Smart Monitoring System using Internet of Things: Application for Agricultural Management in Benin

Pélagie HOUNGUE[1], Romaric SAGBO[2], Gilles DAHOUE[3], Julien KOMACLO[4]
Institut de Mathématiques et de Sciences Physiques
Université d'Abomey-Calavi, Dangbo, Bénin[1,2]
Institut National Supérieur de Technologie Industrielle
Université Nationale des Sciences, Technologies, Ingénierie et Mathématiques, Lokossa, Bénin[3,4]

***Abstract*—One of the major tools of the new era of digital transformation is Internet of Things (IoT) through which, one can look forward to exploring the new technologies in the digital world as well as how they help in improving the real world. This work provides an overview of the approach used to deploy a surveillance system for monitoring any indoor space in general and specifically for agricultural spaces. The entire process starts after motion detection by motion sensors using Machine Learning techniques. This requires coverage and response processing algorithms implemented in the electronic chain. The electronic part of the system relies on the micro-controllers, sensors and communications between them. A mobile application has been developed to allow competent authorities to receive alerts for real-time intervention with the aim of preventing the destruction of crops slaughtered near herds passage. The monitoring system' synoptic diagram and its operation along with the power modules description are introduced. Prototype has been designed and performance evaluation performed to show the system' responsiveness.**

Keywords*—*Monitoring system; agricultural space; machine learning; herds passage; motion detection

I. Introduction

A thriving society offers myriad benefits: joy, peace, and security. Yet, security continues to be critical. This is true whether the safe space is for people, items, or animals. It makes sense to send out a team of guards to monitor and police a safe space. Therefore, having a monitoring system [1], [2], [3] remains the best engagement solution for well-being. Moreover, thanks to the development of the Internet of Things (IoT), one can now keep in real-time, an eye out for its own assets remotely [4].

Despite the crucial importance and active participation of livestock in the Beninese economy, their producers are less protected from the serious threats that often accompany the search for animal feed, especially in the dry season, which leads to loss of the plantations. With this in mind, a monitoring system that is intended to be able to adapt itself to the user needs, has been designed. The service produced by the system, allows receiving alerts when intrusions occur. Recently, in [5], a multi-layered architecture that is useful for various stakeholders (breeding producers, farmers, and policymakers) has been proposed to support Smart Agriculture and Smart Livestock. Transhumance related issues have been targeted, as those issues gain further expansion in developing countries. Indeed, during the transhumance process, passages dedicated to animals, usually referred to as corridors may not be followed by the breeders. This can cause deadly clashes between herders and farmers. In this paper, the above issues are addressed by extending the architectural solution provided in [5], to the implementation of a monitoring system to detect intrusion when the cows are too close to the farmers field, as well as to send alert message on the phone of the authorities that can try to anticipate the conflicts.

Machine Learning is being intensively used to solve real-time computer vision and image processing problems [6], [7]. Our solution is built using Machine Learning techniques associated with OpenCV library [8], [9] and a pre-trained library of objects and animals from Coco (Common Object in Context) dataset [10], [11] that is large-scale object detection, segmentation, and captioning dataset. Thanks to this trained library, the proposed intrusion detection system, based on Raspberry Pi, will allow recognizing some objects and animals such as cows, oxen and persons, using DNN (Deep Neural Network) algorithm [12], [13].

The specific objectives of this work are: i) use IoT to set up a monitoring system that detects intrusion of cows using a training model, ii) carry out the processing of the captured image and ensure the identification of the cows or oxen, iii) trigger an alarm after the detection of cattle movement at the entrance of the field and send an alert message and details about the field' location to authorities who can take appropriate decision in real-time. Sending alerts to the farmers, is avoided to reduce the direct conflicts before authorities intervention.

The remaining of this paper is set as follows. Section II discusses problem statement and motivation. Section III presents the novel IoT-based intrusion detection system followed by section IV that discusses experimental results. Sections V and VI, respectively focus on related work and conclusion, followed by perspectives.

II. Problem and Motivation

Although the rules of arable land are carefully codified, the roads are delimited and respected by the sedentary, the level of destruction caused by the traditional movements of pasture increases day by day. Land degradation has been a constant challenge for farmers and ranchers as it accompanied the spread of agriculture in prehistoric times. It can create dangerous outcomes like death when large herds enter in neighboring fields, making it necessary for authorities to be alerted to their presence, anywhere in the land [5], [14]. In order to reduce deadly outcomes and large herds of animals roaming fields, pioneers need to lessen the conflict between agricultural experts. This work aims to alert authorities as soon as herds of livestock are advancing toward neighboring ranches. In today's world, surveillance systems are predominantly based on more traditional equipment, such as closed-circuit cameras. Unlike, the proposed system not only monitors herds' passage, but is also able to send the exact position of the concrete place where the intrusion takes place. In addition to this, the image processing is done to decipher whether the movement is actually animals or if it is men or otherwise.

III. IoT-based Detection System

Our monitoring system can be divided into two main parts, namely, the electronic component and the mobile application. The first part, dealing with electronic, covers the communication between the various modules and the electronic devices used. When the motion sensor at the entrance of the field, detects the movement of an object, the camera is activated and the object is identified. If there is a cow or oxen among these identified objects, an alarm will be triggered, when it is less than 2 meters from the system, positioned at the entrance of the agricultural domain. This is called pre-intrusion. However, if the cow crosses the border by entering in the domain within 1.5 meters from the system, the same treatment process is followed. Again, for cows and oxen, it sends an alarm message to authorities and assigns them the location of the sensor that detected the movement, reporting the intrusion.

The second important part of the work, is mobile application design. This application acts as intermediary between electronic system and users. Therefore, it receives alerts, displays alerts, displays the history of intruders, and allows administrators to know the status of components of the system.

This section highlights the system architecture along with its functional requirements. Moreover, electronic details have been underlined, as well as the OpenCV library description.

A. Intrusion Detection System Architecture

Our intrusion detection system is based on a client/server architecture. All processing tasks are performed through the server. It is therefore, the brain of the system, which consists mainly of two parts, as shown in Fig. 1.

- Electronic components consisting of motion sensor, ultrasonic sensor, camera, Raspberry Pi 3, NEO-6M GPS module.
- The mobile application obtains information sent by electronic system regarding the intrusion' detection.

B. Detection Processing Steps

Fig. 2 shows the process of pre-intrusion and intrusion detection in agricultural domain. First, when the PIR motion sensor detects motion at the entrance to the monitored area, it triggers the camera, which is in standby mode by default, to identify objects whose presence has been notified by the sensor. For cows and oxen, ultrasonic sensors assess the distance between the object and the system. If the distance between them is less than 1.5 meters, the system will sound an alarm (buzzer). This is the pre-intrusion detection. When the PIR sensor placed in the field, detects movement within the detection area, an ultrasonic sensor is activated and the distance between the system and the trigger object is also calculated. Then, when the distance between the system and the object is less than 1.5 meters, the camera will be activated to check if it is a cow/oxen. In the case of cow or oxen, the system sends notification to the authorities. This is an intrusion detection. If not, no action is required.

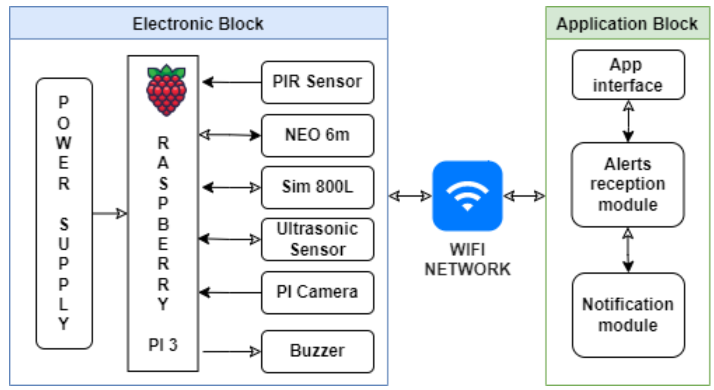

Fig. 1. System architecture

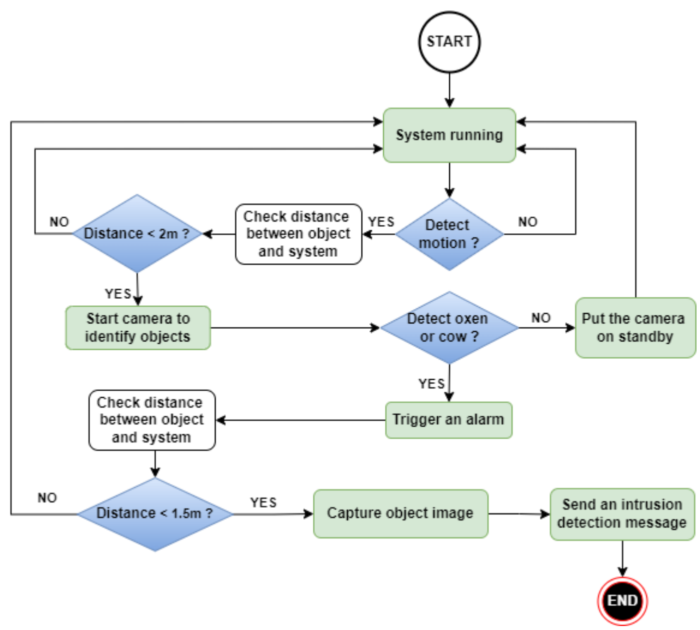

Fig. 2. System operations steps

C. OpenCV Library Usage

The recognition of objects, in particular an ox or a cow, was done using the OpenCV library [8], [9], which makes it possible to manipulate the objects and animals predefined in the Coco dataset [11]. The Coco (Common Object in Context) library is a large-scale object detection, segmentation, and captioning dataset. This library is designed from a large collection of images of each object and animal in different shapes and various landscapes. It allows the Raspberry Pi to identify 91 unique objects/animals and to provide a constantly updated confidence score. The OpenCV library along with Coco dataset are set up on the Raspberry.

Object recognition, specifically, cow and oxen, was performed using the OpenCV library [8], [9]. As library, it allows manipulating predefined objects and animals in the Coco dataset [11]. Coco (Common Object in Context) is a rich object detection, segmentation and captions dataset. It was designed from a large collection of images of each object and animal in different shapes and different landscapes. This allowed the Raspberry Pi to identify 91 unique objects/animals and provide a constantly updated confidence score. An OpenCV library along with a Coco dataset are set up on the Raspberry Pi.

D. Use Cases

Use case diagrams are provided in terms of actions and reactions, allowing to visualize system behavior from the user's point of view and give a complete overview of the functional behavior of a system. Fig. 3 shows "what" the proposed system provides by illustrating the possible interactions with the actors.

After authentication, authorities can:

- Comment on intrusions
- Visualize alerts
- Consult intrusions history

After authentication, administrator can manage the system as follows:

- Add or remove users in the system
- Check system status
- Consult intrusions history

E. Prototyping

Several tools were used in order to design the monitoring system. The following materials/tools are used to set up the prototype:

- Raspberry Pi 3, which is a computer reduced to its simplest form with a single ARM processor card, a bit larger than a credit card.
- Camera Pi, Raspberry Pi Night Vision Camera, that supports all versions of Raspberry Pi.
- PIR sensor, is a motion sensor used to determine whether a human or an animal has entered or left the module's detection field.
- Ultrasonic sensor that evaluates the distance between the object and the system.
- SIM800L GSM module, is the smallest and powerful GSM module which can automatically start and look for network connectivity. It allows SMS exchange, calls and data recovery in GPRS 2G+.
- The NEO-6M GPS module, is a GPS receiver, which has a high performance built-antenna to provide powerful satellite search capability.
- Solar panel kit, which is composed by a 10W 12V solar panel, a 5A 12/24V charge regulator and a 12V 12Ah battery. It is used to power on the monitoring system.

Fig. 4 shows the connections between system components. In fact, all the used components are directly connected to the main element, the Raspberry Pi. Main wires are used to connect various components and circuit boards. Each component has a specific role.

The system also includes a mobile application that allows getting intrusions notifications and consulting the history of intrusions. Thus, authority can consult the history of all the intrusions that take place in different agricultural areas and for which he has been alerted.

Fig. 5 shows what the surveillance system box looks like. At the top, 3 LEDs are positioned: one to signal the powering up of the device, the second to indicate an object detection and the last to highlight data transfer to the remote database. In the middle, the Pi camera and the motion sensor can be identified. Further down, an ultrasonic sensor is positioned to calculate the distance between the system and the detected object. In the profile view, you can easily distinguish the start button and the power plug.

Fig. 6 gives in one view, the proposed system from the implementation to the deployment. It shows: a) intrusion detection system prototype, b) system mounting on 1.5 meters high support covered by a solar panel, c) system deployed in real environment. The system is powered by a 30WATT solar panel, mounted on a 12V-9AH battery. The two elements are interconnected by a charge controller.

IV. Experimental Results and Validation

The designed prototype is experimentally evaluated and validated through the system deployment along a field in order to know the accuracy of the intrusion detection. The passage of cows is simulated in a real environment. A herd of ten cows circulate in front of the device, a hundred times. Each time, how accurately the device reported the intrusion is noted. For the simulation, three significant hours of the day are chosen to perform measurements over three days: Morning on day 1, noon on day 2, and evening on day 3. Fig. 7 shows the simulation results for three different time periods selected. Fig. 8 summarizes the measurements taken statistically.

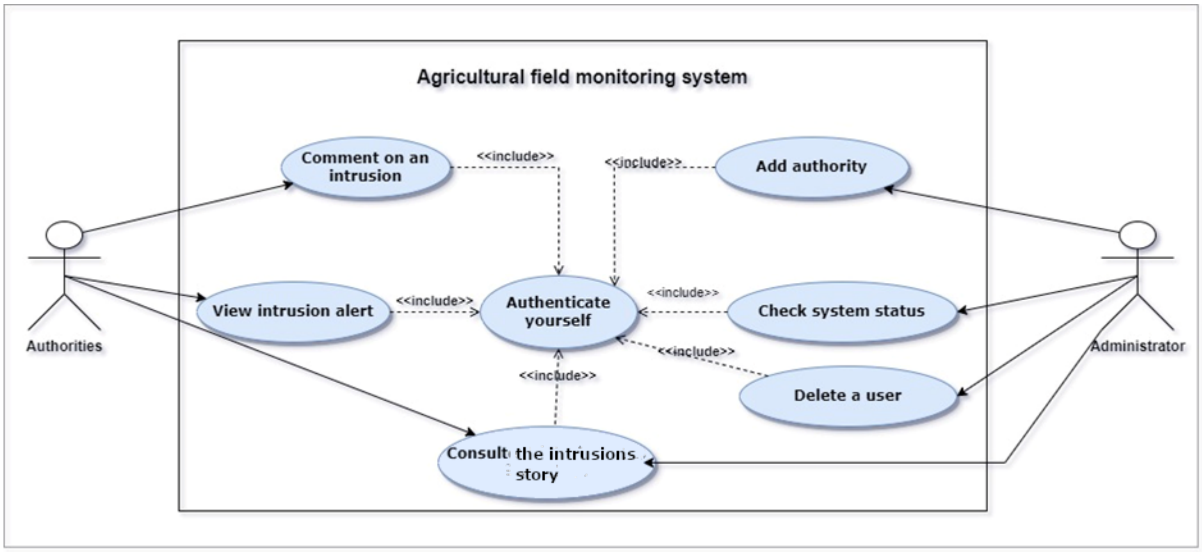

Fig. 3. System' Use Cases

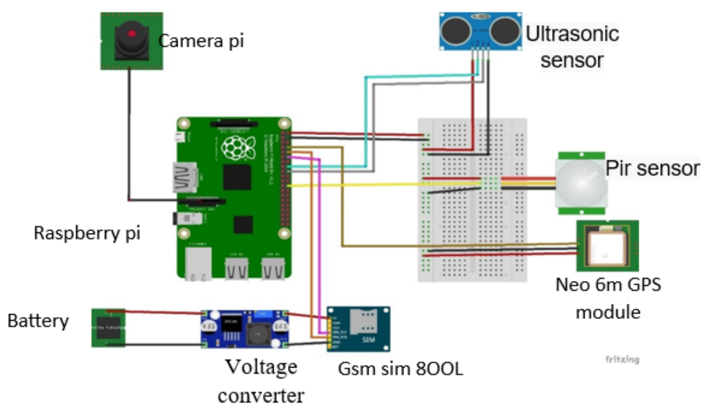

Fig. 4. Electronic circuit' wiring

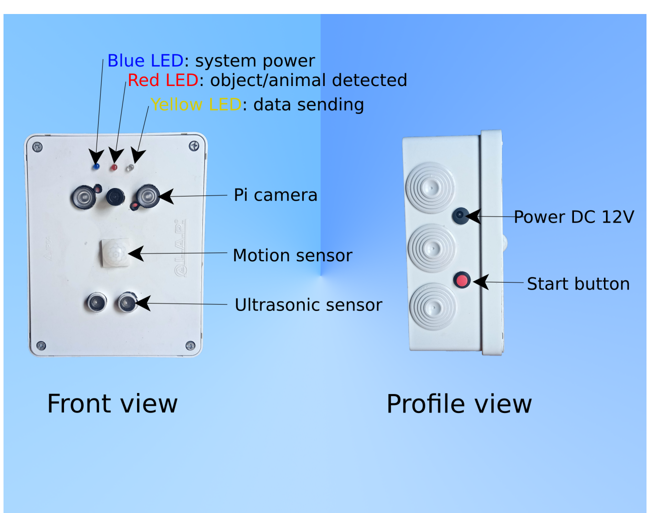

Fig. 5. Monitoring system box

Fig. 7 shows that the proposed system gives better results in the morning and noon, while Fig. 8 shows an accuracy between 0.5 and 1 with averages between 0.74 and 0.82 for morning and noon. Indeed, the evening measurements show an average of 0.53, with detection failing half the time along with a significant value of 0.29 for the standard deviation.

In conclusion, one can notice that noon measurements are more accurate than morning and evening measurements. Detection accuracy in the evening is not so high, although, the system box is equipped with a night vision camera. It turned out that this was due to the brightness and quality of the camera and the low processing power of the Raspberry Pi 3 microcontroller. Future version of the prototype should be equipped with a better camera to improve recognition quality using more powerful Raspberry Pi. This will reduce processing time for cow recognition from images sent by the camera.

V. Related Works

Many studies focused on different aspects of transhumance in Benin and worldwide. From this, it is first possible to draw some solutions about cows' movements monitoring along a specific way called corridor [15]. Secondly, some publications analyzed the effects of constantly greater cattle overflows on total biomass productivity [16]. Thirdly, other relevant research works focus on providing an IoT-based architecture to develop a Smart, Sustainable Agriculture platform as a solution [17]. Finally, some other studies discussed the importance of a good agricultural practice in contrast to forests establishment as a way to increase both rangeland' productivity and the appreciation of its use and management. From the outputs of these studies, one can be able to determine the importance of transhumance and its pipelines in Benin as well as in some countries which have the same challenges.

Endorsements have also been made about how a corridor can be materialized by identifying the factors that contribute to define transhumance routes and analyze the perception of transhumant herders on the determinants of these routes in

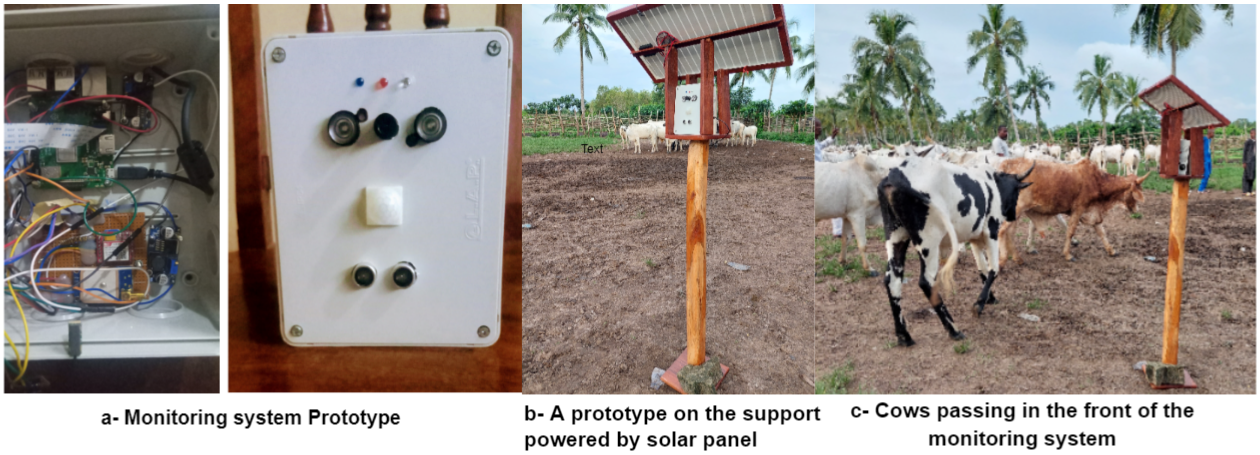

Fig. 6. Monitoring system in one view

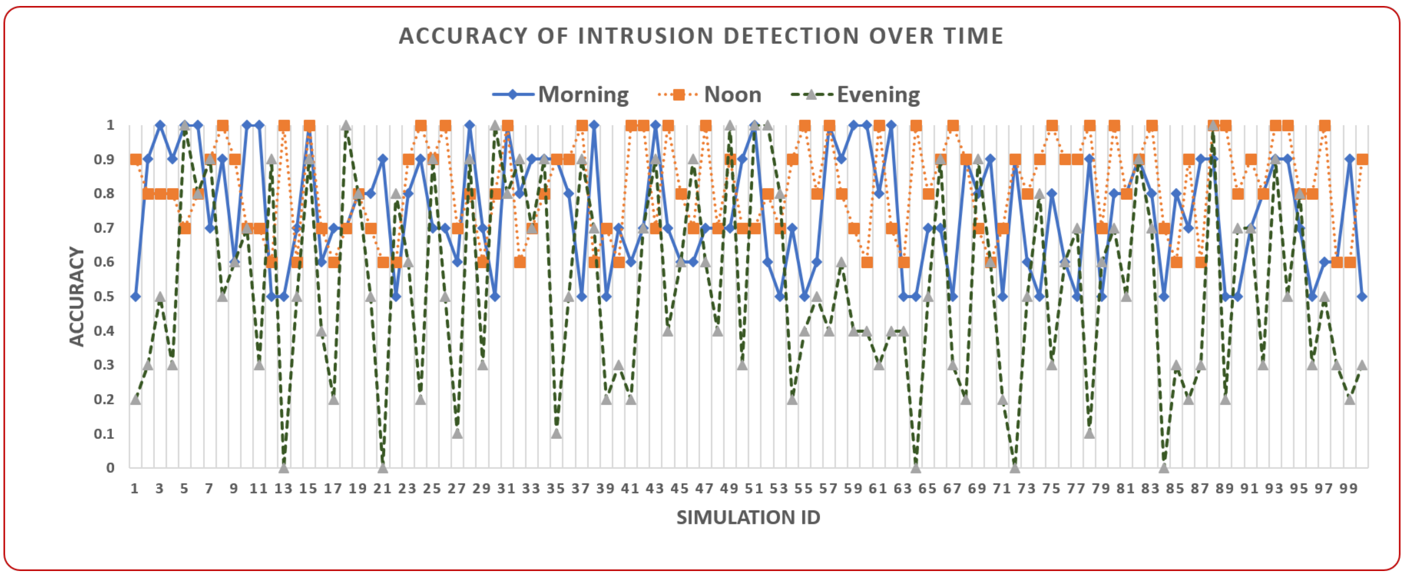

Fig. 7. Accuracy of intrusion detection over time

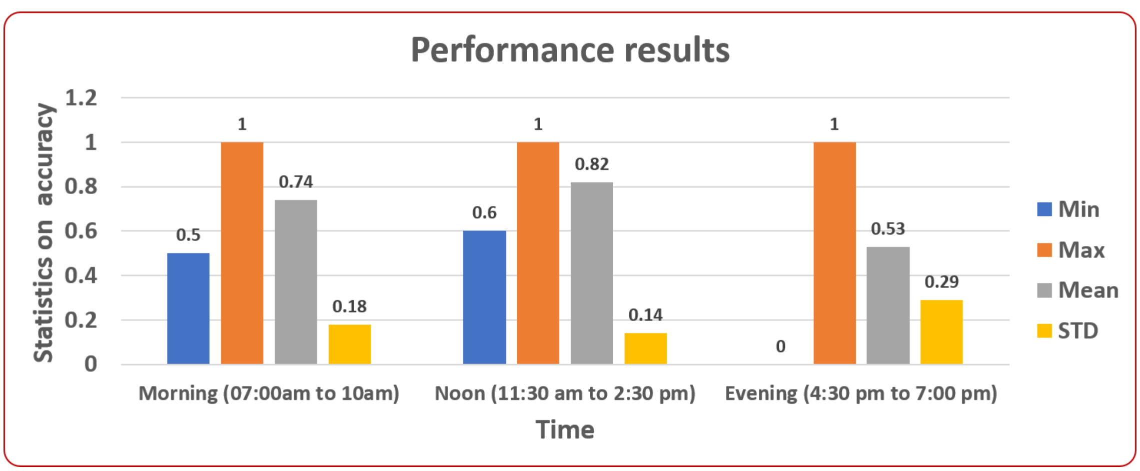

Fig. 8. Statistics on accuracy measured by the system

order to take better decisions in the management of grazed ecosystems [18], [19]. Other solutions are based on monitoring system [20] to manage selected physical conditions and behaviors of livestock across long distances and over large grazing areas in open pastures, as well as in fenced in areas [21], [22]. The solution proposed in [23] is to monitor cows using an IoT enabled sensor installed on the collar of each cow, which associated to the cow, a unique identifier. Livestock farming is assisted more and more by technological solutions such as a vision-based module that allows to automatically detect predators and distinguish them from other animals in order to prevent damages and respecting biodiversity [24]. Sensor technologies are also used to monitor animal health and ensure animal well-being in the fast changing conditions. In addition, authors of [25] try to show relevance of digital technologies for health and welfare monitoring usage and the management of livestock, kept in large pasture areas. Authors of [22] illustrate IoT technology for farmers and use sensors to gather and transfer data using parameters, like temperature, humidity and heartbeat. Once data are collected, they are sent to the Arduino Uno controller.

Moreover, authors of [26] have proposed a farmland surveillance-alert system using unmanned aerial vehicles for cattle presence detection on farmlands as a solution to curbing the problem of farm invasion and destruction. The system, upon detecting cattle presence, higher than a threshold level, sends SMS to farmer's selected number.

In [5], as a previous work, we have focused on a proposal of a multi-level architecture that is able to help through the implementation of a smart guidance system based on IoT Technologies, where herders can better control their livestock following the predefined corridors. Unlike all existing technological solutions, the current work is not intended to identify the cows before tracking them. This is explained by the fact that transhumants often do not adhere to this practice, because they fear that their livestock will be counted. Furthermore, the idea of automatically sending alerts to the farmer upon intrusion detection is rejected, as this does not resolve commonly recorded deadly conflicts. The designed system uses DNN Machine Learning algorithm, to detect intrusion and send alert to the authorities. The system achieved an average accuracy score that varies from 0.53 to 0.82 in real-life test environment.

VI. Conclusion

In this work, we succeeded in prototyping an intrusion detection system for spaces monitoring. The system consists of several modules, that each, plays an important role. The main objective of the project is to send the information collected after processing, to a remote database, specifically Firebase, when there is an intrusion in a monitored space. A test bed has been provided for livestock and agricultural domains. Upon detection, a generated alert is sent to a mobile application to allow visualization and decision-making by authorities. In future work, the prototype will be improved by putting the ultrasonic sensor on a servo motor in order to turn it in the direction of the moving object. Moreover, performance tests will be extended and will include, among other, the evaluation of the time taken to detect the intruding object.

Acknowledgment

We thank the African Center of Excellence in Mathematical Sciences and Applications (CEA-SMIA) for funding this work.

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