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An IoT-Based Virtual Fence System to Control population and Deter Quelea Birds Invasion using Automated Nets

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Abstract:- Quelea birds are small but highly intrusive birds that have become a menace in small grain farms. Previous researches has it that their extreme coordinated and destructive feeding behaviors can result in substantial crop and financials losses for small grain farmers in Zimbabwe, mostly commercial wheat farmers. Traditional methods of deterring and controlling the quelea birds' population such as catch and consume have proven to be labour intensive, time consuming as well as costly. Some Zimbabwean wheat farmers leveraged on drone technology to scare and control the birds' population through chemical control but these proved to be environmentally unfriendly as the chemicals might end up negatively affecting the ecosystem of the surrounding environment. The research is centered on the development of an IoT based virtual fence system to deter invasion and control quelea birds' population using automated nets. The researcher aims to deliver an understanding of how innovative technologies such as virtual fencing, IOT and automated nets can be leveraged to address agricultural challenges caused by quelea birds to wheat farmers in Zimbabwe. The system comprises a network of linked sensors that form a virtual boundary to detect an invasion, automated nets, buzzer to deter flock and wireless network technology to send data to a central or cloud storage for future analysis and further development of the system. Ultrasonic sensors, ESP32 Microcontroller and wireless network technology were used in the development of the model. The IoT based virtual fence system to deter and control quelea birds' population provides a cost effective, efficient and environmentally friendly solution to the quelea birds' menace in wheat farms and ensuring food security for the country.

Keywords:- *Quelea Birds; Virtual Fence; Automated; Population; Insert Agriculture, Ultrasonic Sensors.*

I. INTRODUCTION

Virtual fencing aims to remotely map and control livestock grazing behavior without the use of fixed fences [1]. The virtual fencing technology, which was first developed in 2005, uses Global Positioning System (GPS) sensors and wireless technologies to control the movement and location of animals within an area. It has also been implemented to control wildlife movements in a conserved area. The system [2] uses GPS tracking devices, which are attached to animals' collars, to alert conservation personnel of animal movements so that they can remove animals from restricted areas, thus human intervention involved. This research proposal aims to design an IoT-based virtual fence model designed to deter and control Quelea bird population and invasions using automated net, with minimal human intervention. The proposed model for virtual fence system will leverage IoT devices, such as motion sensors, sound sensors [3], and actuators, to create a networked infrastructure capable of detecting Quelea birds invasion in real-time. By integrating Ultrasonic and audio sensors, micro controller, wireless network technology, and automated nets, the system will be able to detect potential invasion, and trigger automated responses to deter the birds effectively as well as catching some for consumption thereby sustainably controlling the bird population.

II. BACKGROUND AND PROBLE STATEMEN

Quelea birds, [4] scientifically known as Quelea, are small but highly invasive birds that have become a significant menace in various regions, particularly in sub-Saharan Africa. They are known for their highly coordinated and destructive feeding behaviors, which can result in substantial crop losses. According to a UNDP report by (Gift Ntuli, Head of Experimentation, UNDP Zimbabwe Accelerator Lab), [5]. "A swarm of 100,000 quelea birds will consume up to a ton (1,000kgs) of grain per day. Approximately the same amount of grain that an average family of six people consumes per

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year and this proves to be a threat to agricultural productivity and food security". In Zimbabwe several articles reported in the national newspaper, The Herald, some of which include [6], [7], [8]. These reports prove the extent to which the pest birds are a threat to national food security. The editorial comment of [9] highlighted a suggestion, by a wildlife expert in the early 1980s, which was against use of chemicals to control the birds' population but to leverage on the species as a source of protein for humans or even them to contribute to the national economy. He said, "One area where some innovation is needed is converting quelea from a menace to a resource". Zimbabwe wheat and small grain farmers today apply traditional methods of bird population control, like physical barriers and catch and consume as depicted in a documentary by Karanganda TV [10]. These have proven to be labor-intensive, time-consuming, and often ineffective in mitigating bird invasions. Elsewhere, several deterrent solutions of emerging technologies such distressing sound [11], and laser beam/ curtain solutions were implemented but it has been proven that with time the pest birds will become habituated to the solutions rendering them in-effective. Also such technologies require human intervention in the event of an invasion as well as high-cost gadgets like HD human-eye cameras to alert an invasion.

III. LITERATURE REVIEW

In Zimbabwe, agriculture plays an important role in the growth of the economy. Some sectors of agriculture, particularly the small grain farmers, production or yield is mostly adversely affected by the invasion of quelea birds according to [12]. A UNDP report by [13] shows that research on the menace of the pest birds and possible solutions to control them and prevent crop damage, began as early as 1973.

A. Ethical Issues

Quelea bird control Act Chapter 19:10 was an Act that was enacted for Zimbabwe to provide for the control of quelea birds and for matters incidental thereto and connected therewith. The Act reflects the ethical issues pertaining to agro-ecology concerning small grain farmers and the menace of quelea birds. The act states that it is a punishable offence for anyone who does not report the discovery of the roosting places of the quelea birds.

B. Review of Innovative Technologies to Protect Agricultural Crops

Considerable research has been contacted pertaining to innovative approaches to curb human wild life conflicts as well as the use of drone technology to scare away pest birds from small grain fields. The virtual fencing approach has been developed to control movement of domestic animals as reported in a journal article ("Virtual fencing technology to intensively graze lactating dairy cattle. II: Effects on cow welfare and behavior") by *R. R. Megan Verdon et al* [14]. This technology has also been used to manage wildlife that is vulnerable to extinction [15]. In other scenarios mentioned in [2] virtual fencing technology was used as a conservation initiative to prevent human wildlife conflict and prevent spread of disease from wild animals to domestic animals.

The IOT-based virtual fence system aims at reducing the impact of grain consumption due to an invasion by a swam of quelea birds by use of an automated net that will be activated to scare them away and catch some for consumption. A documentary by [10] (Karanganda TV) illustrates the cumbersome manual control of the catch and consume process by local communal small grain farmers. The catch and consume will contribute to the nutrition index of the country as well as controlling the quelea bird population. This method of controlling quelea bird invasion and population is even mentioned by C. Mpala *et al* [16], "The harvesting and utilisation of quelea by the rural communities has always occurred using indigenous knowledge system". That means in other countries for example in Rural Zimbabwe small grain farmers use traditional methods to harvest these birds for source of food and protein. Some research has it that most methods used to control quelea birds' invasion and population were harmful to the environment and other wildlife species. These include chemical control or the use of chemicals like organophosphate or fenthion sprayed in the breeding colonies and roosts.

Emerging technologies have been applied in a bid to bring lasting solution to human quelea bird conflict. These include the use of drones, laser beams to scare away invading birds. However, the technologies ended up being not effective according to [17] as the bird species became habituated to the deterrent methods of the technologies. That is, these deterrent methods were only done to scare them away with no harmful threats hence the repeated actions made the birds become familiar to them.

The virtual fencing is the technology that uses Global Positioning System (GPS) sensors and wireless technologies to mimic the physical fence boundaries. Different literature, for example, the e-Shepheard [14] and [18] reveal that this technology was developed and implemented to manage and monitor domestic animals in pastureland. In other research this technology was used to monitor and control wildlife. However these virtual boundaries worked with sensors attached to collar bands on the animals, which produce an audio cue whenever the animal nears a virtual boundary [14].

"Recently there has been interest in developing technology-based solutions to deter nuisance birds in agricultural settings. While others researchers are exploring more natural methods, including falconry, [17] provide a general overview of bird deterrent methods that are currently in use in agriculture, and explore options for novel methods". In [19] the researchers noted that "virtual fences were increasingly getting popular and soon will offer realistic management strategies for both terrestrial and avian wildlife conservation. [20], developed an IOT application to scare birds away in the agriculture field. MFCC-VQ was used as the method for bird's voice recognition and VQ algorithm was used to determine the positivity of the detected sound in order to generate the output of a flying sound as an action to cast out and scare the birds away from the fields. With an aim of increasing field crop output [21] and [11] designed a model that consists of two main functionality one is the motion

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detection using PIR (Passive Infrared) based motion detectors and the other part that is repeller that will generate sounds of the predator which will drift the birds away from the field, using an MP3 module and megaphone. This method had no set boundaries, the detection and deterrent of invasion was done on birds already in the field instead of preventing them from getting into the field.

The Zimbabwe Newspaper [22] reported that the country was embracing new technology in order to fight these migratory birds. Some Zimbabwean wheat framers were leveraging on aerial operations aircraft to scare away and control the menacing bird population. The drones sprayed chemicals on fields, birds, and even the roosting sites of the birds.

C. Revelations from the Literature Reviewed

Information obtained from various sources, which include, reports, websites and journals, revealed;

- An understanding of quelea birds movement and feeding behaviors and various control methods that have been implemented to manage them
- That drone technology in combination with chemical control had been implemented to control population of quelea birds in Zimbabwe and other African countries but the use of chemicals would be harmful to the environment and other non-quelea species.
- That in Uganda according to [11] a smart agriculture system which was a combination of sensors, cameras, distressing sound emitters and water sprinklers was developed to deter quelea birds invasions from rice fields but the system would scare birds that were already in the rice fields
- That the virtual fence system was developed and implemented in managing domestic and wild animals and sensors were strapped on individual animals to signal an alert whenever the animal approaches the virtual perimeter.
- That the previous technologies implemented where not dynamic hence the repeated deterrent actions ended up not being effective because of habituation of the birds to the measures implemented.

IV. PROPOSED SYSTEM MODEL

The researchers designed a model of an IoT-based virtual fence system to control population and deter quelea birds' invasion using automated nets with minimum human intervention. The model is based on the IoT and virtual fence innovation and is composed of three main modules, which are, the virtual fence, the IoT and the physical. The aim is for the system to trigger automated nets to control population and alert sounds to scare and prevent quelea birds' invasion.

A. Components of the system

- *ESP32 Microcontroller:* The ESP32 Microcontroller acts as the central processing unit, hosting a web server and handling sensor data.
- *Ultrasonic Sensor (HC-SR04):* This determines the distance of objects, used in the model to detect the proximity of quelea birds
- *Audio Sensor:* This type of sensor measures ambient sound levels, aiding bird detection based on the specific noises.
- *Servo Motor:* This component enables comprehensive coverage of the detection area by rotating to sweep the detection area.
- *Buzzer:* Sound an alarm when a flock of quelea bird are detected within a critical range
- *DC Motors (motorPin1 and MotorPin2):* This controls the mechanism to deploy or automatically trigger nets to trap some of the birds in the invading flock

B. The Virtual Fence Module

In the model the Ultrasonic Sensors (HC-SR04) and audio Sensors were used together and strategically positioned to create a virtual boundary. The Ultrasonic Sensor (HC-SR04) would detect the presents and movement of objects that mimic quelea birds within an area. By emitting ultrasonic waves and measuring the time taken by the waves to bounce back, the Ultrasonic sensor will determine the distance on the objects (quelea birds). The Audio Sensor was used to capture the distinctive sound patterns of an object mimicking flock of quelea birds sounds. This is in confirmation that the detected movement was indeed of quelea birds.

C. The Physical Module

The automated net mechanism is the physical barrier that is deployed when a breach on the virtual fence is detected. Communication from the virtual fence component enables the activation of the nets and buzzer or siren to scare away an invading flock,

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D. The IoT Module

This consists of a combination of wireless network connectivity and all the components of the system that work together in real time to control population and prevent invasion of quelea birds from a small-grain field.

E. Block Diagram

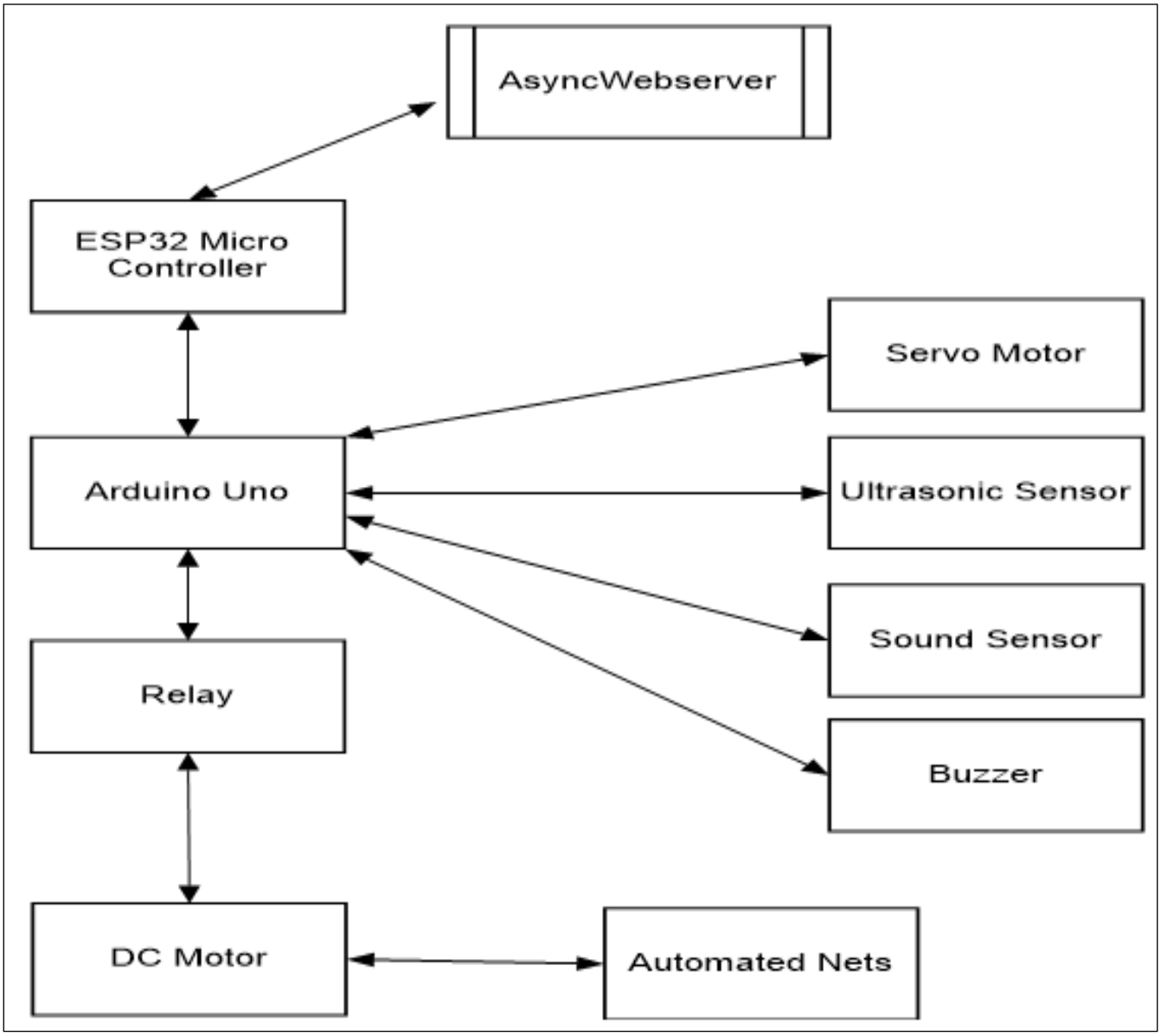

Fig. 1. Block Representation of An IoT-Based Virtual Fence System to Control Population and Deter Quelea Birds Invasion Using Automated Nets

Fig. 1 shows the main components of the system model. The microcontroller will get input from the sensors which will be installed in stipulated points around the field to form a virtual boundary. The input data is processed, the nets and siren will be activated according to the data input from the sensors, that is, either to activate the nets to trap and siren to produce sound to scare or no action to be taken. The ESP32 connected to the configured Wi-Fi network ensures processing and transfer of data gathered from the sensors to a webserver for storage and analysis.

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F. Flow Chart

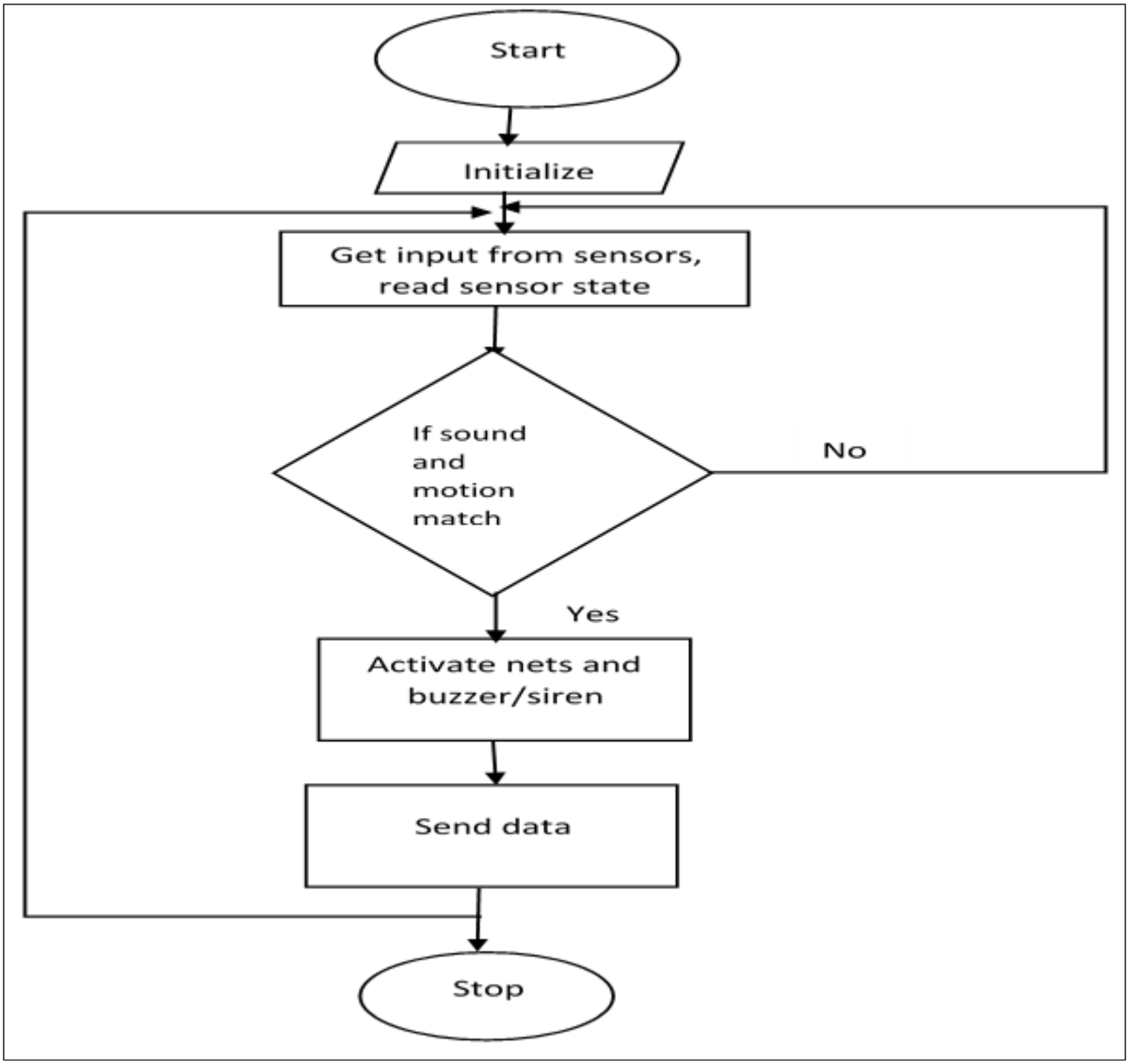

Fig. 2. Flow Chart Representation of the IoT-Based Virtual Fence System to Control Population and Deter Quelea Birds Invasion using Automated Nets

Fig. 2 depicts visual representation of the system showing how the program flows. This helped in giving a bigger picture in demonstrating the pseudocode of the system. In the above diagram, initialization of modules is done by a microcontroller. The decision of action is determined by the state of sensor data as read on the microcontroller

V. RESULTS AND DISCUSSION

The researchers developed a model that simulates the IoT based virtual fence system to deter invasion and control quelea birds' population using automated nets. Model data collected was mainly to identify if the system can perform the anticipated objectives of deterring an invasion by triggering the nets and sounding the buzzer.

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A. Data Acquisition and Analysis

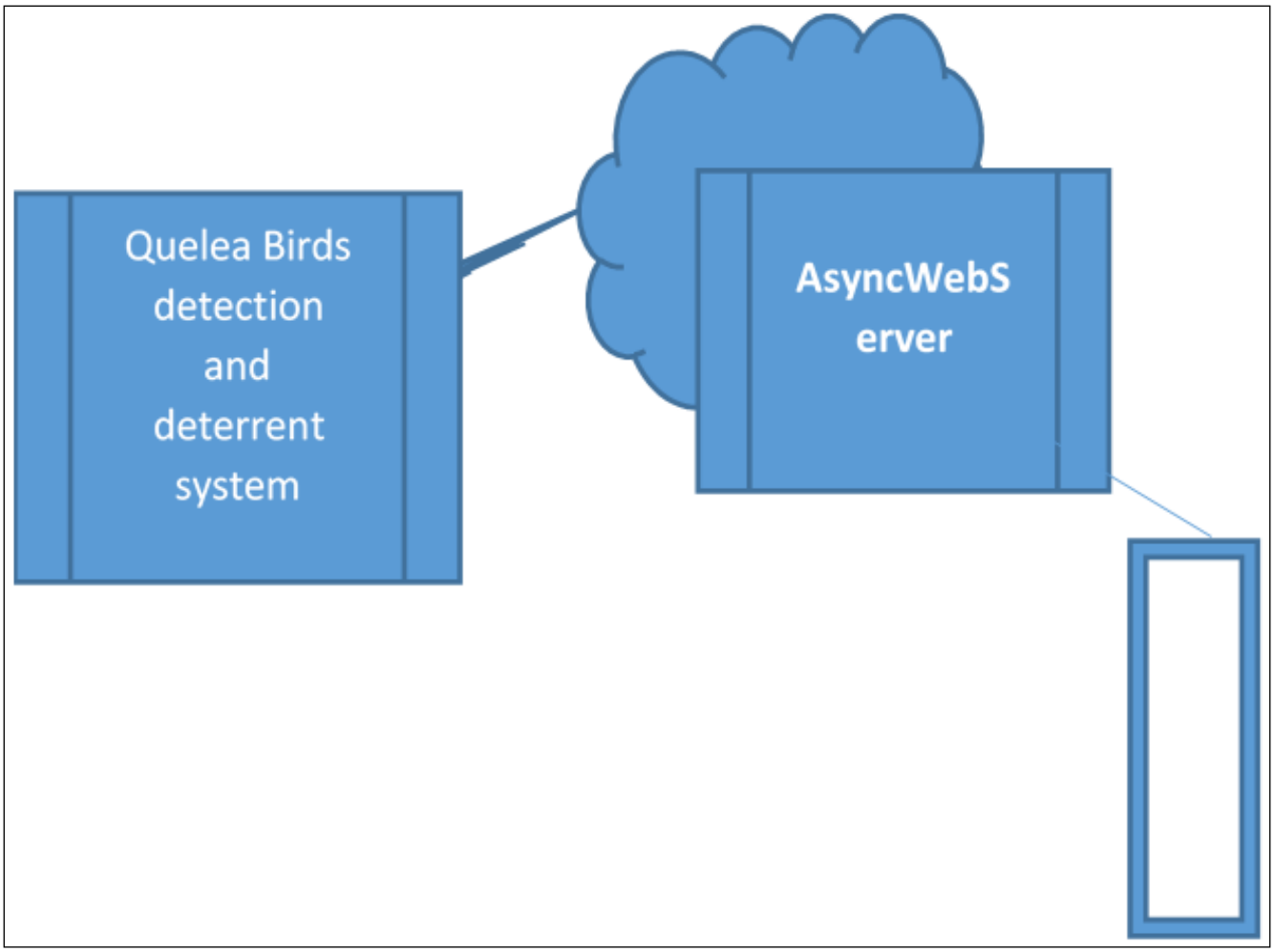

Fig. 3. Data Acquisition Process

Fig. 3. is the data acquisition process. The ESP32 Micro controller which acts as the CPU of the system ensures reading data from the sensors, processing it, and communicates actions taken to AsyncWebserver. The AsyncWebserver is a web application that hosts two web pages. The index page and the reports page. The Index page displays real-time data like distance of nearest object and ambient audio. The Reports page displays historical data of detected birds' instances, including time-stamps, distances readings and audio levels. The system can also be accessed on mobile gadget for remote control in the event of human intervention required.

B. Model Results

Objects mimicking a flock of quelea birds approaching a critical zone of 5cm from the virtual boundary were used and the DC motor which was used in place of actuator could not trigger. This was because the sound of the objects did not match that which was stored. Therefore in order to prevent false positives the sound sensor had to complement the Ultrasonic sensor by detecting the external sound and positively identify it as that of a flock of quelea birds. Data was send to the web application as shown in the picture in Fig. 3 below.

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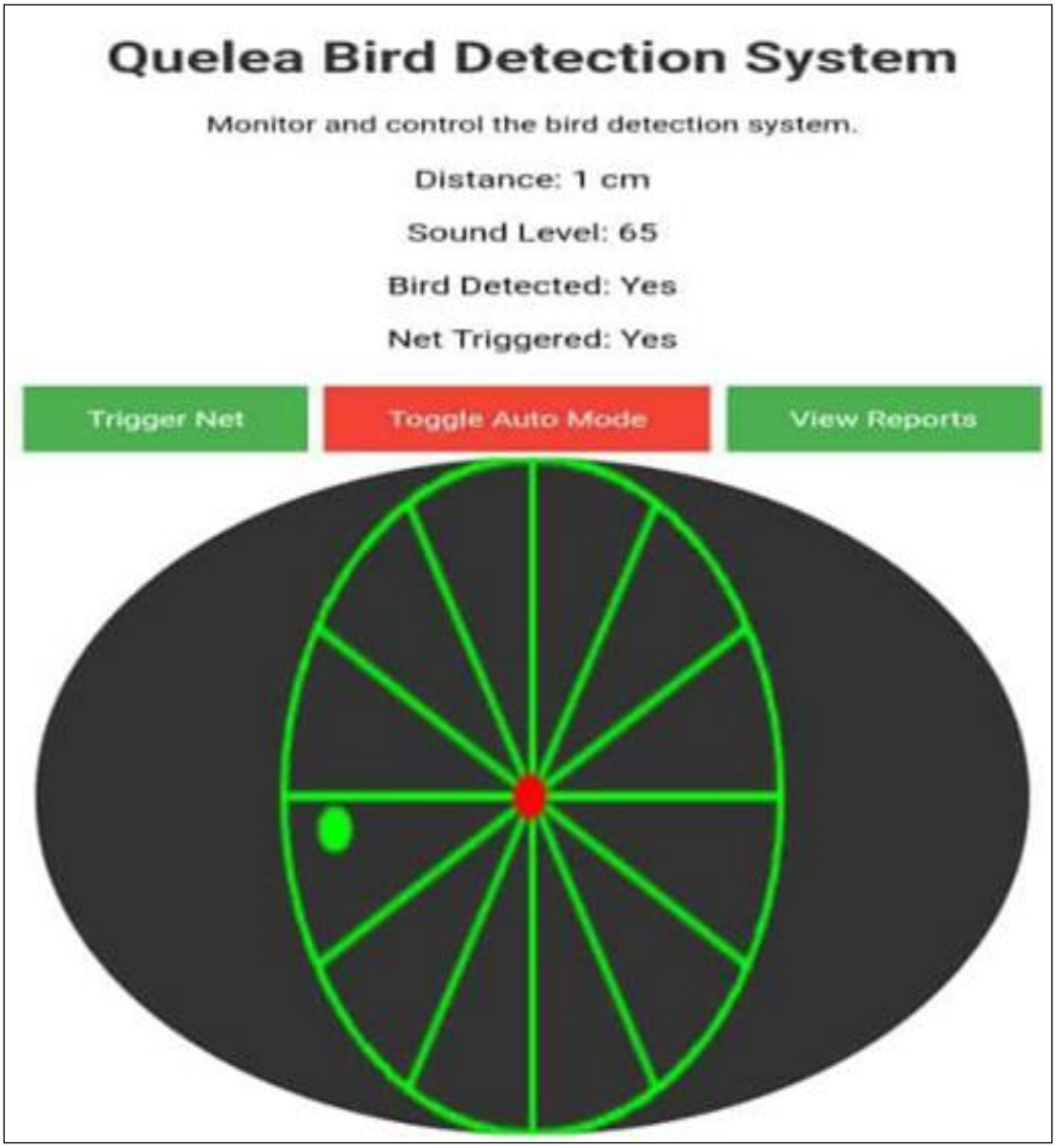

Fig. 4. Index Page Showing Real Timedata

Fig 4 picture shows the dark section with green lines representing the virtual boundary created by the sensors. The red dot represent birds that have approached the critical zone towards the boundary and green dot represent the positon of the servo motor. In the picture real time data reveals that an invasion was detected at a distance of 1cm towards the virtual boundary and sound level of 65 as objects mimicking the flock approached the critical zone. This caused the DC motor representing the nets to trigger.

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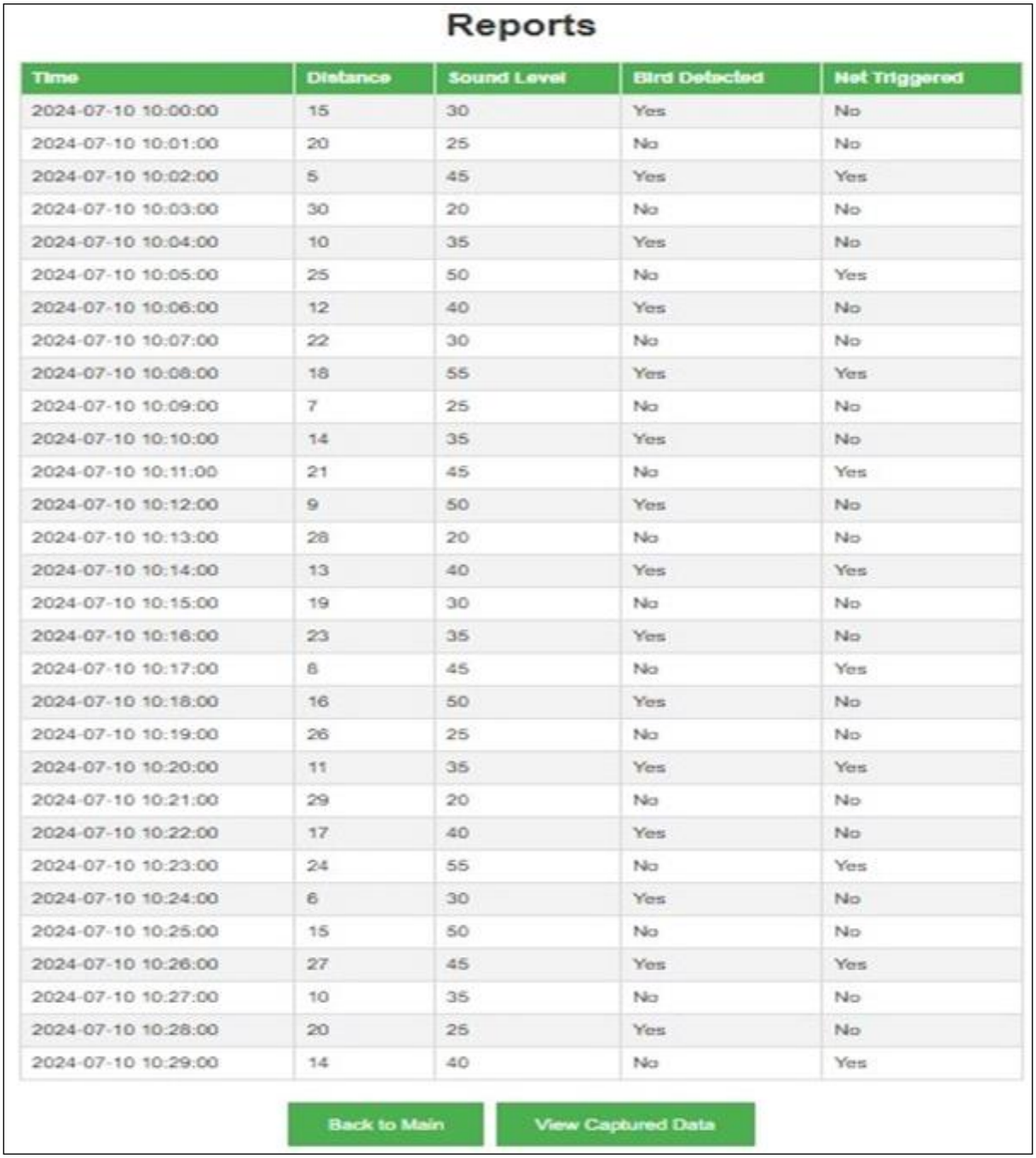

Reports

Time	Distance	Sound Level	Bird Detected	Net Triggered
2024-07-10 10:00:00	15	30	Yes	No
2024-07-10 10:01:00	20	25	No	No
2024-07-10 10:02:00	5	45	Yes	Yes
2024-07-10 10:03:00	30	20	No	No
2024-07-10 10:04:00	10	35	Yes	No
2024-07-10 10:05:00	25	50	No	Yes
2024-07-10 10:06:00	12	40	Yes	No
2024-07-10 10:07:00	22	30	No	No
2024-07-10 10:08:00	18	55	Yes	Yes
2024-07-10 10:09:00	7	25	No	No
2024-07-10 10:10:00	14	35	Yes	No
2024-07-10 10:11:00	21	45	No	Yes
2024-07-10 10:12:00	9	50	Yes	No
2024-07-10 10:13:00	28	20	No	No
2024-07-10 10:14:00	13	40	Yes	Yes
2024-07-10 10:15:00	19	30	No	No
2024-07-10 10:16:00	23	35	Yes	No
2024-07-10 10:17:00	8	45	No	Yes
2024-07-10 10:18:00	16	50	Yes	No
2024-07-10 10:19:00	26	25	No	No
2024-07-10 10:20:00	11	35	Yes	Yes
2024-07-10 10:21:00	29	20	No	No
2024-07-10 10:22:00	17	40	Yes	No
2024-07-10 10:23:00	24	55	No	Yes
2024-07-10 10:24:00	6	30	Yes	No
2024-07-10 10:25:00	15	50	No	No
2024-07-10 10:26:00	27	45	Yes	Yes
2024-07-10 10:27:00	10	35	No	No
2024-07-10 10:28:00	20	25	Yes	No
2024-07-10 10:29:00	14	40	No	Yes

Back to Main View Captured Data

Fig. 5. Reports Page Showing Historical Data

Fig 5 above is the reports page of the web application that displays historical data. This data will help for analysis of bird behaviors and system enhancements to avoid habituation of system by the birds.

VI. CONCLUSION AND RECOMMENDATIONS

From the model designed, the results showed that the system has the potential to be the sustainable solution for the challenges posed by the quelea birds on small-grain yields, if it is fully developed for deployment in real-world situation.
Based on the research findings the researchers propose to recommend that today's small-grain farmers in Zimbabwe should leverage on IoT solutions in order to curb the problems caused by quelea birds and increase their yields.

However, there is need for further research in order:

- To ensure the systems' performance reliability in real-world situations.
- To incorporate machine-learning algorithms to enhance the system and ensure adaptability to behaviour changes and reduce habituation of the birds
- To study on the cost effectiveness of the system to the potential users

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