Smart Border Surveillance System using Wireless Sensor Network and Computer Vision

Neha Bhadwal
Lovely Professional University, Phagwara
Punjab, India
bhadwalneha21@gmail.com

Vishu Madaan
Lovely Professional University, Phagwara
Punjab, India
vishumadaan123@gmail.com

Prateek Agrawal
Lovely Professional University, Phagwara
Punjab, India
prateek061186@gmail.com

Awadesh Shukla
Lovely Professional University, Phagwara
Punjab, India
tech.shukla@gmail.com

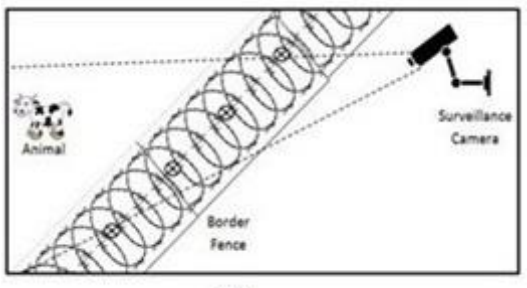
Anuj Kakran
United College of Engineering and Research, Prayag Raj
Uttar Pradesh, India
kakrananuj1@gmail.com

***Abstract*--Border surveillance is the most important task in the field of national defense and security. To maintain peace and to ensure safety of a country's people, the borders need to be kept under 24/7 monitoring. Especially, under current circumstances, when activities like terrorist infiltrations and illegal movement of both living as well as non-living beings have become common, it becomes of utmost importance to strictly protect the border areas against such activities. To curb such happenings on the border areas, the least that can be done is to provide constant monitoring. In current scenario, this monitoring takes place manually by the border security forces which are responsible for continuously keeping an eye on the borders. It takes a lot of manpower and assets as the borders are stretched across hundreds of miles and have extreme terrain as well as climatic conditions. Hence, the need of the hour is to design an automated border surveillance system which can perform the surveillance task without requiring any human assistance. It can eliminate the need of deploying humans at hostile conditions at all the times. Moreover, in case if something suspicious is detected by the system, it must be able to take the necessary decisions and hence actions along with issuing alert messages for the human controllers. The central control rooms can be set up at a distance from the border area. Once the human controller is aware of the intrusion, it is upon him to decide the next course of action. Such systems if deployed successfully, can not only save resources but also can reduce the risk to human life significantly. However, complete automation of border surveillance is not yet attainable due to safety constraints but surely such systems can provide assistance and can work in collaboration with the defense forces and thus, making the country's borders secure.**

Keywords--Border security, Border surveillance, Intrusion detection system, Intelligent Defense System, Video surveillance, Infrared sensors

I. INTRODUCTION

Border security has been a major concern since a long time, not only for India but for the world as a whole. It refers to protecting the country's boundaries against illegal movement of goods, drugs, weapons and humans. It is a key factor in maintaining trade and travelling lawfully as well as providing protection against terrorism, across the globe. This helps in maintaining a country's economy, safety and freedom. Border surveillance systems are the mechanisms employed to monitor the happenings taking place around the borders and identify if some suspicious activities are going on. If anything, which arises suspicion occurs then, execution of a set of pre-determined tasks takes place. It may involve alerting the concerned authorities or invoking some other systems in response such as, a warning or combat system. Intruder Detection Systems (IDS) are integral part of the border surveillance. They are designed to operate in hostile environment to monitor, detect and track the intruders (moving targets), around the clock. For this particular research, the intruders may involve terrorists, drug peddlers, human traffickers and persons for espionage. As it is a really tiring task for humans to watch and monitor the 24x7 live video streaming with full attention, an IDS that can generate automatic alerts can prove to be of great use. The proposed system called Smart Border surveillance system is a border intrusion detection technique that uses wireless sensor network (WSN) technology. The video surveillance camera is mounted on the top of an arrangement of motors and a microcontroller. The microcontroller takes signal from infrared sensors which are installed on the border fence for intrusion detection. The signal is responsible for the positioning of surveillance camera in the direction where intruder has been detected. Depending upon the position of the intruder with respect to the sensors installed on the border fence, three scenarios can take place. Their description is as follows.



(a)

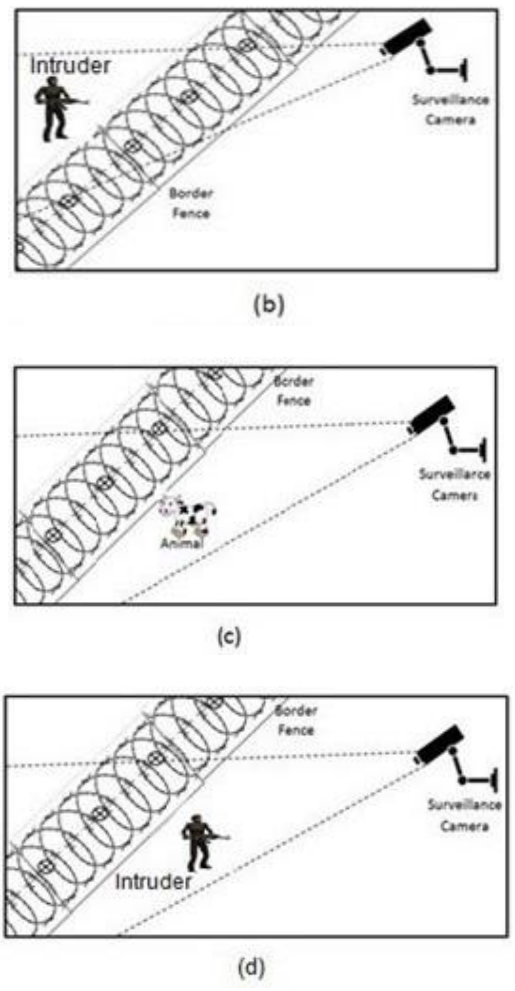


Fig. 1. Four scenarios for the intruder's position relative to the border fence; (a) Potential intruder (specific animal) not yet crossed the border fence, (b) Potential intruder (human being with weapon) about to cross the border fence, (c) Intruder (animal) has crossed the border fence, (d) Intruder (human being) has crossed the border fence

Scenario 1: The potential intruder (an animal) is on the other side of the border and cannot be detected by the PIR sensors but is in the camera's field of view. This is depicted in figure 1(a). Note that potential intruder here could be a human or an animal.

Scenario 2: The potential intruder (Human being with weapon) is close to the border fence and in the proximity of the PIR sensors as well as in the camera's field of view. This can be shown by figure 1(b).

Scenario 3: The intruder (an animal) has crossed the border fence and is still in the proximity of PIR sensors as well as in the camera's field of view as can be seen in figure 1(c).

Scenario 4: The intruder (Human being) has crossed the border fence and is still in the proximity of PIR sensors as well as in the camera's field of view as can be seen in figure 1(d).

The camera position can be shifted both horizontally as well as vertically when the microcontroller gives commands to the motors. The two motors work as actuators and are responsible for the horizontal movement, vertical movement and the accurate positioning of the surveillance camera. The camera is positioned in such a manner so that it can cover the intruder movement and actions in its field of view. It is also important to identify whether it is a human or an animal that causes the movement. Once it is known that it is a human intruder, alert messages are issued to the central control room. These alerts make the controller have a closer look at the video content and decide if the activity warrants a response or not. It then becomes the responsibility of the controller to decide on what should be the appropriate response for the given scenario. He/ She can transfer the information further to the higher authorities and activate some kind of automatic systems to deal with the intruder. To be able to detect the movement at the area under surveillance, pyroelectric infrared (PIR) sensors are used which are low-cost, low power-consuming and can also be used in dark conditions. Step motors are also low on cost and high on reliability. They are interfaced with Raspberry Pi to control their forward and backward motion plus the accurate positioning.

The system is designed in Python as it is easy to write, understand and flexible to handle large tasks. The information gathered at the control room system is stored locally and can further be shared wirelessly between multiple heterogeneous devices via a common Wi-Fi network. The devices could be PCs, laptops or any other mobile devices. The proposed system can prove to be beneficial for assisting the security forces for protecting the border areas. It can provide continuous surveillance in those parts where human deployment is a challenge due to extreme hostile conditions. It is an effort in the direction to automate the border surveillance system.

II. LITERATURE REVIEW

Arjun et al. [1] present a survey of wireless sensor networks for Border Surveillance and Intruder Detection. The aim is to devise a multi-sensing system which is developed by combining different techniques of surveillance and intruder detection, for varying border scenarios such as, flat surface movement or water-body movement. Different sensors for human intruder detection such as, geophone, hydrophone, infrared and surveillance cameras are discussed. Palagati et al. [2] propose a model to study videos captured by surveillance cameras and extract features from it after converting video to shots. Basic features are extracted by employing an object tracking method based on ROI. At last, semantic content extraction results in recognizing the intruder without any false matching. Bhaskar [3] presents a framework which combines the human target detection, tracking and face-recognition based human identification for surveillance purposes. Background subtraction is employed for the detection of moving targets. Face recognition involves detecting the face of the target. If face detection fails, then target tracking continues

without augmenting targets identity.

Jisha et al. [4] propose a system for intruder detection which employs an object detection technique using Wireless sensor networks. PIR (Passive infrared) sensors are used which are further connected to MICAz sensor node. The proposed system is expected to detect and track the intruder and report its speed and direction of movement to a central base station for further processing. Sagar et al. [5] apply image processing techniques to implement a robotic smart home security system. The system is able to detect faces, sign-boards and provide notifications to the user if an intruder is detected. Raspberry pi is used to control the motion of the robot via Arduino and all the sensors are connected to it wirelessly. Singh and Khushwaha [6] propose a mechanism for smart border surveillance and automatic combat. It makes use of features extracted from optical flow information of the scene. Once the automatic detection of intruder takes place, suitable action is taken depending upon the relative position of the intruder with respect to the border fence. If the intruder happens to be behind the fence, mere tracking is followed. If the intruder is above the fence and trying to cross it, an alarm is raised. Auto-firing can be activated when the intruder has actually crossed the fence.

Sun et al. [7] introduce hybrid wireless sensor network architecture for border patrol system, called BorderSense. It constitutes of three layers. The first layer consists of underground and ground sensors. The second layer has multimedia sensors which carry the visual information. The third layer consists of unmanned aerial vehicle which enhances the coverage and flexibility. Furthermore, deployment of the system components is discussed. Jin et al. [8] present a method for detecting and classifying a target by using seismic and PIR sensors. The target can be classified into one of the three classes of vehicle, animal or human. A wavelet method called symbolic dynamic filtering (SDF) is used for feature extraction from the sensor signals. Zhang and Liang [9] propose a new method to detect moving human body based on the technique of background subtraction. Initially, a background image is obtained. To extract the moving regions from the current frame, difference between the current frame and the background image is obtained. At last, the shape features of the extracted regions are used to determine if the moving region is a human or not. Ye et al. [10] present a method to detect moving target via using the technique of background subtraction and shadow removal. The method is applied for RGB color space. Metrically trimmed mean and mean absolute deviation are the estimators used for background subtraction. The Chromacity difference and brightness difference are the estimators for shadow removal.

TABLE I. A COMPARATIVE ANALYSIS OF PROPOSED BORDER SURVEILLANCE SYSTEMS

S. no.	*Authors & Year*	*Name*	*Key Features*	*Limitations*
1	Palagati et al. (2014)	Intruder Detection by Extracting Semantic Content from Surveillance Videos	• avoids false matching of the intruder	• accuracy scales with huge amount of training data and number of concepts • can be generalized to many data domains • effective use of unstructured media and structured metadata
2	Bhaskar (2012)	Integrated Human Target Detection, Identification and Tracking for Surveillance Applications	• novel face composition technique that combines several representations into a single frontal representation • can further be used for face recognition	• the computational demand of the face composition process • need for appropriate contrast enhancement methods prior to face recognition • the inherent complications in capturing high quality surveillance videos
3	Jisha et al. (2010)	Intruder tracking using WSN	• the moving path, average speed and direction of the human intruder are detected • integration of PIR sensor and MICAz.	• More than one person if coming in a sensor range cannot be detected by the application or can be interpreted as a single intruder.
4	Sagar et al. (2017)	Smart Home Intruder Detection System	• can be used in real-time monitoring and data transmission from remote location • controllable from any android phone. • flexible to move in any direction and portable	• requires internet connection for data transmission and hence if network down, the system cannot transmit or receive any data • Power consumption is more.
5	Sun et al. (2011)	BorderSense: Border patrol through advanced wireless sensor networks	• accurate detection as well as large detection range • the ground sensors provide additional information • the heterogeneous sensors cooperatively detect the intrusion and	• need of adaptive detection technique for ground/underground sensors • the coordination between multiple adjacent • camera sensors is required to detect and track nonline-of-sight intruders

			report the results to a remote administrator	
6	Essendorfer et al. (2009)	An Integrated System for Border Surveillance	• data sharing among multiple sensors • enhanced situation awareness • surveillance of large areas with reduced manpower	• access to the common database needs to be restricted • huge amount of information produced by large sensor networks

Mishra et al. [11] design and test a system to detect border intrusion by deploying wireless sensor network and artificial neural network (ANN). The distributed sensor motes send the information to the central base station which contains an ANN to discover patterns and train itself using Backpropagation algorithm. Experimental results are shown for various cases depending upon the change in environmental conditions. Alkhathami et al. [12] investigate the performance of border surveillance simulation using WSN arrays. They provide experimental results for the OPNET (Optimized Network Engineering Tools) while using wireless sensor ZigBee nodes. Mesh and tree cluster are the two topologies for which experiment is performed and results are compared. Shivani and Kaur [13] propose a method in which CCTV cameras can be utilized for border intruder detection. Multiple events can be detected from a surveillance video using ROI (regions of interest) of the scene. A brief review of the existing work on the border security surveillance is reviewed.

Felemban [14] present a survey of experiments and the research work that has been done in the two fields of border surveillance and intruder detection. The main focus is on the use of WSN technology by placing a large number of small and low-cost nodes at the border areas to provide geographical and time-specific information. The challenges and technical requirements for such systems are discussed. Essendorfer et al. [15] describe the architecture of a project named SOBCAH (Surveillance of Borders, Coastlines and Harbors) which integrates the information gathered from heterogeneous sensors. All the information is first converted to a common standard data format. SOBCAH Shared Database (SSD) holds the data from all the sensors. Benet et al. [16] describe an infrared (IR) sensor which can measure the distances up to 1m and it is based on the intensity of light back scattered from the object. Reflection coefficient is the only parameter used by the presented model. Finally, the experimental results are shown. Ferdoush and Li [17] describe their work which uses Raspberry Pi and Arduino for building a wireless sensor network. Both are open hardware platforms. The system architecture along with hardware and software requirements is discussed in detail. At last, some sample experimentations and their results are shown. The system is told to be cost effective as well as scalable.

Kulkari et al. [18] propose a model that allows file sharing between mobile devices inside a Wi-Fi network. They present the architecture and the implementation of the system. Alkhathami et al. [19] describe a system for intruder detection which is able to detect whether intruder is a human, an animal or an object. The method considered most effective called Dynamic Mechanical Analysis (DMA) is discussed. WSNs are discussed along with barrier and sensor coverage. Agrawal et al. [20] propose a system for monitoring and inspection that is capable to detect moving objects even when the images captured are of low resolution. Table 1 gives an analysis of some proposed border surveillance systems along with their prominent features and limitations.

III. PROPOSED METHODOLOGY

The proposed system is a smart border surveillance system which can prove to be helpful for our border security forces. It is able to provide round the clock video surveillance at the places where human deployment is not possible due to geographical, climatic or some other reasons. Multiple pyro-electric infrared sensors (PIR) are disguisedly installed on the border fencing which monitor the border area for any intrusion.

Multiple responses are possible depending upon the position of the intruder with respect to the border fence. As we have shown three different scenarios in figure 1, each of them requires a different response. For the first scenario, when the potential intruder is on the other side of the border fence and not in the sensor proximity, the camera just keeps observing without moving itself and no other action is taken. For the second scenario, when the potential intruder has entered the sensor proximity but not yet has crossed the border, sensors generate signals which decide the movement and positioning of the surveillance camera such that the potential intruder movement can be recorded. The third and the most critical scenario is when the intruder has finally crossed the border. The video cameras are installed at a distance to continuously keep an eye on the border area and if any movement is detected in the area under supervision by the sensors, the camera positions itself according to the signals sent by the sensors and it is checked whether it is a human or animal. In case, it is found to be a human the camera starts taking snapshots of the live video. An alert message along with the images is sent to the controller. The controller first issues an alert via a sound system to warn the intruder and asking him to surrender. If after a couple of warnings, the intruder is not willing to surrender, an auto-combat system is activated, which will shoot the intruder. In addition, the controller can send the intrusion alert to the closest military base such that they can get ample time to prepare themselves for taking the required actions. Furthermore, the generated images (snapshots) are transferred wirelessly from the remote system

to the main system where they can be viewed and analyzed for further inquiry.

Figure 2 shows how PIR sensors are installed on the border fencing. They are placed apart a distance depending upon their proximity value. For instance, as shown in the figure, if the sensor proximity is 10 meters then every two sensors are kept 15-18 meters apart. The sensors are placed on the fence in such a way that the intruder is not able to identify and destroy them. PIR sensors are chosen over ultrasonic sensors as their response time is shorter with higher resolution. Ultrasonic rays are affected by environmental factors such as humidity, ambient noise and temperature. [21]

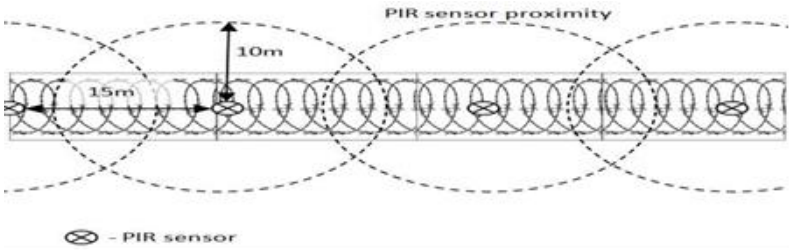


Fig. 2. Hidden PIR sensors installed on the border fence

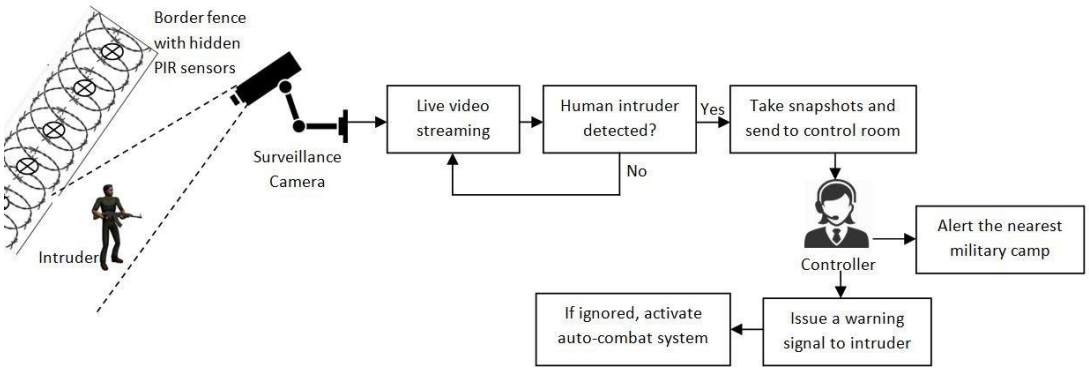


Fig. 3. Smart Border surveillance system architecture

The smart border surveillance system working can be described into 6 steps. Figure 3 illustrates the modules involved in the proposed system. A description of each step is as follows.

Step 1: Here, the most important consideration is the communication between the camera and the hardware. The hardware consists of two step motors controlled using Raspberry Pi. Figure 4 shows the surveillance camera and the hardware. The hardware consists of step motors and Raspberry Pi board interface. A step motor can be accurately positioned and can continuously rotate along with moving forward and backward. Two motors are used to cover the horizontal as well as the vertical field of view. For a stepper motor, the number of steps per revolution and the stride (step) angle are related as per the given equation.

Steps per Revolution = 360^0 / Step Angle

Hence, for a 200-step motor, the angle covered per step is 1.8^0.

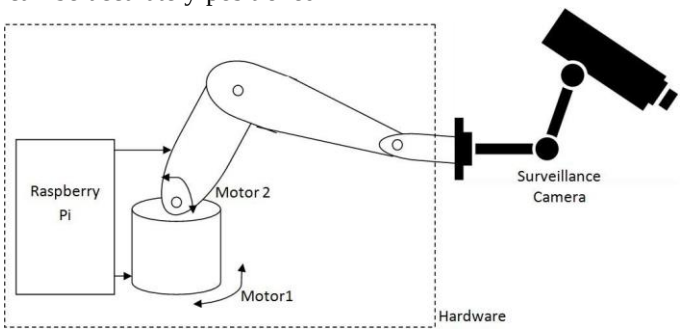


Fig. 4. Surveillance camera and its positioning hardware

Step 2: The movement of the stepper motors and hence the camera depends upon the sensor information received by Raspberry Pi. These PIR sensors are installed at the border fencing such that they are unrecognizable by intruder. Each of them is separated by a distance depending upon their sensory range. The moment a sensor detects any intrusion, it notifies Raspberry Pi, which in turn rotates and positions the two motors according to the sensor information, such that the camera can capture the intruder movement.

Step 3: Once the camera is accurately positioned, it tries to detect any moving object in its field of view. Then, the system tries to identify whether the intruder is a human or an animal. For faster and more accurate intruder detection, TensorFlow Object detection API is used, which is an open source framework and is built on top of TensorFlow [22]. It makes creating, training and deploying Object detection models. Furthermore, it works on the system which does not have high computational capability. If a human intruder is detected, an enclosing box starts displaying around the intruder also showing the accuracy of prediction as shown in figure 5.

Step 4: The camera then, starts taking snapshots from the live video stream. This camera is connected to a central control room to where an alert signal is sent along with the snapshots of the possible intrusion as shown in figure 5.

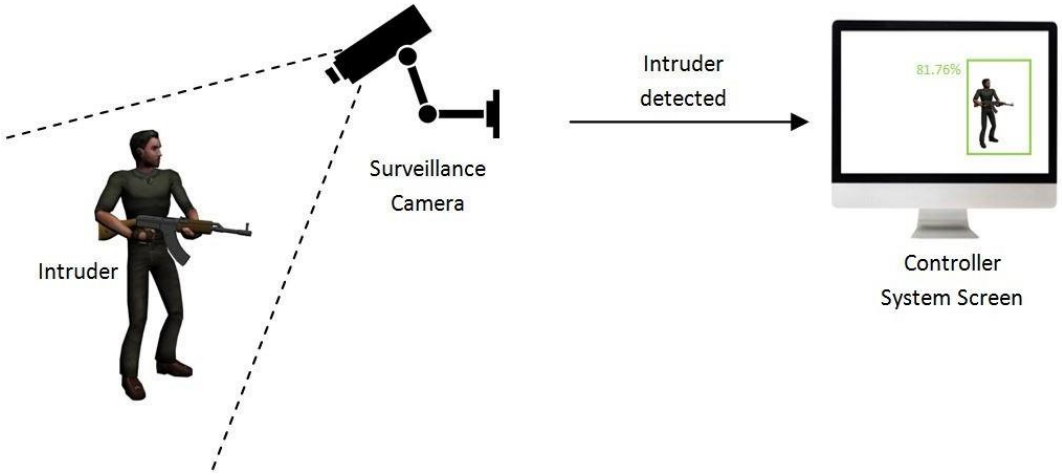


Fig. 5. Intruder detection alert message at control room

Step 5: The controller after taking note of the whole situation will decide whether the activity demands a response or not. Firstly, the controller will issue a warning via deployed sound systems allowing the intruder to surrender or move back. The warning can be repeated a couple of times before taking further extreme actions. If the warning is ignored then, the controller will activate the auto-combat system which consists of multiple automatic guns placed around the area. This system will be used to take down the intruder if he tries to escape ignoring the warning. Also, the controller needs to alert the nearby military base camp(s) about the intrusion so that they can take quick steps to tackle the situation. The controller response is displayed in figure 6.

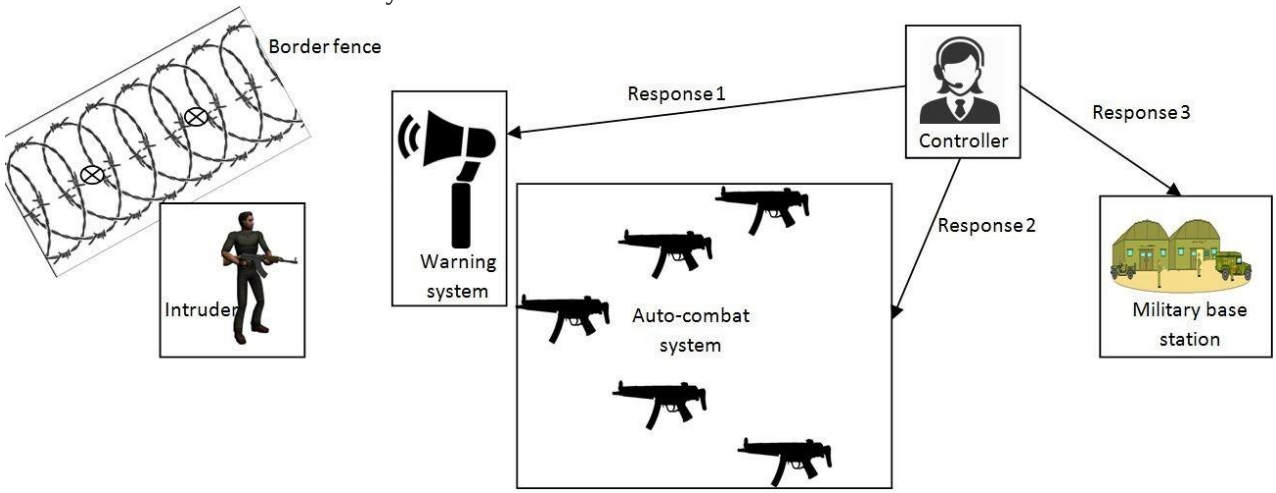


Fig. 6. Controller response after intruder detection

Step 6: The images stored in the remote-control room can be shared via file sharing between multiple systems using the method of IP sharing. Once the captured images are stored on the master system, they can be accessed wirelessly by any other system, be it a PC or any other device that can be connected via Wi-Fi. Each device will receive a list of folders or files which they can access remotely. The same is depicted in figure 7.

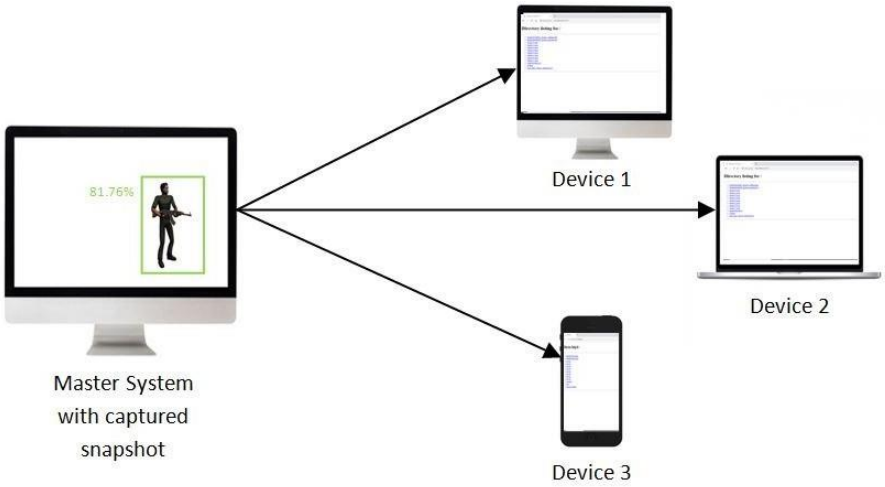


Fig. 7. File sharing between master system and other devices

IV. CONCLUSION AND FUTURE WORK

The proposed system could be a great help in enhancing the security of our border regions especially, the areas facing extreme climatic or terrain conditions where human deployment is a major peril. Although the system may not be able to provide advanced border security but can surely provide solutions to border security surveillance on a small scale. As the system detects intruder, an alert message is generated along with the transfer of the snapshot of the intruder to the main system. Then, the appropriate steps are taken to eliminate the threat as the location of generation of the signal is also available.

The smart border surveillance system can not only assist the defense forces to enhance the security of border areas but also can help save a considerable amount of labor and assets. It involves the use of advanced technology keeping in mind the cost effectiveness of the constituent modules of the system with a goal that any infiltration recognized at the border can instantly be transmitted and results in a necessary move. Appropriate utilization of the system may help our border security forces to control those unwanted and suspicious exercises in a better and accurate way.

In future, we can design this system for use on a larger scale. As with passing time the technology is constantly improving, the system can be equipped with more advanced and sophisticated hardware. The proximity sensors, object detection mechanism and response mechanism, if made using state-of-the-art technology, can make the working of the proposed system even more accurate and time-saving. As of now, this research will further be extended to design and develop the surveillance system based on the above proposed architecture. Moreover, the experiments will be conducted, and the results recorded for further retrieval.

REFERENCES

[1] Arjun, D., Indukala, P. K. & Menon, K. A. U. "Border surveillance and intruder detection using wireless sensor networks: A brief survey," International Conference on Communication and Signal Processing (ICCSP), pp. 1125-1130, Chennai, 2017.

[2] Harish, Palagati, Subhashini, R. & Priya, K. "Intruder detection by extracting semantic content from surveillance videos," In Green Computing Communication and Electrical Engineering (ICGCCEE), 2014 International Conference on, pp. 1-5. IEEE, 2014.

[3] Bhaskar, Harish. "Integrated human target detection, identification and tracking for surveillance applications," 6th IEEE International Conference Intelligent Systems, pp. 467-475, Sofia, 2012.

[4] Jisha, R. C., Ramesh, Maneesha V. & Lekshmi, G. S. "Intruder tracking using wireless sensor network," In Computational Intelligence and Computing Research (ICCIC), 2010 IEEE International Conference on, pp. 1-5. IEEE, 2010.

[5] Sagar, R N, Sharmila, S P, Suma, B V. "Smart Home Intruder Detection System," International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), 6(4), pp. 2278 – 1323, 2017.

[6] Singh, Dushyant & Kushwaha, Dharmender. "Automatic Intruder Combat System: A way to Smart Border Surveillance", Defence Science Journal, 67(1), pp. 50, 2016.

[7] Sun, Zhi, Wang, Pu, Vuran, Mehmet C., Al-Rodhaan, Mznah A., Al-Dhelaan, Abdullah M. & Akyildiz, Ian F. "BorderSense: Border patrol through advanced wireless sensor networks," Ad Hoc Networks 9, 3, pp. 468-477, 2011.

[8] Jin, Xin, Sarkar, Soumalya, Ray, Asok, Gupta, Shalabh & Damarla, Thyagaraju. "Target detection and classification using seismic and PIR sensors," IEEE Sensors Journal 12, 6, pp. 1709-1718, IEEE, 2012.

[9] Zhang, Lijing & Liang, Yingli. "Motion human detection based on background subtraction," 2010 Second International Workshop on Education Technology and Computer Science, pp. 284-287, 2010.

[10] Ye, Jianhua, Tao Gao, and Jun, Zhang. "Moving object detection with

background subtraction and shadow removal," 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery, pp. 1859-1863, 2012.

[11] Mishra A., Sudan K. and Soliman H., "Detecting border intrusion using wireless sensor network and artificial neural network," 2010 6th IEEE International Conference on Distributed Computing in Sensor Systems Workshops (DCOSSW), pp. 1-6. IEEE, 2010.

[12] Alazzawi, Lubna, Alkhathami, Mosad and Elkateeb, Ali. "Border Surveillance and Intrusion Detection Using Wireless Sensor Networks," International Journal of Advances in Engineering & Technology, 8, pp. 17-29, 2015.

[13] Shivani & Kaur, Lakhwinder. "A Brief Review: Border Intruder Detection System Based On Computer Vision," Imperial Journal of Interdisciplinary Research, 2(7), pp. 2454-1362, 2016.

[14] Felemban, E. "Advanced Border Intrusion Detection and Surveillance Using Wireless Sensor Network Technology," International Journal of Communications, Network and System Sciences, 6(5), pp. 251-259, 2013.

[15] Essendorfer, Barbara, Monari, Eduardo & Wanning, Heiko. (2009). "An Integrated System for Border Surveillance," in Fourth International Conference on Systems, pp. 96, 2009.

[16] Benet G., Blanes F., Simó, J.E. and Pérez, P. "Using infrared sensors for distance measurement in mobile robots," Robotics and Autonomous Systems, 40(4), pp 255-266, 2002.

[17] Ferdoush, Sheikh and Li, Xinrong. "Wireless Sensor Network System Design Using Raspberry Pi and Arduino for Environmental Monitoring Applications," Procedia Computer Science, 34, pp. 103–110, 2014.

[18] Kulkari, Shubham, Kumar, Sanath, N, Shivaraju and Shivaraj. “File sharing between mobile devices”, International Journal on Recent and Innovation Trends in Computing and Communication, 4(5), 2016.

[19] Alkhathami, Mosad, Alazzawi, Lubna and Elkateeb, Ali. "Model and Techniques Analysis of Border Intrusion Detection Systems,” Global Journal of Engineering Science and Researches, 15, pp. 33-44, 2015.

[20] Agrawal, Prateek, Kaur, Ranjit, Madaan, Vishu, Babu, M. and Sethi, D., "Moving Object Detection And Recognition Using Optical Flow And Eigen Face Using Low Resolution Video", *Recent Patents on Computer Science*, 11(2), pp 1-10, 2018.

[21] Sasidharan, Adarsh, Mohamed Kaleemuddin, S, Bose, Dinesh and I Ramachandran, K. "Performance comparison of Infrared and Ultrasonic sensors for obstacles of different materials in vehicle/ robot navigation applications". IOP Conference Series: Materials Science and Engineering, 149, pp. 02141, 2016.

[22] Huang J, Rathod V, Sun C, Zhu M, Korattikara A, Fathi A, Fischer I, Wojna Z, Song Y, Guadarrama S, Murphy K. "Speed/accuracy trade-offs for modern convolutional object detectors", Computer Vision and Pattern Recognition, 2017.