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Development of an IoT-Based Drowning Detection System for Private Swimming Pools

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ABSTRACT

Drowning is among the top three leading causes of unintentional death worldwide, accounting for over 8% of all injury-related deaths. Annually, over 22,000 deaths occur due to drowning in adults, teenagers, and children. The highest rate is among children aged 0–15 years. Available solutions to this murder (drowning) involve traditional fencing of swimming pools, the use of wrist bands with RF connections, heartbeat sensors, monitoring systems using LASER and LDR, etc. These methods are not sufficient to solve the problems, as past methods involve wearable buildings systems. This paper proposes a method that is dependent on the swimming pool (the swimmer does not need to wear any device). The proposed system utilizes multiple sensor technology and IoT technology; PIR sensor for motion detection and Raspberry Pi module v3 for capturing and detecting possible drowning events via a trained model using yolo v5 architecture integrated into Raspberry Pi 4 8GB RAM. The system sends an email message to the authorized user if it senses motion around the swimming pool environment, detects a human in an un-save zone, and sends an alert of possible drowning.

Keywords: Safety swimming pool, Object detection, Yolo v5 architecture, Raspberry pi 4 8GB, PIR sensor, IoT

INTRODUCTION

Drowning of individuals in swimming pools for children, teenagers, and adults is increasing daily. Most deaths of children worldwide are attributed to drowning [1]. Annually, over 220,000 deaths due to drowning have been recorded, involving children between the ages of 1 and 14 [2]. Over 450,000 deaths have occurred in children and teenagers [3]. From this study, it can be seen that there is a high mortality death rate of individuals due to drowning in public and private pools.

Drowning prevention among children below the age of 18 years and teenagers is a very broad public health issue. The World Health Organization and several bodies have provided simple and achievable steps to avoid or prevent drowning in pools and water bodies. However, all these are not enough since there is an increase in the mortality death rate due to drowning. People drown in different places because of different factors, such as geographical, regional, and health related factors. Individuals of different ages drowns in different locations and volumes of water. Teenagers and adults are liable to drown from falling overboard, boating, waterfalls, or surfing whirlpools [4]. Children are liable to drown in bathing tubs, and rainwater tiredness [5].

Drowning of children could occur due to several reasons, but all can be summarized as a lack of basic swimming skills, inadequate monitoring by guide, nearness to water, and health related factors. Considering other age grades like the elderly, it is more complex to determine why and how to prevent drowning. Many factors come into consideration to determine why and how to prevent drowning. This finding could be due to health related factors (respiratory tract infections and diseases), diet, and alcohol consumption [6].

The problem of drowning cannot be overstated. High-income countries are less susceptible to drowning while middle income countries and low-income countries are more liable to record more drowning cases. Africa is categorized as a low-income country. Over 70% of drowning cases occur in private swimming pools, and it occurs due to the lack of proper monitoring systems, surveillance, and access to the swimming pool environment [7].

Efforts have been made to fight the deadly trend of drowning worldwide. This includes public awareness campaigns by various organizations on the dangers and preventive measures to be taken to prevent drowning. Such measures include impacting individuals with proper swimming and survival skills [8]. Most individuals drown because they lack adequate swimming skills. They do not engage in proper swimming lessons and feel it’s all about floating and balance, hence, are liable to drown when they engage in swimming.

Creating water safety education campaigns and awareness programs to educate the public about the risks and precautionary measures associated with water bodies. Such measures include fencing the swimming pool environment to prevent children from gaining access.

Alcohol consumption alters the normal function of the human body. The intake of alcohol causes nausea and dizziness, which increases the risk of drowning. Awareness campaigns by the World Health Organization and other organizations should educate people about avoiding alcohol consumption [6].

The introduction of technology into the swimming pool environment has led to great efforts in combating the problem of drowning. Technology has provided solutions for monitoring the swimming pool environment with the aid of sensors, which has enhanced the traditional fencing method [9].

Biomedical engineering has also made it possible to prevent individuals from drowning. This was implemented by taking measurements of an individual’s heartbeat on land and under water; monitors the heartbeat and checks for irregularities, which help to detect if an individual is having difficulty in swimming; hence is liable to drown [10].

Advanced underwater surveillance with the aid of cameras, sensors, and real-time motion monitoring to track humans under water incorporating artificial intelligence and machine learning to propose a more accurate prevention system [11].

REVIEWED LITERATURE

Drowning individuals in swimming pools, especially children, is among the top three leading causes of death globally [12]. Every year, over 360,000 deaths occur globally within middle income countries and more percentage in low- income countries [13]

Drowning of individuals could be in two formats: active and passive drowning. Active drowning occurs when the specific individual involved undergoes physical distress and possible convulsions that could be easily seen by other people around, while passive drowning occurs due to medical conditions of the swimmer; this could be due to heart attacks, allergy, stroke, hypertension, and reaction to water or weather.

All these forms of drowning can be fatal or nonfatal. In Australia, fatal and nonfatal drowning events account for over 2272 reported cases within a minimum period of 13 years. On average, over 281 deaths have been caused by unintentional fatal drowning in Australia, including children under the age of 5 [14]. In the US, drowning is the second leading cause of accidental death in children. On a daily basis, more than 10 fatal deaths are due to fatal drowning, including children below the age of 15. Over 5 children are recorded in the hospital for nonfatal drowning occurrence. Nonfatal occurrence may be underestimated since there is no accurate systematic method for recording such statistics; however, due to the percentage of children visiting the hospital, this should not be taken for granted [15].

Previous Drowning Prevention Measures

Multiple factors can lead to drowning in swimming pools. based on the swimming pool's environmental features. Individuals have no bearing on these things. A lack of skill or incapacity to swim could cause a person to drown.

On a general view, drowning can be reduced or prevented via the following methods: adequate monitoring of swimming individuals; surveillance of the swimming pool environment and swimming pool itself; restriction of individuals, especially children, from swimming pool.

In Northern Iran, studies show that ripping currents in the Caspian Sea, standing waves, and eddy lines in local rivers buffer the possibility of people drowning. As a result, solutions were proposed to curb this. Such methods involve setting up barriers to control the availability of access to rivers, developing awareness and tutorials on swimming exercise, the development of rescue traits, and the development of associations to monitor processes and swimming-related matters [16]. Drowning of individuals can also be reduced by close monitoring. This can be referred to as a man marking system. The swimmer should not, in any case, be out of site, teaching basic swimming skills, regulation, or detecting distress of swimmers in swimming pool, which indicates discomfort (uneasiness), which is a possible attribute of drowning. This enables an individual to be saved on time. This system deploys the use of sensors, microcontrollers, and machine learning. Machine learning enables early detection of distress among swimmers in a swimming pool [9]. As research continues, more advanced options are being employed to curb the problem of drowning. They include wrist bands that contain sensors that can detect threats such as falls or drowning depending on the operation. Other methods include placing an overhead camera to monitor and detect distress systems or drowning possibilities at surface level via analysis of behavior. This employs the use of “AI” and machine learning [17]. In addition, a method is proposed that employs the use of underwater cameras for surveillance, object detection, and tracking to monitor and help detect drowning to help prevent drowning. The proposed method also helps detect motionless drowned victims under water. A 5G-based deep learning method that detects and draws the attention of a child’s parents or care giver to focus on the child [11]. Different drowning prevention measures are efficient. Wearing necessary floatation devices in swimming pool. This enables the individual to remain at the top. Preventing an individual from drowning provides a high result for individuals, but they are limited to certain movements. In addition, we propose a method that prevents drowning of children in swimming pools by monitoring the motions of children in water. It also integrates the use of an app-based system that monitors specific parameters, such as water conductivity, movement of the child in the swimming pool, and then alerts the concerned (parents, lifeguard) via “SMS” notification using the developed Android app [16]. As research continues, more enlightenment of previous methods is delivered, and advances are made to existing methods. Educating the public and creating awareness about water safety and good ethical conduct around water environment. This can be achieved through house-to-house discussions, mass media, social media, newsletters, and parent education on safety. In addition, denial of access to the swimming pool environment can be achieved by automated covering of the swimming pool(advanced), door barriers, and fencing. Furthermore, it is important that strict supervision of children is ensured. Children’s location should always be considered. Synergy of the above-mentioned methods can help prevent drowning of children in swimming pools. Drowning can also be a determinant of the environment and geography of a region, such as considering the geography of an ice region. Drowning in such regions is prevented by the enforcement of strict laws, ice safety; ice picks, protective clothing, and tracking of ice formation. [18]. In other words, to prevent drowning more efficiently, an in-depth study of drowning cases must be carried out. From the result of the collated statistics, it is easier to propose a solution for various cases or integrate solutions to solve various cases simultaneously. Such parameters may include the submersion time and health record of the swimmer. Incorporating technology of monitoring and surveillance to the system to help reduce drowning occurrence [1]. The advent of "IoT" has made systems more efficient. This integrates monitoring and tracking systems that can locate any individual liable to drown in the swimming pool and alert lifeguards to save them. This system uses a combination of "GPS" tracker, and a red liquid substance to enable the precise location of *drowning individual*. The system requires stable internet access and is for immediate monitoring, real-time tracking, and swift location of victims [19]. Different wearable device approaches have been established, including wearable pulse oximeters and accelerometers that work based on real-time data collection. The algorithm consists of heart rate values, oxygen saturation, linear regression, analysis of heart rate, and oxygen regression slopes. This enables the system to determine the risk of a drowning individual [10].

Ai in sports:

AI is defined as the collection of various technologies, including machine learning, deep learning, machine vision, perception, reasoning, and natural language analysis and processing [20]. With the rapid advancement of AI, safety in sports (swimming) is enhanced. The rate of drowning is drastically reduced. AI provides and analyzes data from AI technology, such as machine learning and deep learning, enabling one to develop better sporting results, decision making, analyze real-time data, and send feedback that could determine if an individual is drowning [21].

Machine learning and deep learning technologies have improved safety and drowning prevention(detection). This is possible through various algorithms and analyses that access human behavior and detect possible drowning possibilities.

Algorithmic Approaches for Drowning Detection

Several computational techniques have been proposed to improve drowning detection accuracy:

1. **Motion-Based Detection**: Using machine learning models, systems can analyze the sensor data to identify unusual motion patterns, such as prolonged immobility or erratic movements [22]. These systems rely heavily on large datasets for training and continuous improvement.

2. **Biometric Monitoring**: Wearable sensors can track heart rate and oxygen levels, providing additional data for detecting distress. A sudden drop in vitals combined with abnormal movement patterns can signal potential drowning.

3. **Predictive Analytics**: Advanced algorithms can predict drowning risk by continuously analyzing swimmer behaviour. For example, sudden deceleration or change in swimming direction may indicate fatigue or distress, enabling early intervention [26].

Machine Learning

Machine learning is a computer algorithm that can learn (recognize patterns similar to the human brain nature) from data. The basic concept is to enable machine devices to learn automatically and make decisions based on the analyzed input data. ML can be considered a subset of AI, which involves the absolute use of statistical techniques to enable system improvements with experience. There are Three types of ML which are supervised learning, unsupervised learning, and reinforcement learning. In supervised learning, systems are fed with a large number of training patterns that learn and use it to compute new patterns. This learning method is used in deep learning architectures and current waves. Unsupervised learning is based on clustering algorithms, which is useful for exploratory data analysis. Large amounts of data are fed to the

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system related to the target problem but do not provide information in the result. The ML algorithm classifies the inputs into accurate relevant outputs. Reinforcement learning makes decisions based on trial-and -error system approach. It is used where decisions are made based on delayed rewards. It learns from the consequences of its actions and adjusts its behavior [23].

Computer Vision

Advances in science and technology have enabled computer systems and machines through various learning and research activities to study, process, analyze, and interpret images and video recordings. This was achieved through deep learning (DL), GPU, and open-sourcing datasets [24].

Deep Learning

Traditional ML is limited in the application of smart and intelligent systems due to various challenges which includes The of choice of manifold architecture, implementation of options, bias and drift in data, mitigation of black box, and reuse of pre-configured models. Therefore, deep learning helps to handle more complicated cases autonomously. Deep learning is a concept in ML that is based on artificial neural networks. Deep neural networks consist of more than one layer and are organized deeply in the nested network architecture. DL is employed to process high-dimensional data, such as images, videos, speech, audio, and text data. DL is used for tasks like object detection or natural translation [25]. DL is characterized by efficient learning, ability to handle complex input data, high accuracy, end-to-end learning, and automatic feature extraction [21].

Deep Learning (DL) models

Models of DL are Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), autoencoders, [17]. DL models also include Deep Belief Networks (DBNs) and long short-term memory networks (LSTMs).

Going in-depth on the models of DL mentioned above; The CNNs are typically used for image and video analysis [25] With CNNs ability to learn the spatial hierarchies of features using convolutional layers; thus, they are used for object detection, classification, recognition tasks, and so on [21]. RNNs are capable of processing sequential data, such as audio, video, and time-series data. RNNs are used to generate text, model language and speech recognition and natural language modeling [25]. DBNs are generative models used for unsupervised learning, missing data, anomaly detection, and imputation. Autoencoders are forms of neural network architecture used for unsupervised learning, where the goal is to learn the input data distribution by encoding it to a lower-dimensional space and decoding it back into the original space. LSTMs is an architecture similar to RNNs but with gated memory cells that allow for enhanced handling of long sequences of data and overcoming the vanishing gradient problem that can occur in RNNs.

Internet of Things (IoT) in Drowning Detection: A Modern Safety Approach

The Internet of Things (IoT) has become a transformative technology in safety applications. In drowning detection systems, IoT allows for real-time data collection from interconnected sensors to monitor pool environments and swimmer activity. IoT systems integrate sensors, communication networks, and cloud-based analytics, enabling fast and efficient responses to emergencies [26]. In private pools, these systems provide autonomous monitoring and rapid detection of potential drowning incidents, reducing response times and improving overall safety [27].

IoT has different architectures, such as the Architectural Reference Model (ARM). The International Telecommunication Union (ITU) recommends the use of architecture which consists of layers which are sensing, network, access, middleway, and application layers. Another architecture includes transport, processors, and applications. Swimming technology has enabled rapid communication and data processing to prevent drowning through fast communication with lifeguards [28].

Related Works Using IoT in a Swimming Pool

IoT in combination with transfer learning, hardware components such as motion sensors, Wi-Fi device stations, and cameras were used. It uses computer vision; image processing to classify objects detected (captured). Data collected is processed and analyzed, and the results of the data collected are sent to the *owner's *mobile phone [29]. However, the system in [29] achieved a precision of 95% to 96%, which, when compared to the precision of the proposed system—the IoT-Based **Drowning Detection System for Private Swimming Pools—the proposed system achieved a better precision (99.579%).** The use of IoT was also employed by sending data collected by sensors to an online server and displayed through an android application enabling remote control of actuators by users with login permission after monitoring PH, temperature, chlorine, water level, and water pressure [29]. The systems reported in [28] are more expensive compared to the proposed system because they are more sensor-based than image processing-based.

Related Works

Based on previous research, drowning detection systems can be categorized into two major categories: sensor-based systems and image processing systems. The former uses sensors, such as pressure, heartbeat, motion, and depth, and the latter applies multiple algorithms to detect drowning by capturing images from live videos [30]. Different drowning detection methods are compared by assessing the accuracy levels, complexity, and costs involved for the systems. In terms of cost and complexity, sensor-based devices are categorized into low-to-moderate classifications, whereas image processing systems are considered complex and expensive [31]. They often require drones to cover a wide area, *involving* safety complications and practical challenges such as charging batteries. Accuracy is the only aspect where image processing techniques outperform sensor-based systems [31]. However, this is not the case when drowning occurs underwater, where the swimmers are not visible in murky water. There have been increasing attempts to develop sensory systems in the form of wearable devices to detect drowning.

METHODOLOGY

This method uses PIR motion detectors, raspberry pi module v3 camera, and Raspberry Pi 4 Model b 8 GB RAM. This involves design, implementation, and evaluation. The proposed system is smart and uses IoT technology to transfer information to authorized individuals. It is divided into three major stages which are: Motion detection around the swimming pool environment, and division of the swimming pool into two sections; safe zone and un-save zone. The camera is positioned to cover only the un-save zones. The camera detects images in real time to authorized users, thereby creating awareness that an individual in an un-save zone is at risk of drowning. This process occurs again to attain certainty for a drowning person and then gives a final warning via the app and alarm to notify authorized individuals and people in the swimming environment via alarms.

Materials

PIR HC-SR501, Raspberry pi Cam module 3, Raspberry pi 4 8GB, python codes, operating systems and some programing languages and libraries used in the research.

Methods

In this study, many datasets of humanoid toys were used for processing and developing a suitable model. Figure 1 shows a block diagram of the proposed system. This process involves image preprocessing, image segmentation, feature extraction, and other commands to determine a drowning individual.

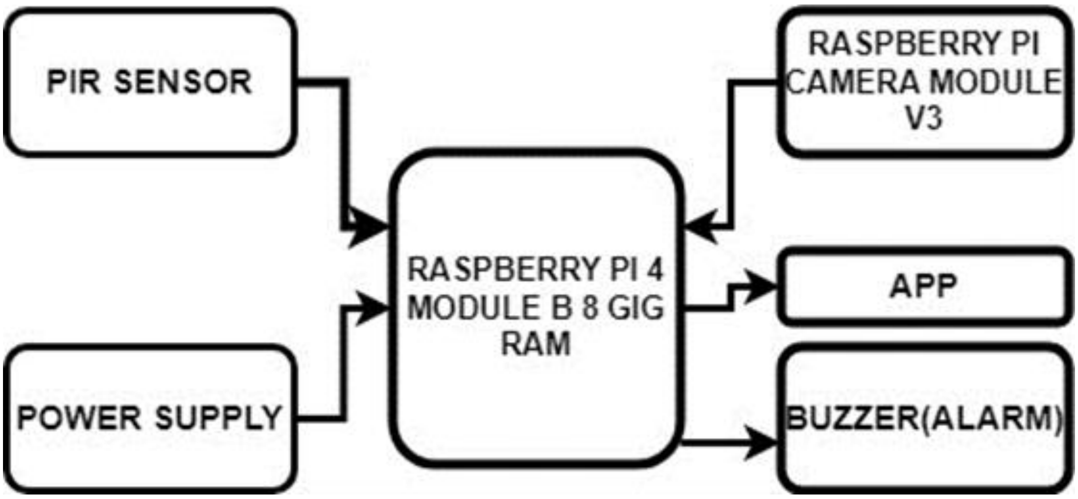

Figure 1: Block Diagram of the drowning detection system.

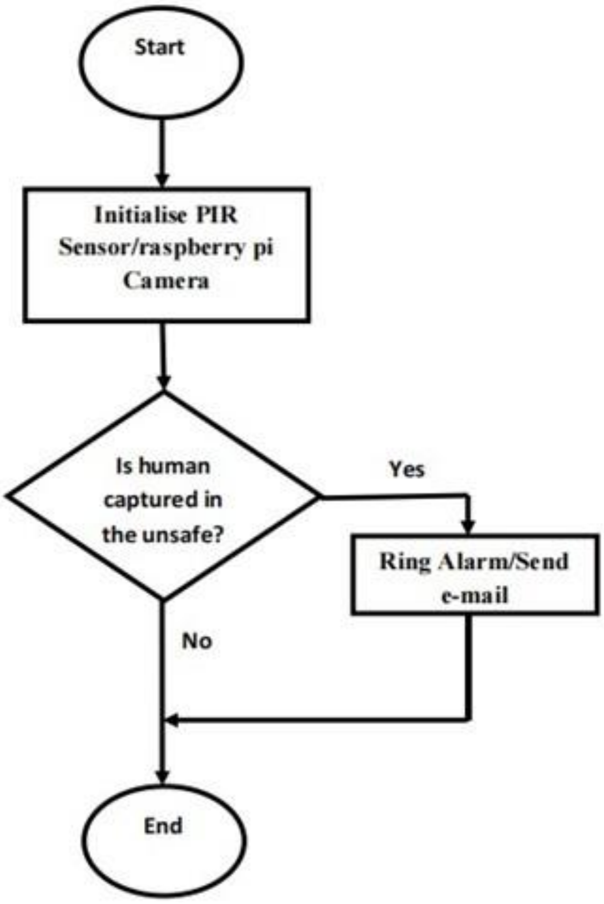

Figure 2: System Flow chart of the drowning system.

The flowchart in Figure 2 explains the many stages involved in creating the proposed system, including motion sensing, image processin, andd email message notification. shows the flow chart for achieving the desired result. Step-by-step procedures from start to finish. This includes the arrangement of components, PIR sensors, raspberry pi camera, Raspberry Pi 4 8 GB RAM embedded with models and codes used in this system.

Image Identification

This section describes the necessary tools (development of a model) that enable the computer to detect human presence in un-save zones via the aid of cameras. Two Raspberry Pi cameras were used for the

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system, which can be strategically placed around the swimming pool to capture the swimming pool area. The cameras are pl. Figure 3 illustrates the labeling of dataset classes as humans recognized and detected.

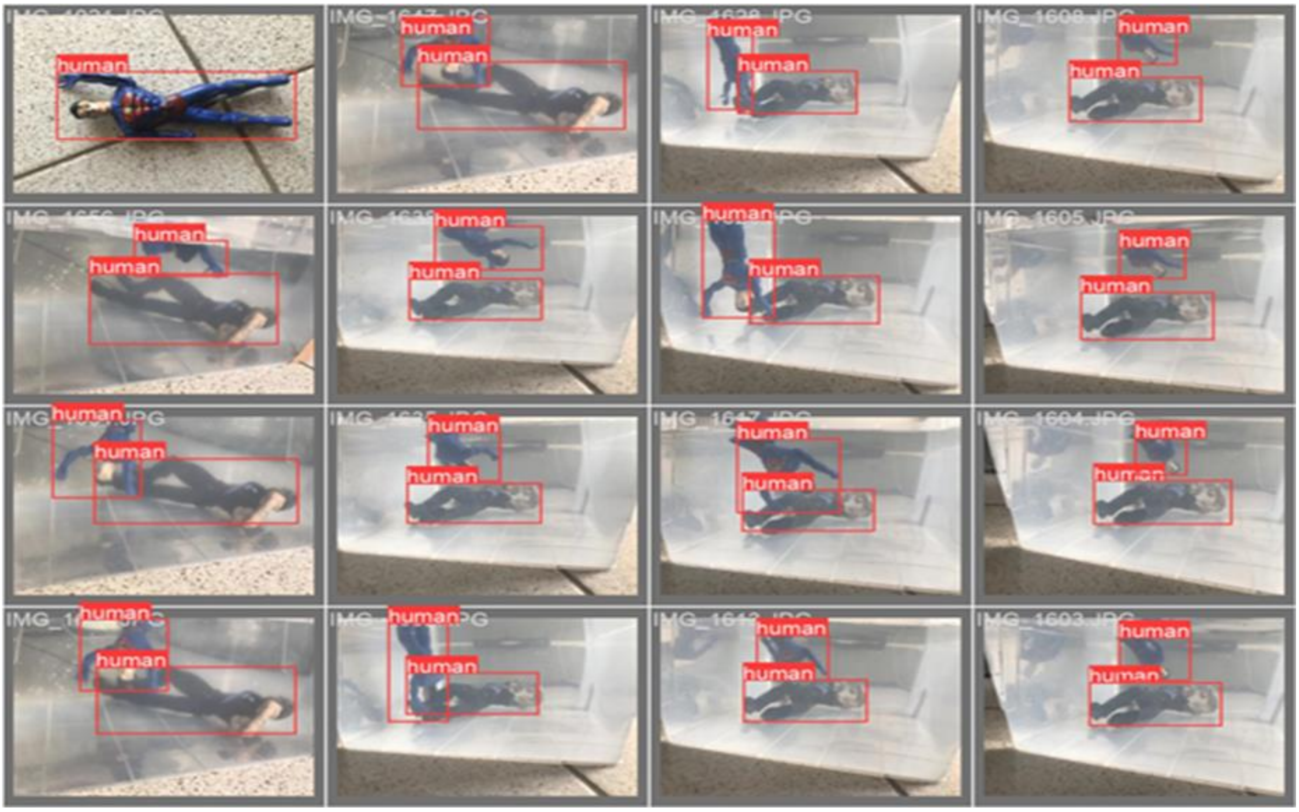

Figure 3: Labeling of data sets.

Using deep learning techniques to recognize and extract license plate numbers involves several key steps, with character segmentation being a crucial one. The overall process includes detecting an image, segmenting the characters, and then using deep learning models to recognize the individual characters. Character segmentation makes it possible to recognize and find multiple objects.

Optical Character Recognition (OCR)

In this section, the application of Optical Character Recognition (OCR) involves a multi-step process to convert images into machine-readable text. First, image acquisition captures the text using cameras, ensuring high-quality inputs. This is followed by preprocessing, where techniques such as grayscale conversion, binarization, noise removal, and skew correction enhance image clarity, making it suitable for text recognition.

Next, text detection identifies areas containing text using deep learning models. Segmentation then separates text regions into lines, words, and characters to prepare them for recognition. For text recognition, modern OCR systems predominantly use deep learning models Convolutional Neural Networks (CNNs) for individual character recognition for handling sequences of text.

RESULTS AND DISCUSSION

The proposed system, "Development of an IoT-based drowning detection system for private swimming pools," uses a PIR sensor for motion detection and a deep learning Yolo v5 CNN model architecture for human detection and recognition in the un-save zone.

This will be discussed based on the following building of system (woodwork and installation), in line with the objectives; motion detection and camera capture of humans when present in the un-save zones.

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Physical installation of swimming pool.

Figure 4: Physical development of the system structure

Motion Detection.

When the system notices movement near the swimming pool, it notifies the authorized owner. Figure 5 displays an email notification of an object discovered in a picture form, indicating the user of human presence in the vicinity of the swimming pool.

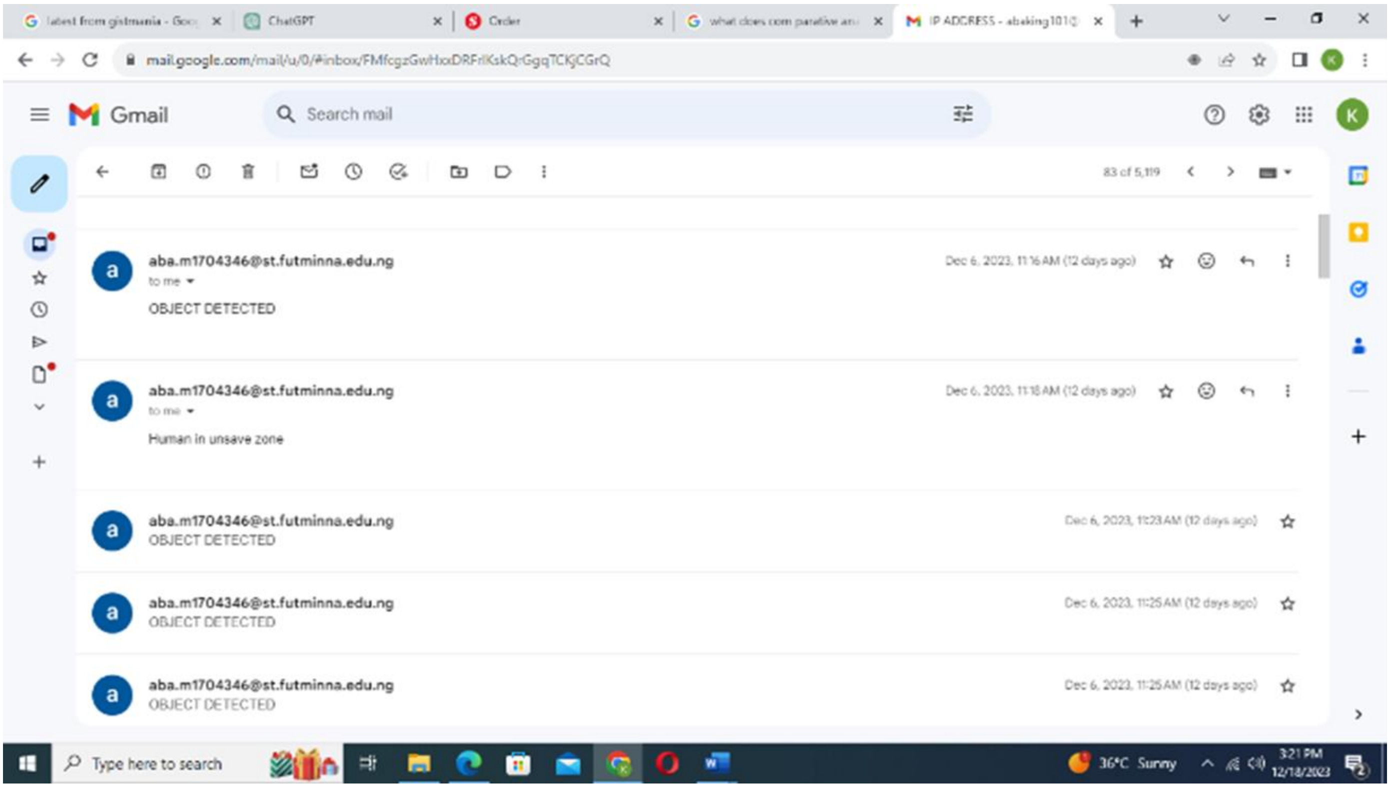

Figure 5: E-mail notification.

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Human detection and awareness of drowning

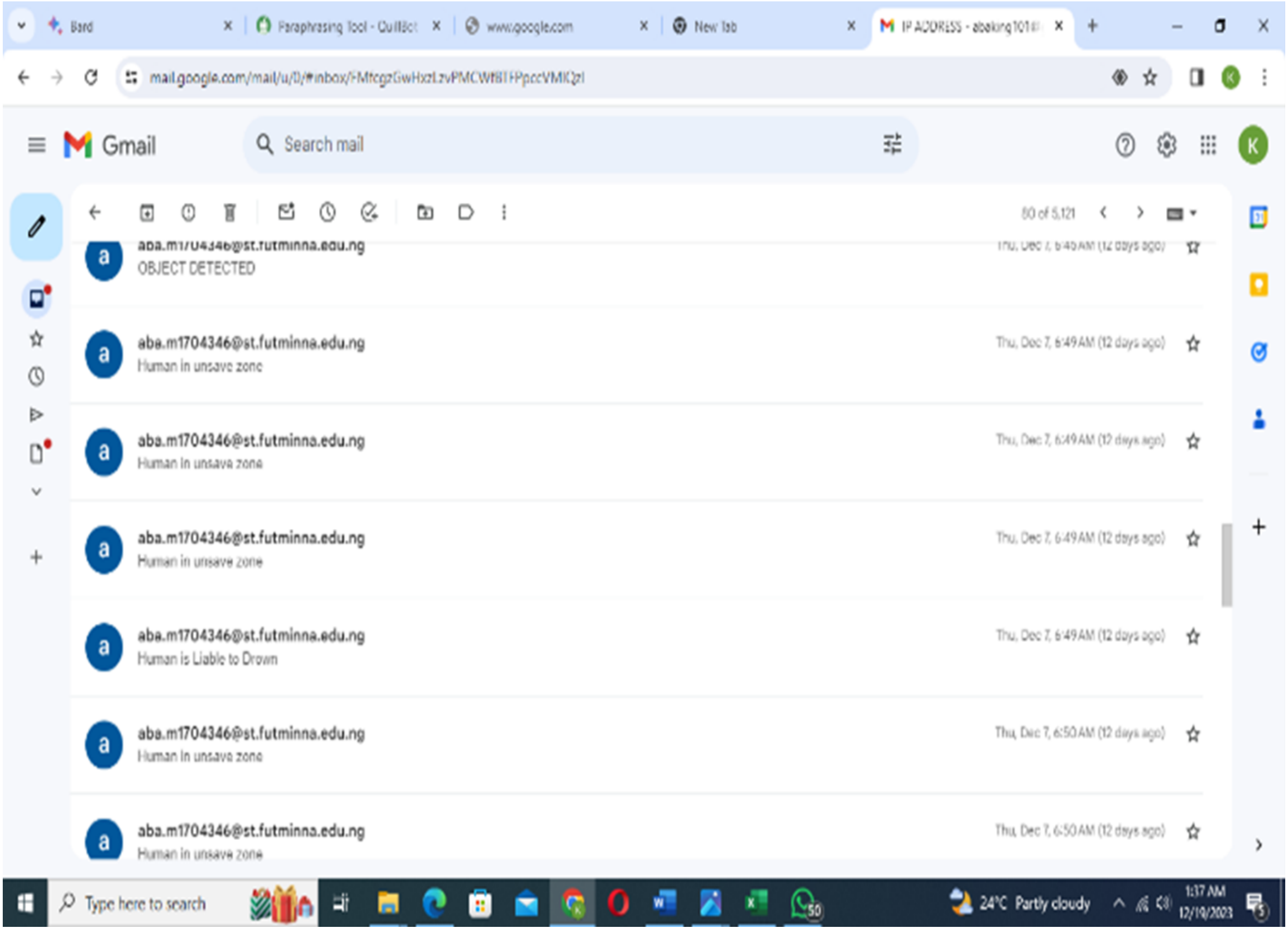

Figure 6: E-mail notification system.

Figure 6 shows the e-mail notification of messages sent to the required user, and the identification of humans in the un-save zones and humans liable to drown got from the model.

Table 1: Performance evaluation Metrics.

PRECISION	RECALL	Map_0.5	Map 0.5:0.95
0.99579	0.9881	0.99419	0.80357

To determine the efficiency of the system performance, the Yolo v5 architecture (CNN) was analyzed and evaluated using the collected dataset and real-time testing. This approach attained 99.57% precision and 98.81 recall.

Precision is the measure of the accuracy of the positive prediction by the model. Here, is the ratio of true positives to the sum of true positives and false positives. The trained human detection model in the non-safe zone had precision of 0.669 for all classes one at 0.669. The precision obtained was very high, which indicates that the confidence of the trained model in detecting humans was true or accurate.

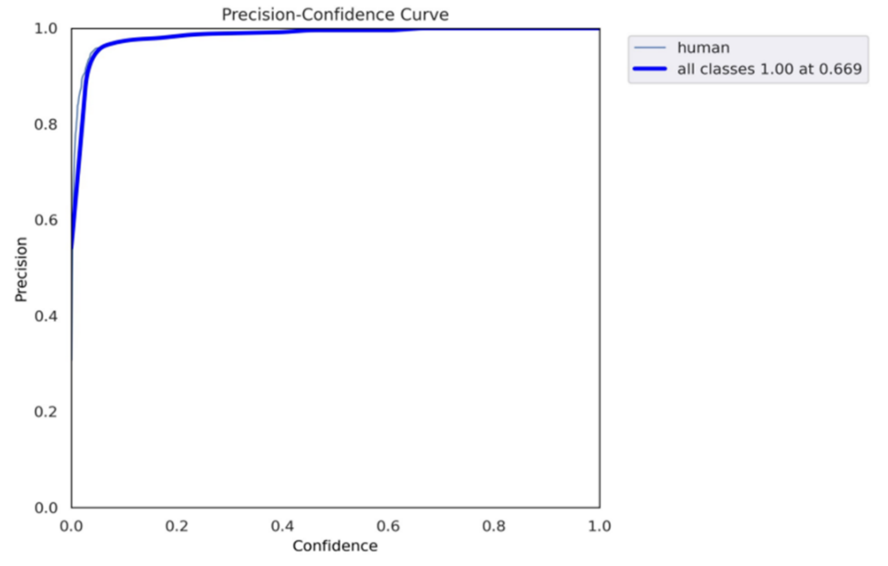

Figure 7: Precision-Confidence curve

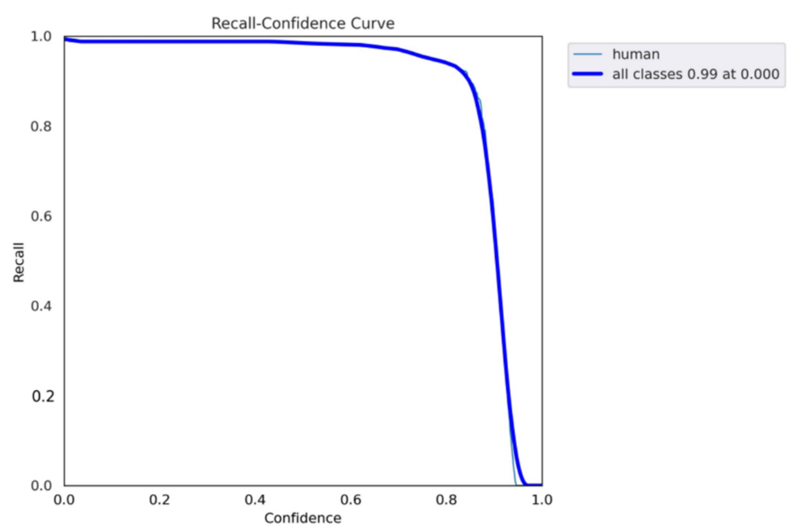

Figure 8: Recall-Confidence curve

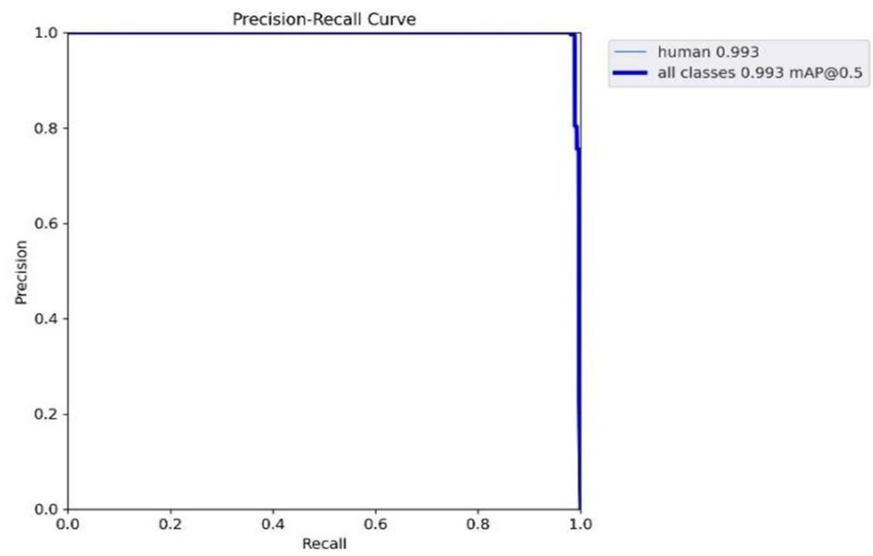

Figure 9: Precision -Recall Curve

The successful completion of the proposed method" development of an IoT-based drowning detection system for private swimming pools" has significant use at homes and public places. This enables parents/guardians to have full monitoring and security over * swimming * pool environment. Guardians can now access swimming pool safely without being physically present. This integrates motion detectors and cameras to detect humans in the un-save zone. The motion sensor senses motion in the swimming pool environment and emails authorized users. The camera only covers the un-save zones. Via the help of the trained model on the Yolo v5 CNN architecture, it captures images in the un-save zone for various times. At first capture, it sends a message that reads, "human in un-save zones, this continues for three consecutive times, and if still present, it sends a final warning that the individual in the un-save zone is liable to drown. From the graphs, it can be seen that the system is highly efficient, with a recall value of 98%. Recall is defined as the number of true positive rate. At this rate, the model identifies a high probability of drowning for each individual. This means that there are very few false positives. Figure 7 explains the precision-confidence curve, which is the measure of the accuracy of the positive prediction by the model. Here, is the ratio of true positives to the sum of true positives and false positives. The trained human detection model in an un-safe zone had precision of 0.669 for all classes one at 0.669. The precision obtained was very high, which indicates that the confidence of the trained model in detecting humans was true or accurate. The recall-confidence curve describes how well the model identified the number of positive class instances in the dataset (class of interest). From the graph in Figure 4, it can be seen that 0.99 for all classes at 0.00. This gives 99% accuracy of identifying the class of interest (humans in the un-save zones). Figure 9 illustrates the precision-recall curve, which shows the relationship between precision (positive predictive value) and the recall(sensitivity) for every possible cut-off. From the graph, for all humans, a value of 0.993 is obtained. Higher precision implies that the algorithm returns a more relevant results from irrelevant ones, and high recall means that the algorithm returns the most relevant results.

CONCLUSION

Drowning incidents in private swimming pools are increasing daily. Most deaths of children worldwide are attributed to drowning. In private pools, the risk is amplified by limited supervision, weak underwater surveillance, and inadequate human detection and tracking systems.

This research study proposes a method employing the integration of hardware and software components to detect early possible drowning occurrence. Strategically positioned motion sensors scan the swimming pool area for movement, and cameras are positioned to capture only the unsafe area to identify potential drowning incidents through various analytical techniques.

At the end of the research, the system achieved precision of 0.99 (99%) and recall of 0.98 (98%). The system also sends a message via the Email address to authorize the user for all processes

RESEARCH DIRECTION

The system can be further developed to include both an IOT and GSM module so that when a human is identified in *the* unsafe region, both an SMS message and an e-mail message can be sent to the authorized user. This will help when the authorized user expresses network fluctuation or difficulty in accessing his/her email.

Future modifications can be made to the system to include four raspberry pi cameras instead of two used in the system to provide better coverage of the swimming pool from the four edges or corners.

Another key limitation of the proposed system is that it can use either 4G, 5G, or less network generation. Further improvement could be made so that the system can be modified to work under 6G whenever 6G is fully deployed to improve performance, which will give better precision and recall when compared to the proposed system.

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