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Development of a Smart Wearable Anti-drowning System for Swimmers

Nuhu Bello Kontagora[1], Buhari Umar Ugbede[1], Abu Adishetu Khadijat[1], Blessed Guda[1], Jinsul Kim[2]

[1] Department of Computer Engineering, Federal University of Technology, Minna, Nigeria

nuhubk@futminna.edu.ng, buhariumar@futmunna.edu.ng, abu.m1605301@st.futminna.edu.ng, blessedg@andrew.cmu.edu

[2] Department of ICT Convergence System Engineering, Chonnam National University, Gwangju, 61186, South Korea

jsworld@jnu.ac.kr

Abstract. Drowning is one of the major causes of unintentional death in the world. owning to this reason, there is a need to curb the issue of drowning. some systems have been developed over the years, but most of the systems are not accurate in detecting a drowning person and do not provide an effective rescue scheme to prevent the swimmers from drowning. The smart anti-drowning and alert system is a system which detects, rescues the swimmer experiencing drowning and alerts the necessary authorities. The system uses two sensors, pulse sensor and accelerometer for the detection of the heartbeat rate and tilting pattern of the swimmer. The Arduino Nano microcontroller receives analogue signal from the sensors and sends a signal to trigger the air vacuum pump and sends a message, when the threshold value is met. The threshold value of the pulse sensor is 45bpm-150bpm (minimum and maximum value) while the threshold value of the accelerometer is 750 -1100 (minimum and maximum value).

Keywords: Anti-Drowning, Floatation Device, Photoplethysmogram Sensor, Accelerometer

1 Introduction

Drowning is the third leading cause of unintentional deaths and one of the most painful death worldwide. According to World Health Organization (WHO), drown-

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***Corresponding Author;** Nuhu Bello Kontagora
Tel: +82-02-2275-4435
E-mail: nuhubk@futminna.edu.ng

ing is the process of experiencing respiratory impairment from submersion/immersion in liquid" (Riva et al., 2019). The best scientific evidence available reveals that 1.2 million people die every year due to drowning worldwide, that is more than two persons per minute (ILF, 2014). When drowning occur, the human respiratory system is blocked which may affect the lung and brain due to the lack of oxygen in the bloodstream. The blood quickly loses its capacity to circulate oxygen effectively which could amount to loss of life (Leonard, 2018).

Drowning can be classified into five types, which are; wet drowning, dry drowning, active drowning (Wedro, 2019), passive drowning, and secondary drowning. In wet drowning, the liquid floods the lungs and causes damage to the lining. Dry drowning occurs when the larynx blocks anything from getting into the lungs including oxygen, theory suggests that the heart suddenly stops and goes into cardiac arrest. Secondary drowning happens when a little quantity of water damages the lining of the lungs causing inflammation, loss of oxygen being processed, fluid filling the lungs, and even death. In active drowning, the victim exhibits some actions that is noticed by others while in passive drowning, there is no visible action that is shown by the victim. Passive drowning occurs when the victim goes unconscious or due to medical issues like a stroke, heart attack. These characteristics make it difficult for even professional lifeguards to detect a person experiencing drowning (Roy & Srinivasan, 2018).

Lots of effort have been implored to prevent drowning, which involves following swimming safety guidelines, carrying out some safety measures which includes wearing of life jacket. Also, there have been existing technologies implemented such as video-based drowning detection system and wearable drowning detection systems, but most of these technologies earlier invented have their shortcomings. In this work, some of the limitations present in this previous technology is solved.

2 Literature Review

The key contributing factor to drowning is not being able or capable of swimming. Some other factors may also be the water level distance from solid footing, inability to see clearly, loss of consciousness or the state of the water itself. Also, anxiety caused by fear of drowning (thalassophobia) or fear of water (hydrophobia)which can cause fatigue, further increasing the risk of drowning (Sink, 2013). Some effects of drowning include Cardiovascular Effects (Mayoclinic, 2020), Central Nervous System (CNS) Effects (Clevelandclinic, 2021), prolonged hypoxia, gastrointestinal injuries, hepatic, metabolic acidosis and intravascular coagulation which also includes the complication or failure of numerous organs (Patricia Cantwell, 2019).

(Chaudhari et al., 2018), implemented an anti-drowning system using remote alert. The system developed uses a RF module for wireless communication consisting of a transmitter and receiver, a heartbeat sensor which monitors the heartbeat rate of the user, was interfaced with an At-Mega 328 microcontroller which was also interface with LCD, LED and a buzzer for indication. The system is scalable, flexible and of low cost. However, the anti-drowning system using remote alert communicates at a very short range and not so efficient in informing the person, if the person is not close to the buzzer or LED. (John et al., 2019) developed a similar system, the device is constructed in form of a wristband-watch which consists of a heart rate pressure sensor on the transmitter side, which is interfaced with an Arduino Lily-Pad microcontroller while the receiver end consists of an Arduino Uno microcontroller, a buzzer and LCD display. The advantage of this system over the one developed by (Chaudhari et al., 2018) is that the device is portable and it is wearable by users.

An Automatic Video-based Drowning Detection System for Swimming Pools Using Active Contour was proposed by (Salehi et al., 2016). This is a real time system which captured the images of users in a pool from the point the user dives into the pool. A camera is mounted above the pool at an angle which eradicates background shadow so that the shadow would not represent the swimmer. The system sends an alarm once the swimmer's image can no longer be detected which may be possible signs of drowning. The system uses an algorithm that is able to detect drowning cases accurately.

Hemalatha et al., (2017), proposed an Automated Drowning Detection and Security system in Swimming pool. The proposed system consists of a laser &LDR implantation, timer circuit for ATMEGA8, GSM module, Buzzer and inclination circuit, the human identification in the swimming pool depends on the Light Dependent Resistor (LDR) which senses the laser light, It uses the data from the water pressure sensor to detect if a body is in water, an iron metal plate is placed in the floor of the swimming pool while the laser and the LDR source will be placed in the side of the wall of the pool. The system is able to send messages to alert the life guard, making it more convenient to use when compared to others. However, this system can only be installed in a pool or in a small controlled and remote area.

An Early Drowning Detection System for Internet of Things (IoT) Applications was developed by Muhammed, et al, (2018). The system implemented a wearable headband for drowning detector that can be monitored via web application or mobile phone. The designers considered the possible heartbeat of a drowning person due to panic attack. Photoplethysmogram (PPG) sensor was used to measure a user's heart rate signal which is converted to analog signal through a microcontroller. This system cannot tell the exact location of the drowning person which makes a drowning person difficult to locate which serves as a setback.

The development of a Sonar based drowning detection system was done by Almahmoud (2018), where the system comprised of sonar sensors that formed a three-dimensional grid of sonar waves within the water body. A movement part tracing unit is adapted, which is connected to the sonar sensors for tracing the movement path of a person within the water body by determining a sequence of successive grid cells crossed by the person. The determination of the successive grid cell is made based on detected propagation delays of the sonar waves forming the grid.

The system is however limited because it could only be used in a remotely small area.

Zakwan et al., (2020) developed a child drowning alert system in form of a wrist band, the detection is done using a PPG heart rate sensor which records the child's heartbeat per minute, the information is then delivered to the parents. If the signal of heart rate surpasses the designated threshold, the system will send an alert notification to the smartphone of the parent using Blynk application. There is no automatic rescue system for the child, should incase the parent is far away or distracted.

Jose & Udupa, (2020) proposed a Gantry Robot for drowning prevention, the system consists of mainly three parts consists of mainly three parts, which are an over-head camera, gantry robot, and a LED display with an alarm unit. The overhead camera is equipped with a drowning detection algorithm which is capable to evaluate the condition of the swimming person by analyzing features like shape and motion. Whenever the camera discovered a drowning incident, the system will pass the coordinates to the gantry robot, then the robot will move to the coordinates provided by the camera and drop ring buoy to the nearest coordinate of the victim. Whenever the camera discovered a drowning incident it will trigger the LED display and alarm unit which will help to bring some additional aid to the drowning victim. The system is quite expensive to implore and can be used only in a pool.

3 Methodology

3.1 System Overview

The development of the smart anti-drowning and alert system consists of five (5) integrated units which includes; the processing unit (microcontroller), power supply unit, sensing unit, alert unit, and the actuator unit. The system is designed to have a combination of two sensors which serves as inputs to the microcontroller (Arduino Nano), while the Air diaphragm pump and GSM module acts as outputs, Figure 1 shows the architecture diagram of the smart anti-drowning and alert system. The microprocessor receives analog readings from the sensors, if the threshold value is met, it sends a signal which triggers the air pump (actuator) and also sends an alert. The power unit, supplies 5v to the microcontroller which powers the sensors in the system. Figure 2 depicts the block diagram of the system.

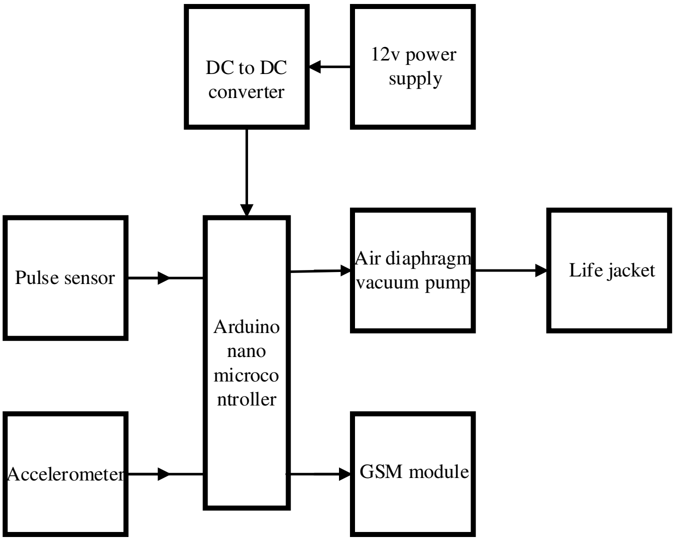

Fig. 1 Architecture diagram of smart anti drowning and alert system.

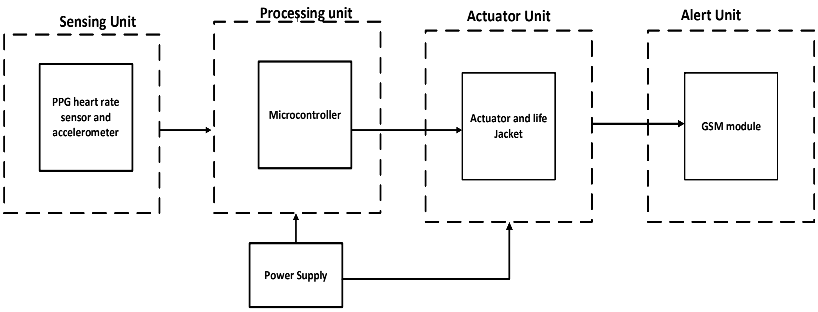

Fig. 1 System block diagram

3.2 Sensing Unit

A heartbeat sensor and an accelerometer which is used to convert physical / analog signal to digital signal are the main component of the sensing unit. This signal is inputted to the microcontroller. The heartbeat and accelerometer sense the pulse and tilting movement of the user underwater, when either of the threshold conditions are met, a signal is sent to the microcontroller. The heartbeat sensor is placed on the skin which could be on the ear, chest, finger-tips or toes. It takes the heart beat reading of the user in beats per minute. The thresh hold value is within 45bpm-150bpm, if it exceeds the maximum threshold and rapidly falls below the minimum threshold value, a signal will be sent to the Arduino Nano microcontroller. While the MPU6050 accelerometer/gyroscope is embedded on the life jacket, it detects both the angle of tilting or inclination along X, Y and Z axes and the rotational velocity along of the body. When it reaches the slated thresh hold which is between 75-120 degrees, it sends a signal to the microcontroller.

3.3 Processing Unit

The Arduino Nano microcontroller is the brain of the system which all the rest components are connected to. The power unit supply's Direct Current (DC) to power the Arduino microcontroller, which in turn powers the rest of the components which are interfaced with the microcontroller. The Arduino microcontroller gets sensor readings from the sensor unit when the thresh hold value which is 45bpm to 150bpm (minimum and maximum value) for the pulse sensor and 75-120 degrees (minimum and maximum value) for the accelerometer Table 1 shows the algorithm of the system. When the set conditions are met, it triggers the air vacuum pump to inflate the jacket and also send signal to the GSM module to send a message to the lifeguard, Figure 3: Flow chart of smart wearable anti-drowning and alert system and Figure 4 depicts the circuit diagram of the smart wearable anti-drowning and alert system.

Table 1. Algorithm of the system

Algorithm
1. Initialize
2. Read heart beat sensor
3. Read accelerometer tilting position
4. If heart rate is at maximum heartbeat threshold and drops below minimum heartbeat value within 5secs, inflate
5. Else if at heart rate threshold value and tilting angle is at threshold, Inflate
6.. Else if at heart rate threshold value and time is ≥30secs, Inflate
7. While action = inflate. inflate life jacket.
8. Wait for 5secs
9. Send alert message
10 End While
11. End If
12. Else, keep checking
13. End.

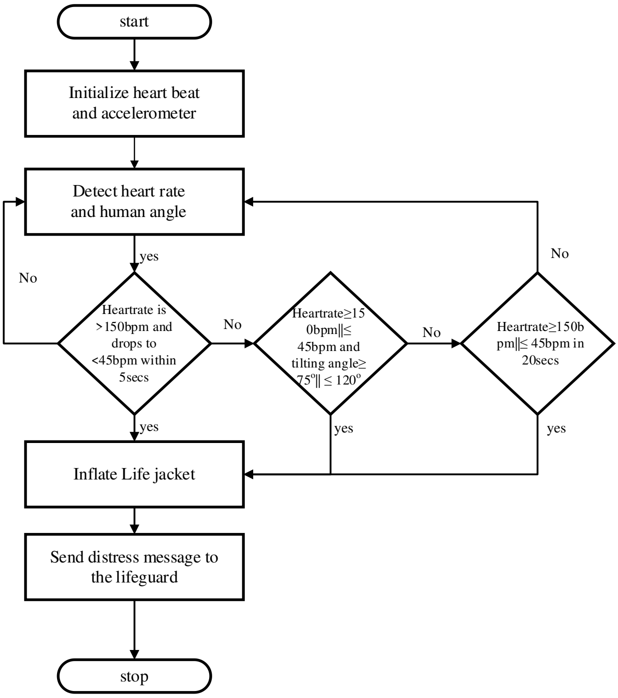

Fig. 3 Flow chart of smart wearable anti-drowning and alert system

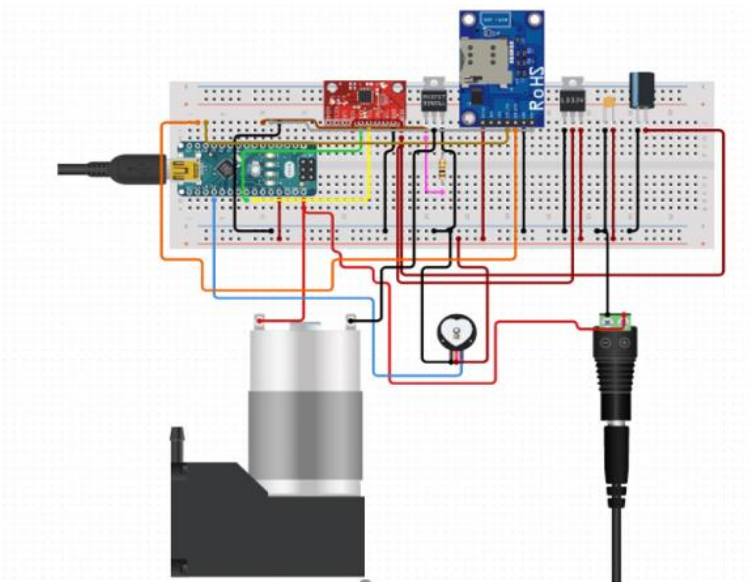

Fig. 3 Circuit diagram of the smart wearable anti-drowning and alert system

3.4 Actuator Unit

The actuator unit consists of an air diaphragm vacuum pump, pipes, ball and life jacket. The ball which serves as a buoy is attached to a pipe, which is connected to the inlet of the air diaphragm vacuum pump. Air passes through the pipe from the surface of the water into the air diaphragm vacuum pump inlet. When a signal is sent from the Arduino Nano microcontroller to the air diaphragm pump, it pumps air through the outlet to fill the life jacket. The air diaphragm pump was picked for this project considering the amount of air required to fill the life jacket. The size of the air diaphragm vacuum pump required to fill the life jacket adds to the weight of the project.

3.5 Alert Unit

The GSM module (sim800l) interfaced with the Arduino Nano makes up the alert, when a signal is sent from the sensing unit to the microcontroller it sends a message to the lifeguard's phone with the use of the GSM module.

3.6 Power Supply Unit

Three 3.7V battery was connected in series to give a 12V DC output voltage. Which is used to power the air diaphragm Pump directly without regulation, while a DC-to-DC bulk converter is connected to the 12V DC to give an output of 5V to power the Arduino Nano.

4 Results and Discussion

The developed anti-drowning and alert system was evaluated using three metrices which are response time, accuracy and sensitivity. These evaluation matrices depict how effective and efficient the developed system is when put into use. Response time of the Smart anti-drowning and alert system is the time it takes to react or prompt an action when the user is experiences drowning. accuracy of the anti-drowning system is the ability for the system to give the correct output correctly.

4.1 Response Time Result

The response time is a measure of the time it takes for the sensors to react to given inputs. The response time and average response time of the system is evaluated using equation 1 and 2

$$\text{Response time} = \text{Tr} - \text{Ts} \quad (1)$$

$$\text{Average response time} = \frac{\sum(Tr-Ts)}{N} \quad (2)$$

Where Tr denotes the time to receives an output signal, Ts is the time it is sends an input signal and N denotes the number of times records were taken.

Table 2. Total Response time of the system

Attempts	Response Time to trigger an output	Response Time to fill the life jacket	Total Response Time
1	2	33	35
2	3	35	38
3	3	35	38
4	4	36	40
5	5	35	40
6	4	34	38
7	2	35	37
8	2	36	38
9	3	35	38
10	2	36	38
11	2	33	35
12	3	35	38
13	4	35	39
14	2	36	38
15	3	35	38
16	3	34	37
17	2	35	37
18	3	36	39
19	2	35	37
20	2	36	38

The average response time of the entire system is 38 seconds. Figure 5 depicts the graphical representation of the total response time of the system.

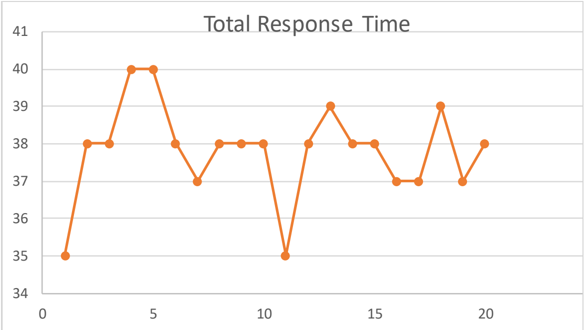

Fig. 5 Result of the total response time of the system

The total average response time of the smart anti-drowning and alert system is 38 secs.it takes an adult approximately 1mins (60sec) and a child approximately 40 second to lose consciousness when experiencing drowning

4.2 Accuracy and Sensitivity

The summary of the results obtained from 40 trials are given in Table 3 to evaluate the system performance using accuracy and sensitivity. Using the derived equation 3 & 4, the accuracy and sensitivity of the system is derived in Table 4.

$$\text{Accuracy} = \frac{T_p+T_n}{(T_p+T_n+F_p+F_n)} \tag{3}$$

$$\text{Sensitivity} = \frac{T_p}{(T_p+F_n)} \tag{4}$$

Tp denotes true positive (number of correct values), Fn represents false negative (number of incorrect values), FP represents False positive (number of negative values classified correctly), and Tn denotes True negative (number of correct cases classified wrongly.

Table 3. Summary of result recorded for 40 trials

TP	FP	TN	FN	TOTAL
28	5	6	1	40

Table 4. Performance measurement evaluation of the system

Performance metrics	40 tests
Accuracy	85%
Sensitivity	96%

From the above result the anti-drowning and alert system accuracy and sensitivity is 85% and 96% respectively.

4.3 Developed Smart Wearable Anti-Drowning and Alert System

The smart wearable anti drowning and alert system casing is made up of a transparent plastic, the casing houses the Arduino Nano microcontroller, batteries, air diaphragm vacuum pump, GSM module, circuit board, Light Emitting Diode (LED) and switches. Figure 6 shows the smart wearable anti drowning and alert system casing, with the components inside it. The heartbeat sensor and accelerometer are embedded on the life jacket in order to get a more stable reading. Figure 7 show the image of the developed smart wearable anti drowning and alert system for swimmers. The life jacket is made up of polyester material. A ball which serves as a buoy is attached to a pipe, which is used to allow the passage of air from the surface of the water into the air pump inlet. Another pipe is connected to the outlet of the air diaphragm vacuum pump into the life jacket.

Fig. 6 Smart Anti-Drowning and Alert system casing

Fig. 7 Developed System

5 Conclusion

The pulse sensor and accelerometer acts as a two-way verification process for detecting a drowning person, the air vacuum pump which acts as a quick rescue scheme by inflating the life jacket, which lifts the user above water surface and the GSM module is used to send a message to alert the lifeguard. The system performance was evaluated using response time, accuracy and sensitivity as shown in chapter four. The system is designed in a manner that when two logical outputs of the sensor are matched to the given range, it will initiate the rescue process. Combining the two sensors makes the system more accurate and reliable. The quick rescue scheme provided by the system makes it more effective and efficient in rescuing the user.

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