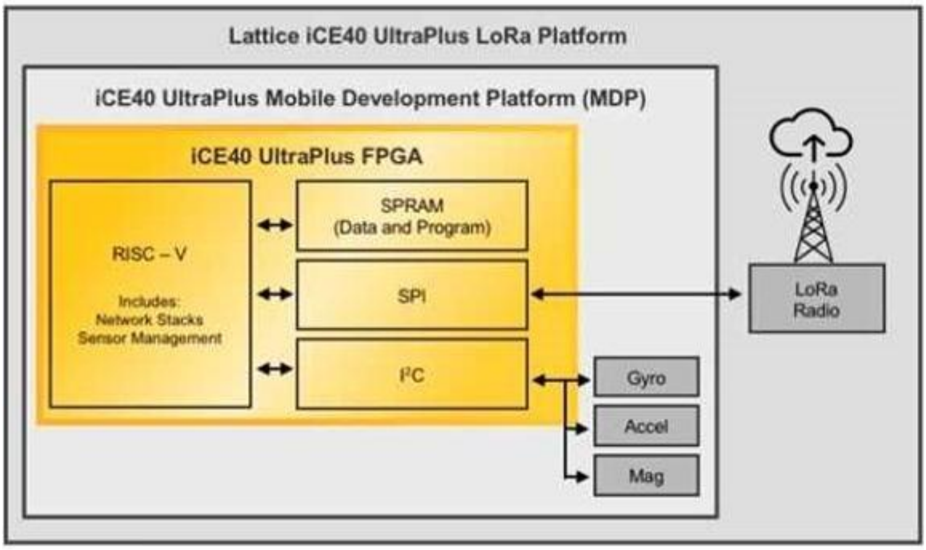

Fig. 6. Block diagram of iCE40 UltraPlus FPGA

IV. RESULTS AND DISCUSSION

To evaluate the proposed method, an experimental analysis was conducted. The set-up parameters have been used to determine the performance of the system. Three different conditions of sweats with variants in temperature state were taken from 5 individuals to analyze and validate the theoretical information of pH level. These individuals voluntarily submitted themselves to be subjects for this experiment set-up. The said subjects were all in favorable state of health as evidenced by their medical records, at the time of the conduct of the experiment.

Tables 2 to 6 shows the results of the gathered sweat sample, and its equivalent measured value of the pH level in three different scenarios. Table 1 to Table 6 displays the pH level in perspiration among individuals experiencing minimal stress condition, As can be observed, his/her pH level in perspiration is within the average of balance to a little alkalinity.

Table 2. Person A's tabulated information.

Condition		measured pH value	measured current
Running		6.40	32.29 mA
Regular activity	@ 30°C	6.80	11.43 mA
	@ 15°C	7.36	-20.57 mA

Table 3. Person B's tabulated information.

Condition		measured pH value	measured current
Running		6.38	35.43 mA
Regular activity	@ 30°C	6.63	21.14 mA
	@ 15°C	7.28	-16.00 mA

Table 4. Person C's tabulated information.

Condition		measured pH value	measured current
Running		6.40	34.29 mA
Regular activity	@ 30°C	6.70	17.14 mA
	@ 15°C	7.25	-14.29 mA

Table 5. Person D's tabulated information.

Condition		measured pH value	measured current
Running		6.10	51.43 mA
Regular activity	@ 30°C	6.70	17.14 mA
	@ 15°C	7.42	-24.00 mA

Table 6. Person E's tabulated information.

Condition		measured pH value	measured current
Running		6.50	28.57 mA
Regular activity	@ 30°C	6.75	14.29 mA
	@ 15°C	7.57	-32.57 mA

IV. CONCLUSION

In our paper, we proposed a non-invasive monitoring model for pre-cognitive impairment as well as a tracking device to reflect one's state of health which are inevitable device in preserving life. The consideration of using human's sweat/perspiration which phenomenally inducted provided useful information in identifying personal health condition has been very evident. Likewise, the study proves the significant application of emerging technologies like IoT and LoRa in the real-time transmission of data to facilitate administration of immediate remedies and the giving of appropriate medical attention. Moreover, this provides for real-time monitoring of patient's state of health prior the giving of appropriate attention most specifically in places where medical providers are limited, and immediate medical attention cannot be given.

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