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Machine Learning-Based Intrusion Detection System For Space Monitoring : Case Study Of Farming In Benin

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Abstract— The Internet of Things (IoT) is one of the major tools of the new era of digital transformation. Through the Internet of Things, we are looking forward to exploring the new technologies in the digital world and how they help in improving the real world. In this work, we provide 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 relates to microcontrollers, sensors and communications between them. A mobile application has been created to allow competent authorities to receive alerts for real-time intervention with the aim of preventing the destruction of crops slaughtered near herds passage. We have introduced the monitoring system's synoptic diagram and its operation along with the power modules description. Prototype has been designed and performance evaluation has been performed to show the system is responsive most of time.

Keywords— Monitoring System; Intrusion Detection System; Machine Learning; Deep Neural Network; Cow 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), we can now keep in real-time an eye out for our own assets remotely.

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, we have designed a monitoring system that is intended to be able to adapt to the user needs. The service produced by the system allows receiving alerts when intrusions occurs. Recently, in [5], a multi-layered architecture that is useful or various stakeholders (breeding producers, farmers, and policymakers) has been proposed to support Smart Agriculture and Smart Livestock and combine with existing digital technologies. We have targeted on transhumance related issues resolution, as transhumance issues gain further expansion in developing countries. Indeed, during 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, we address the above issues by extending the architectural solution provided in [5], to the implementation of monitoring system to detect intrusion when the cows are too close to the farmers field and 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], [8] is intensively. Our solution is built using machine learning techniques associated with OpenCV library [9], [10] and a pre-trained library of objects and animals from Coco (Common Object in Context) dataset [11], [12] that is large-scale object detection, segmentation, and captioning dataset. Thanks to this trained library, our intrusion detection system prototype, based on Raspberry Pi, will allow recognizing certain objects and animals such as cows, oxen and person, using DNN (Deep Neural Network) algorithm [13], [14].

The specific objectives of this work are to use IoT to setup a monitoring system[15], [16] that detect intrusion of cows using a training model, to carry out the image processing of the captured image and ensure the identification of the cows or oxen, trigger an alarm after the detection of cattle movement at the entrance to the field and send an alert message and details on the location of the field in situation to authorities who will take quickly appropriate measures. We will avoid to send the alerts to farmers to reduce the direct conflicts before authorities come.

We aim to use IoT to setup an intrusion detection system [15], [16], [17] that will trigger an alarm upon the detection of intruders using a specific training model. The image processing of captured images using the trained filter model will facilitate identification of the cows or oxen. The system will also send an alert message and send details of intruders' location to authorities for early rescue. There will be no alerts to farmers to reduce direct conflicts before authorities arrive.

The remaining of this paper is set as follows. Section II discusses problem statement and motivation. Section III presents our 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 deaths when large herds enter neighboring fields, making it necessary for authorities to be alerted to the presence of brows anywhere in the land [5], [18], [19]. 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 advancing toward neighboring ranches. In today's world, surveillance systems are predominantly based on more traditional equipment, such as closed-circuit cameras. Unlike, our 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 part and a mobile application.

The first part, dealing with electronics, covers the communication between the various modules and the electronics devices used. When the motion sensor at the entrance of the field, where our system is installed detects the movement of a person, 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 2m from the system at the entrance to the agricultural domain. This is called pre-intrusion. However, if the cow crosses the border by entering in the domain within 1.5m of 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 our work is mobile application design. Application act as intermediary between electronic systems and users. Therefore, it is the application that receives alerts, displays alerts, displays the history of intruders, and allows administrators to know the status of components of the system.

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

3.1. Intrusion Detection System architecture

Our intrusion detection system is based on a client/server architecture. All processing performed is done 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 systems regarding the intrusions detection.

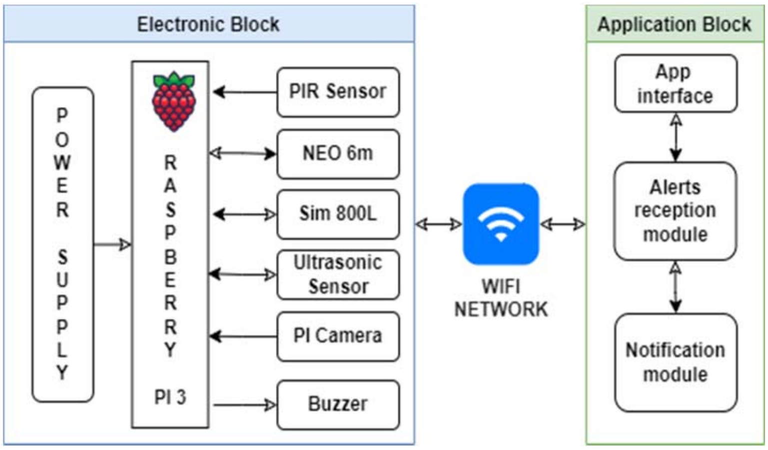

Fig. 1. Detailed system architecture

3.2. 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 pre-intrusion. 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 intrusion detection. If not, no action is required.

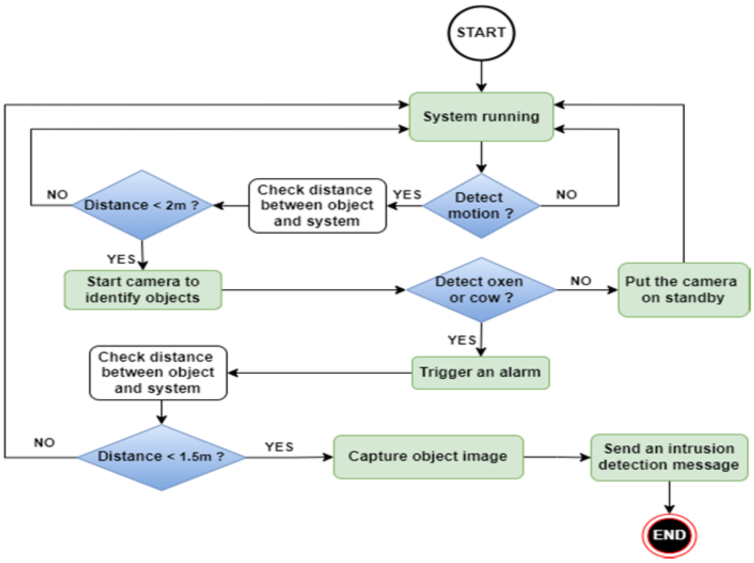

Fig. 2. System Operations Steps

3.3. OpenCV library usage

The recognition of objects, in particular that of an ox or cow, was done using the OpenCV library [9], [10], which makes it possible to manipulate the objects and animals predefined in the Coco dataset [12]. The Coco (Common Object in Context) library is a large-scale object detection, segmentation, and captioning data set. This library is designed from a large collection of images of each object and animal in different shapes and various landscapes. It allowed our Raspberry Pi to identify 91 unique objects/animals and provide a constantly updated confidence score. The OpenCV library with Coco dataset are setup on the Raspberry.

Object recognition, specifically, cow and oxen, was performed using the OpenCV library [9], [10]. As library, it allows manipulating predefined objects and animals in the Coco dataset [12]. 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 our Raspberry Pi to identify 91 unique objects/animals and provide a constantly updated confidence score. An OpenCV library with a Coco dataset is set up on the Raspberry Pi.

3.4. 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. In fact, as shown in Fig. 3, we model the "what" the system provides by organizing the possible interactions with the actors.

After authentication, authorities can:

- comment on intrusions
- Visualize alerts
- Consult intrusions history

After authentication, administrators manage the system as follows:

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

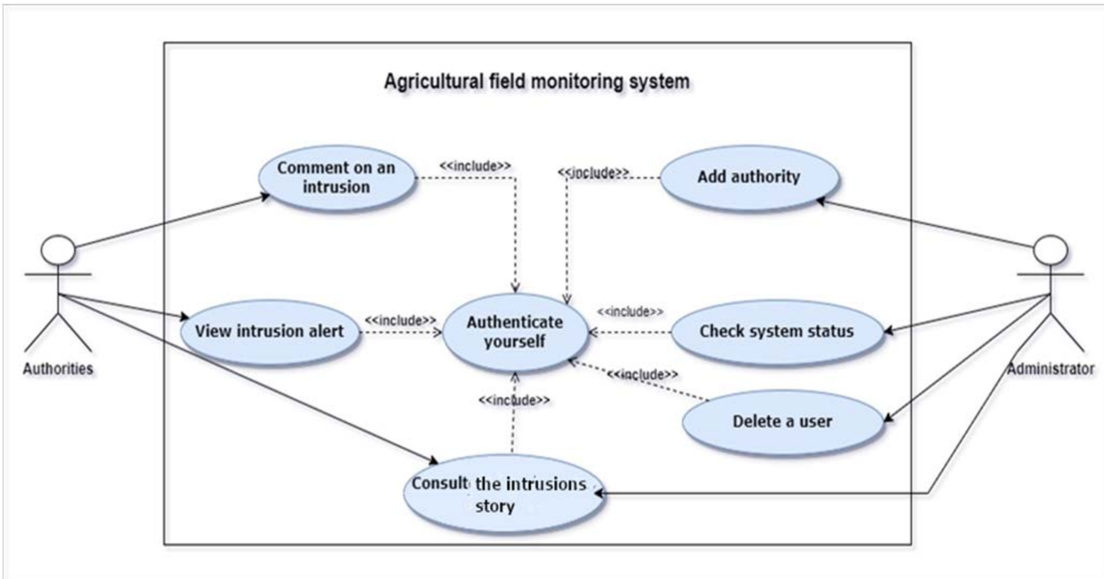

Fig. 3. Use cases showing the features of our system

3.5. Prototyping

Several tools were used in order to design our monitoring system.

The following materials/tools are used to setup our 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 [20].
- Camera Pi, Raspberry Pi Night Vision Camera, that supports all version of Raspberry Pi [21].
- PIR sensor, is a motion sensor used to determine whether a human or an animal has entered or left the module's detection field [22].
- Ultrasonic sensor that evaluates the distance between the object and the system [20].
- SIM800L GSM module, is a smallest and powerful GSM module which can automatically start and look for network connectivity [23]. 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 [24].
- 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 our 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.

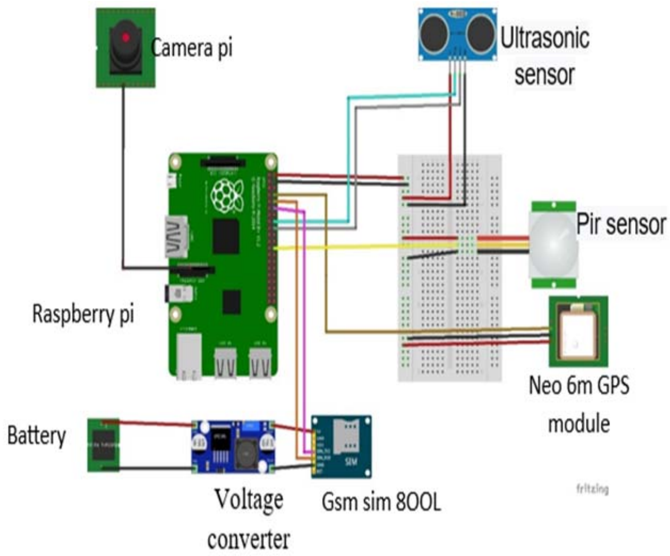

Fig. 4. Wiring of the electronic circuit

Fig. 5 shows the interface of getting intrusions notifications and consulting the history of intrusions in the mobile application. At this stage, authority can consult the history of all the intrusions that take place in different agricultural areas and for which he has been alerted.

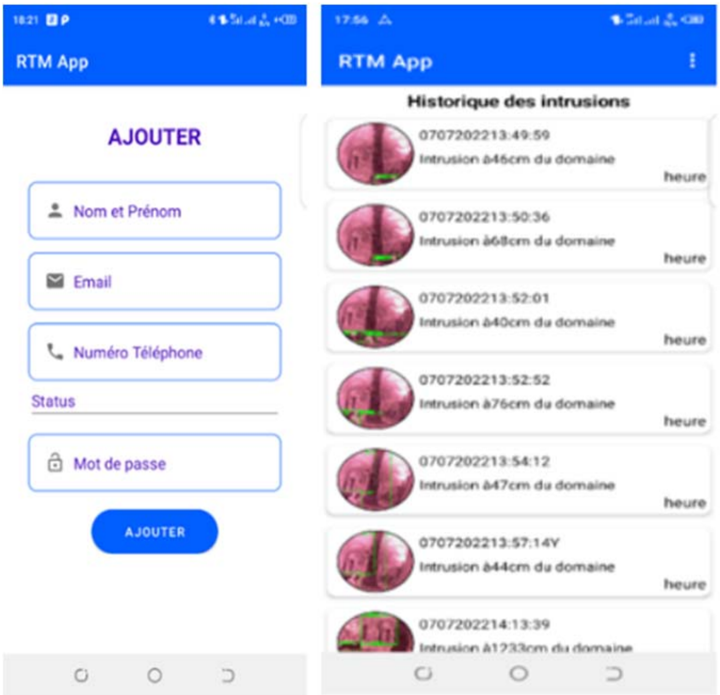

Fig. 5. Mobile app for intrusion notification

Fig. 6 gives in one view our system from the implementation to deployment. It shows:

a) Intrusion detection system prototype.

b) System mounting on 1.5 m high support covered by a solar panel. The system is powered by a 30WATT solar panel, mounted on a 12V-9AH battery. The two elements are interconnected by a charge controller.

c) System deployed in real environment.

a- Monitoring system Prototype

b- A prototype on the support powered by solar panel

c- Cows passing in the front of the monitoring system

Fig. 6. From the beginning to the end – Monitoring system in one view

Fig. 7 shows what our 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, 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.

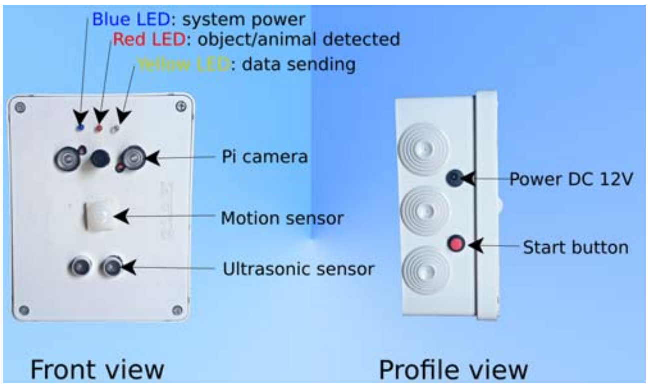

Fig. 7. The monitoring system box

IV. Experimental results and validation

We experimentally evaluated and validated our prototype, by installing our system along a field in order to know the accuracy of the intrusion detection. In a real environment, we simulated the passage of cows in a real environment. We passed a herd of ten cows in front of our device a hundred times and noted each time we noticed how accurately the device reported the intrusion.

For the simulation, we chose three significant hours of the day to make measurements over three days: Morning on day 1, noon on day 2, and evening on day 3. Fig. 8 shows the simulation results for three different time periods selected. Fig. 9 summarizes the measurements taken statistically.

Fig. 8 shows that our system gives better results in the morning and noon, while Fig. 9 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.

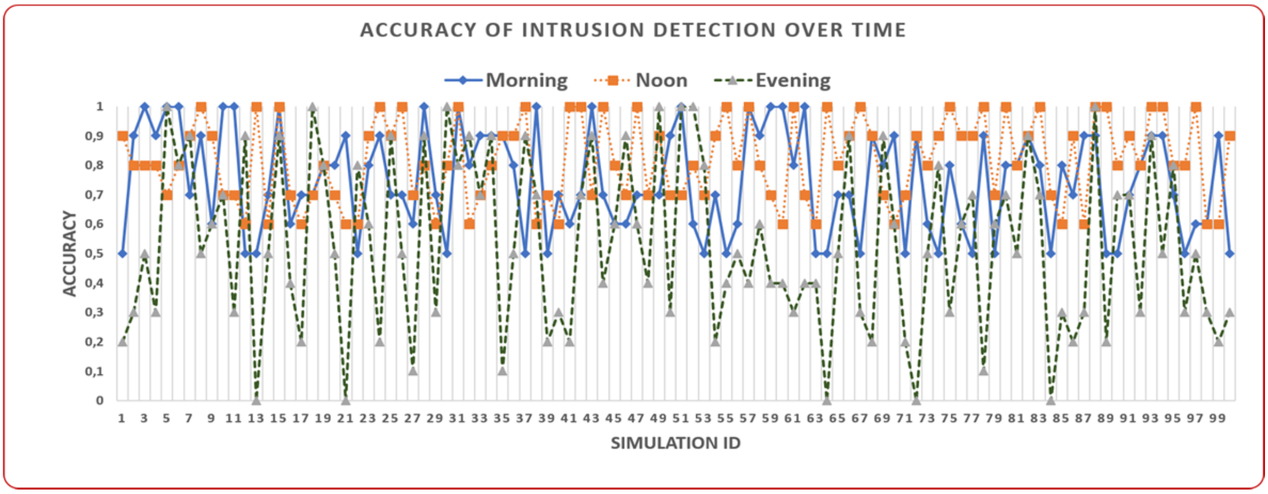

Fig. 8. Accuracy of intrusion detection over time

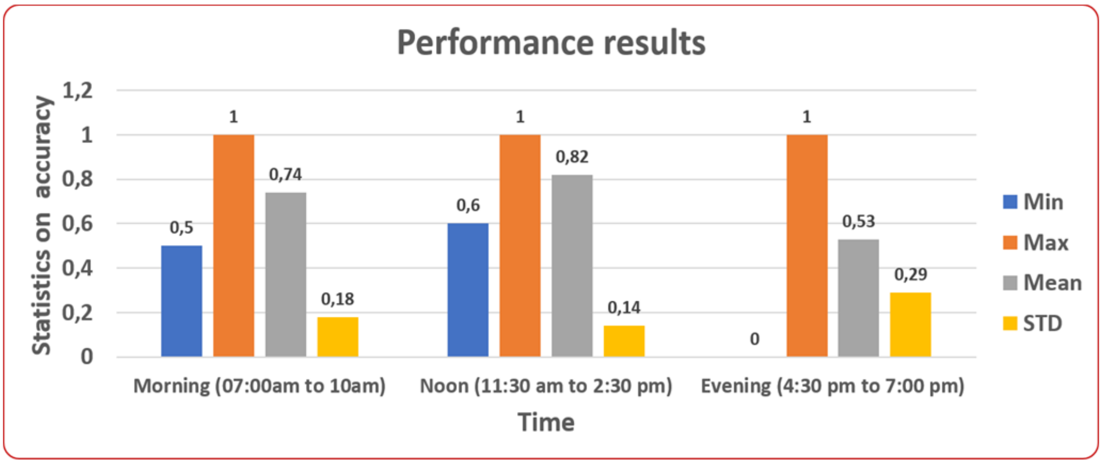

Fig. 9. Statistics on accuracy measured by our system

In conclusion, note 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 cameras.

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[25]. Secondly, some publications analyzed the effects of constantly greater cattle overflows on total biomass productivity[26]. Finally, some other studies discussed the importance of a good agricultural practice in contrast to forests establishment as a way to increase both rangelands' productivity and the appreciation of rangeland use and management. From the outputs of these studies, we are able to determine the importance of transhumance and the pipelines of transhumance in Benin and some countries who have the same challenges[19].

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 order to take better decisions in the management of grazed ecosystems[27], [28]. Other solutions are based on monitoring system[15] 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[29], [30]. Solution proposed in [16] 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[31]. Sensor technologies are also used to monitor animal health and ensure animal well-being in the fast changing conditions[32]. In addition, authors of [33] 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 [30] 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 [34] 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 track 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, we reject the idea of automatically sending alerts to the farmer upon intrusion detection 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. Our technique was based on an excellent review doing by [7] about machine learning techniques for intrusion detection. Our 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, we will improve our prototype by putting the ultrasonic sensor on a servo motor 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 for the detection of the intruding object.

VII. Acknowledgment

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