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# Border Security System for Intrusion Detection Using Robotic System, Thermal Imaging Camera, Computer Vision and Machine Learning

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***Abstract*- Border Security is a very crucial issue for every country, nowadays handling terrorisom and security breach is the biggest challenge for every country, terrorists generally use multiple on and off terrain ways to breach the border lines. As per the BBC NEWS report every year 70+ intrusions happen in border areas, Also as per the report of The New Indian Express 111 terrorist infiltrates j&k border since 2019. These intrusions are very dangerous for the country in terms of GDP growth. The novelty of our research is we are developing a system which has capability of detection and identification for human presenase, with the same we are trying to achieve detection and recognition for weapons if the same person is carrying. This system can be used at multiple places such as Government Private Sectors, Research facilities, National and International Banks, Military Facilities. Some Secrete Private Factories. The Design aspect of this system we came up with a novel idea where we are using a Thermal Imaging Camera and a Normal CCTV camera, we are processing both the images at the same time towards finding the Presence of Human living beings. As per the study Times of India border line breach happens in the form of animals means Territories wear such costumes.**

***Keywords*- Border Security System, Thermal Vision,Computer Vision, Intrusion Alert System, Robotics, Image Processing.**

## I. INTRODUCTION

Maintaining security of private, public, restricted places are very difficult, with this pandemic as organisations can't be able to put manpower on working hours. As a team we have come up with a project design which deals with security issues for maintaining security and safety. Nowadays for security we generally use CCTV (Closed Circuit Television)[1] as a solution but to a great extent it is not viable because CCTV needs a Steady person who needs to continuously watch the TV Screen.

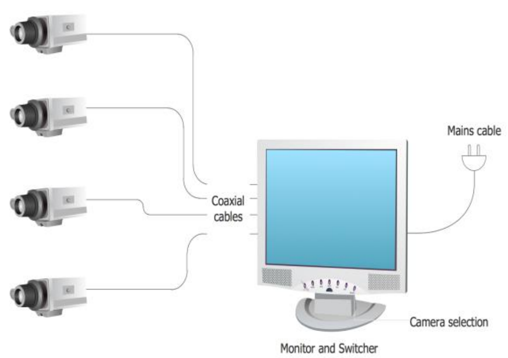


Fig 1. CCTV Security System.

Currently we are leaving the age of Artificial Intelligence and Advanced Robotics so as a team we thought that we can build a system which has capability of Automatic detection and Recognition for Threads.We also put more features as a key part of our project.

Border Security is not only crucial nowadays but also it ensures security and safety of the country. One can ensure peripheral security by detecting intrusion and this can be achieved by designing a Robotic system which will detect trespassers using Thermal Imaging camera, this system will be integrated by Machine Learning and Computer Vision algorithms.

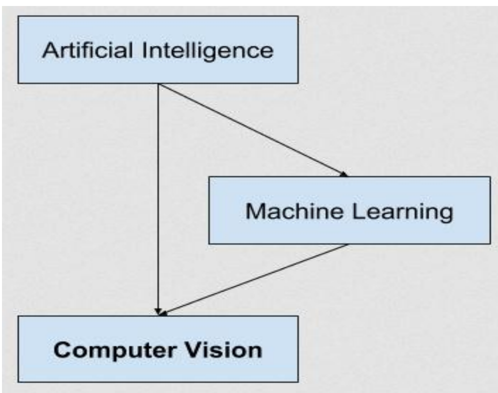


Fig 2. Relationship between AI, ML and Computer Vision.

This system has copious applications, it can be used in personal homes or garages, international banks, various types of government properties wherein encroachment is prohibited and also in military camps and bases thus, playing a vital role in safety and allowing us to take the right action at the right time. Since it is not only linked in personal security but it will also help to reduce crimes which makes it a very dominating field.

## II. LITERATURE SURVEY

The authors of this paper[1] presented research on intrusion detection during winter conditions.They created a dataset for the same which .The main objective was fulfilled using the YOLO algorithm along with some

The authors of this paper[2] presented a deep learning approach to detect the humans in the real time during the winter season.The real time video, where the people walked, ran, after arduous training achieved an average precision of 90%.The dataset used was FLIR ThermaCAM P10 thermal camera dataset.The AP increased significantly when the Yolo Model was trained on their thermal dataset. The intrusions ranged from 30m to 215m from the camera lens.More than 3000 images were used for training obtaining an AP of 23% with bYolo model which increased significantly by 74%with tYOLO model.

The paper[3] consists of Control room mechanism and Robot module mechanism, the control room mechanism is responsible for the overall control and communication with system whereas the robot module mechanism consists of sensors like Proximity sensor which emit IR rays to detect any intrusion, secondarily it used LDR sensor for detecting fire flames and lastly it has one metal detector which relies on eddy currents which create magnetic field and takes the signal to receiver which results in sound to aware the user. Since it relies on sensors which are not very accurate it may miss intrusions furthermore it doesn't survey an area angularly it only scans linear area which limits the area of search.

The fire sensor uses LDR which is not accurate to measure fires as it can give false alarms it detects some other luminant object such as torches or high beams which are majorly used in such areas. Lastly the metal detectors are relying on eddy currents generating magnetic fields that are only accurate to very small distances magnetic intensity gets weaker as the distance increases so not useful for long range detections. But I do concede that the researchers have contributed to the surveillance systems and this technology can certainly be used in small areas or home backyards wherein intruder detection range is small.

The paper[4] uses Raspberry Pi technology for surveillance. It uses PIR sensors to detect objects around its environment which actuates the cameras to record video of the intruder which in turn stores it in a web server. This entire project uses IR, PIR and cameras to detect and record the intrusion and this whole process is controlled via the Raspberry Pi controller. The loopholes which we can see in this project are there is no live recording of the environment since it only records the instance of intrusion the user will not know from where the breach leak happened. Secondly the system doesn't ensure no-intrusion in areas covering the wider environment since the area being governed is less. Lastly, there is no alarm which can alert the security for the same.

## III. WORKING PRINCIPLE

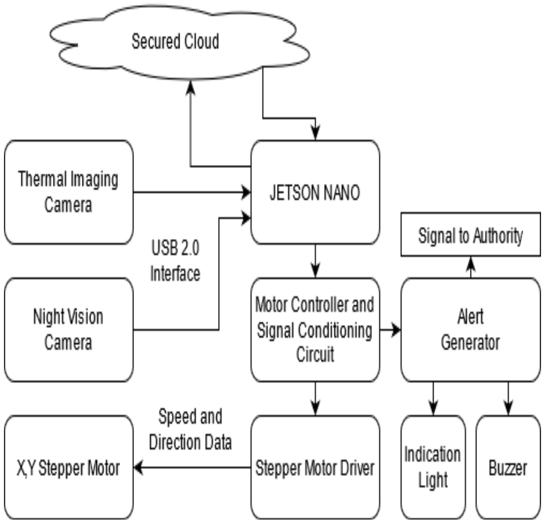

Fig 3. Block Diagram for Electronic System of Border Security System.

This system is based on Jetson Nano as a main processing unit which controls all the operations in the system. The system consists of two cameras and a robotic module which controls all the axial movements. When the HD camera and Thermal imaging captures live footage and sends to jetson nano, it operates on linux system and programming done in python language also this system uses opencv, numpy scipy, matplotlib and keras engin along with tensorflow for detection and recognition for trained objects such as suspicious activity, unknown person, weapons using normal, night vision and thermal image data.

The movement capture system allows it to track the suspicious objects in front of the camera for the same; it uses robotic module control circuitry which drives stepper motors along with a PID control algorithm to move smoothly with speed, acceleration and angle control data provided by motor controller and signal conditioning circuit.

The object recogniser algorithm sends all the data to the cloud using service API key which is generated using Microsoft Azure cloud service. Which stores all the data and users can assess it over the time period. If any

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suspicious activity is detected' system send's alert to control unit or authority using alert generator, which also generates alert using high intensity indication light and buzzer.

## III. TECHNOLOGY

As per the Fig C shows design and development of this system happens in 3 phases.

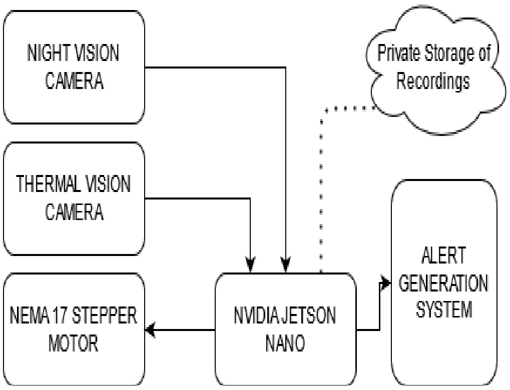


Fig 4. General Block Diagram for Border Security system for Intrusion Detection.

As the data represented in block diagram (Fig: C) The First part involves the designing of a Robotic module which comprises a 2 Axis Rotation similar to the conventional gimbal.

Second part is the Electronic System which includes a stepper motor controller to control NEMA 17 servo motors in X and Y Direction respectively. NVIDIA Jetson Nano Board serves the purpose of controlling the stepper motors and handling the Machine learning and Image Processing part. NVIDIA Jetson nano works on the linux operating system, so it is compatible with the python language. For developers, it is easy to design and test the application or software during the development phase.

Third part includes Advanced Computing which includes: Image processing, Machine Learning and Deep Learning based on python programming.

### 1. Robotic Module:

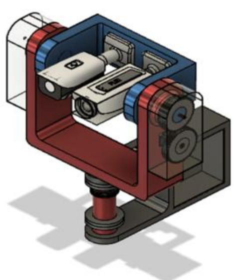

Fig 5. Isometric View of Border Security System.

The Robotic Module is designed using Fusion 360 software, while designing, some technical specifications taken into consideration such material we used is 4mm Aluminium sheet, the body design can be manufactured using laser cutting and folding machines. In the same design we have used 4mm allen nuts and bolts to fix attachment and parts.

In the same module we have specifically designed sprockets for stepper motor attachment and each joint is designed by maintaining Center of gravity to reduce the motor stress in terms of torque and current requirement. The Robotic Module design is inspired by conventional 2 Axis Gimbal. Which has 120 degree rotation in horizontal Axis (x direction) this axis rests on 110 degree of angle and 170 degree of rotation in verticalAxis (y direction) this axis rests on 90 degree of angle.

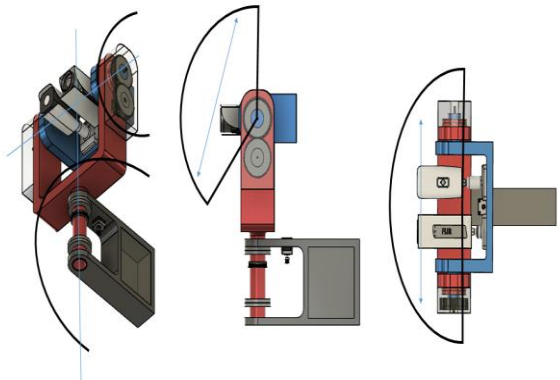

Fig 6. Region of Coverage for Border Security System.

While designing the same system we think of torque and speed, so togetherly we come up with 108 Teeth Gears which provide us sufficient torque and movement speed.

### 1.1 Design Specifications:

Table 1. Design Specifications of Border security system.

| S. No | Name of Item | Specifications |
|---|---|---|
| 1 | Body Metal: | Aluminium 4 mm (AMS-ASTM-EN-DIN-B.S.ND-AA-IS) |
| 2 | Motors | 12V Stepper Motor NEMA 17 (1.8° step angle (200 steps/revolution)) |
| 3 | Drive | Gear Drive 108 Teeth. |
| 4 | Torque | Holding Torque of 3.2 kg-cm |
| 5 | Power | NEMA 17 requires 4.8 A 12V |
| 6 | Dimensions | L=400mm, W=569mm, H=630mm |

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### 1.2 Stepper Motor:

We have selected the NEMA 17 Stepper Motor[5] for our project. This motor is apt for our desired range and needs, this motor is known for its precision and its price as it is very cost effective and offers great accuracy at given price range. Which makes it famous amongst hobbyists, students and people engaging in project activities.

Fig 7. NEMA 17 Stepper Motor Driver.

A stepper motor basically works by moving its shaft in steps, that is it moves by specific degree per step. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how many steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications.

The basic working principle of the stepper motor is the following: By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field. By supplying different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position.

Table 2. Specifications of DC Stepper Motor.

| | |
|---|---|
| Rated Voltage | 12V DC |
| Current | 1.2A at 4V |
| Step Angle | 1.8 deg |
| No of Phases | 4 |
| Steps per revolution | 200 steps per revolution |
| Operating Temperature | -10degC to 40degC |
| Max continuous power | 5W |
| Weight | 0.24kg |

### 2. Electronic System:

The Electronic and electrical system of the Border Security System contains JETSON NANO as the brain of the entire system. Which controls the entire working of our device and it is placed in the safe box which is not an essay to access also it provides alert when someone anonymously opens the cover.As shown in above block diagram detail interfacing structure Border Security system, is parts and specifications as follows.

### 2.1 Jetson Nano:

Discover the power of AI and robotics with NVIDIA Jetson Nano 2GB Developer Kit. It's small, powerful, and affordable for everyone. This means educators, students, and other enthusiasts can now easily create projects with fast and efficient AI using the entire GPU-accelerated NVIDIA software stack.

Fig 8. NVIDIA Jetson Nano 2GB Developer Kit.

All these resources are enabled by NVIDIA JetPack, which brings to each Jetson developer the same CUDA-X software and tools used by professionals around the world. JetPack includes a familiar Linux environment and simplifies the development process with support for cloud-native technologies such as containerization and orchestration.

Table 3. Specification.

| | | |
|---|---|---|
| 1. | Model | • NVIDIA Jetson Nano 2GB |
| 2. | GPU | • 128-core NVIDIA Maxwell |
| 3. | CPU | • Quad-core ARM A57 @ 1.43 GHz |
| 4. | Memory | • 2 GB 64-bit LPDDR4 25.6 GB/s |
| 5. | Storage | • micro SD (Card not included) |
| 6. | Video Encode | • 4Kp @ 30<br>• 4x 1080p @ 30<br>• 9x 720p @ 30 (H.264/H.265) |

| | | |
|---|---|---|
| 7. | Video Decode | ● 4Kp @ 60<br>● 2x 4Kp @ 30<br>● 8x 1080p @ 30<br>● 18x 720p @ 30 (H.264/H.265) |
| 8. | Camera | ● 1x MIPI CSI-2 connector |
| 9. | Connectivity | ● Gigabit Ethernet<br>● 802.11ac wireless |
| 10. | Display | ● HDMI |
| 11. | USB | ● 1x USB 3.0 Type-A, 2x USB 2.0 Type-A, 1x USB 2.0 Micro-B |
| 12. | Others | ● 40-pin Header (GPIO, I2C, I²S, SPI, UART) 12-pin Header (Power and related signals, UART)<br>● 4-pin Fan Header |
| 13. | Length (mm) | ● 100mm |
| 14. | Width (mm) | ● 80mm |
| 15. | Height (mm) | ● 29mm |

**2.2 Cameras:**
This system uses 2 cameras: night vision camera and thermal vision camera both send data to jetson nano directly using the usb 2.0 on board interface which makes system plug and play type.

**2.2.1: Day and Night Vision Camera:**

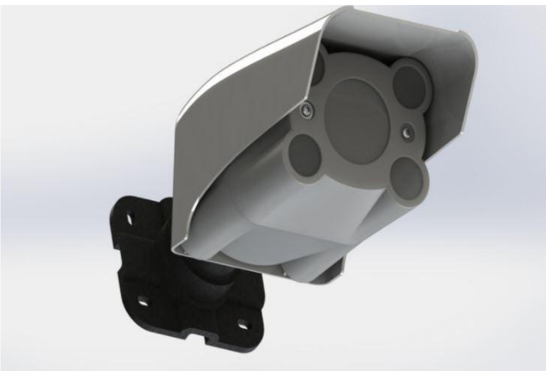


Fig 9. Night vision CCTV Camera.

The camera used in this research[7] for day and night vision is the ANPR camera.It incorporates HD image quality, high speed ANPR recognition, zoom capability and long range pulsed IR lighting, making it a basis for the selection. These intelligent ANPR cameras combine the pedigree of the HD and Analogue ranges alongside a powerful, yet eco-friendly, ANPR processor to create formidable all-in-one ANPR cameras. These cameras set new benchmarks in easy installation, long life, low maintenance, high quality making it perfect for detection of anomalous objects.

We installed this camera in our design to optimise the level of anomaly detected and augment the capturing quality for our model.Finally, the images recorded are sent to the jetson nano which processes it further and then finally the deep learning model learns and helps detect the intrusion.

**2.2.2 Thermal Vision Camera:**


Fig 10. FLIR Thermal Vision Camera.

The camera used in our research[8] is the FLIR A615.It is a feasible,viable, and compact thermal imaging camera for condition monitoring, which sends the thermal images from the source to the jetson nano for further scrutiny.

This camera can be fully controlled by a PC, and is compatible with the other vision softwares such as National Instruments, MVtec, and Stemmer Imaging.

**2.2.3 Advantages:**

- **Excellent Image Quality:** The FLIR A615 features a 640 x 480 pixel microbolometer that detects temperature differences as minute as 50 mK, for better accuracy.
- **16-Bit Temperature Linear Output:** The camera detects temperatures in non-contact mode using any third-party software due to the presence of the 16-bit temperature linear output.
- **High-Frequency Streaming:** It also streams full-frame 16-bit images at 50 Hz, or in windowed mode as high as 200 Hz, for high-speed processes which is essential for intrusion detection. This can be achieved using the state-of-the-art models of deep learning.

**3. Advance Computing:**
**3.1Model Training:**
Model training and testing was implemented on a computer with the following specifications: i7-8700 CPU 64-bit 3.20 GHz, 16 GB RAM, NVIDIA Quadro M4000 GPU, CUDA v10.2, cuDNN v7.6.5, OpenCV v4.2.0.

Dataset was downloaded from roboflow for the thermal human image.

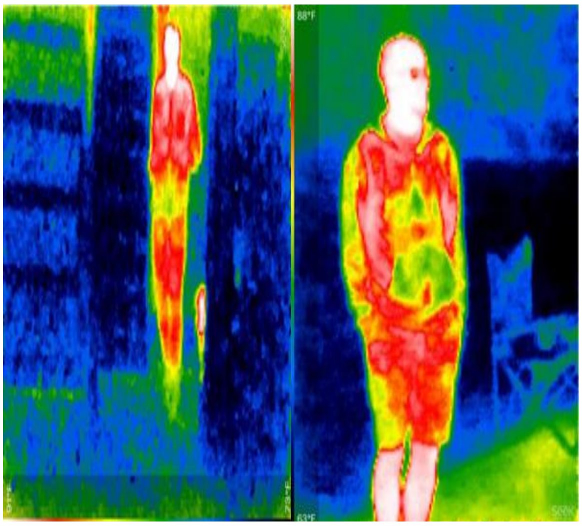


Fig 11. Image processing on normal vision footage and thermal vision footage.

Before training and testing, it is important to find the size of the anchor box that is most likely to be counted from the constructed dataset, instead of using the default anchor box configuration provided by YOLOv3 to create specialized predictors. The K-mean clustering algorithm was used to generate 9 clusters at $416 \times 416$ pixels according to 3 scales of detection layer.

The anchors were arranged and assigned in descending order to each scale to improve the YOLO v3 models. Because the datasets of thermal and normal vision were categorized into Raw, 0.5 ratio and 0.25 ratio, three different 9 clusters were generated. The obtained results of average IoU show that Raw is 77.45%, 0.5 ratio is 78.33% and 0.25 ratio is 78.55%.

The model receives inputs images of $416 \times 416$ pixels. The adjustment of the learning rate reduces training loss20. The learning rate was chosen to be 0.001 between 0 and 4000 iterations with maximum batches of 4000, because the input images contain two classes (ripe and unripe tomato). In order to reduce the memory usage, the Batch and Subdivision were respectively set to 64 and 16. The momentum and weight decay were set to 0.9 and 0.0005, respectively. Furthermore, a random initialization approach was used to initialize the weights for training the YOLO v3, while the official pre-trained weights was used for YOLOv3 and YOLOv4.

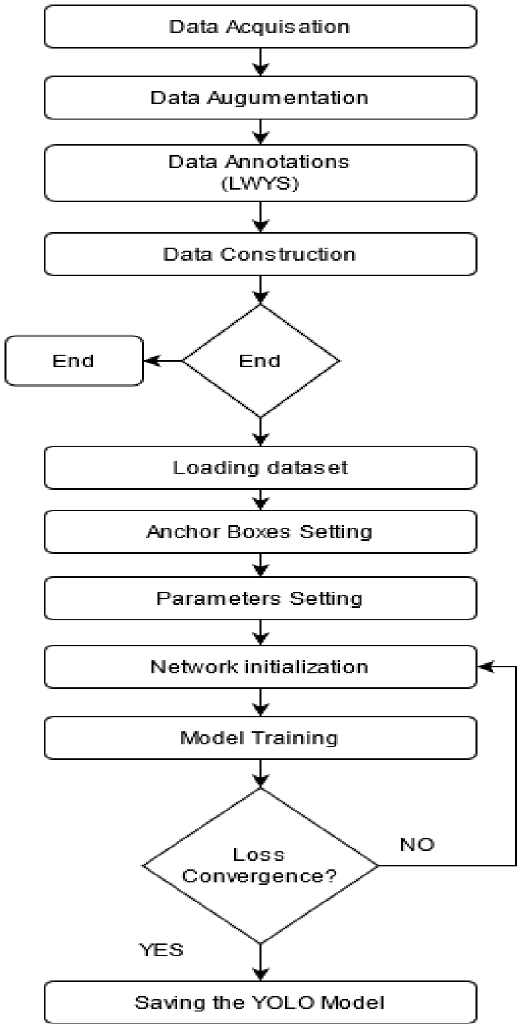



Fig 12. Flowchart for Training YOLO v3 on custom dataset

To verify the effectiveness of the conducted experiments on the trained YOLOv3, and YOLOv4 models, Precision, Recall, F1-score and AP are used as evaluation parameters. The calculation method is shown in Eqs. (1)–(4).

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \quad (1)$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \quad (2)$$

$$F_1 = \frac{2 * \text{Precision} * \text{Recall}}{\text{Precision} + \text{Recall}} \quad (3)$$

In these equations, TP, FN, and FP are abbreviations for True Positive (correct detections), False Negative (missed detections), and False Positive (incorrect detections). F1 score was conducted as a trade-off between Recall and

Precision to show the comprehensive performance of the trained models8, defined in Eq. (3). Average Precision–AP33 was adopted to show the overall performance of the models under different confidence thresholds, expressed as follows:

$$AP = \sum_{n} (r_{n+1} - r_n) \max_{\tilde{r}:\tilde{r} \geq r_{n+1}} p(\tilde{r}) \quad (4)$$

where p(r~) is the measured Precision at Recall r~.

**3.2 Model Testing:**

The model testing could be done on normal python opencv python based algorithms. The pretrained model was loaded then formatted into 416x416 aspect ratio. And given a trained model for prediction this model can give us results in the form of class index and confidence. The process for prediction for results from input image or live footage works as follows.

Firstly normal vision camera and thermal camera captures live data, opencv and python formats images as per the specifications requirements by the machine learning model. Such formatted data used for the prediction.

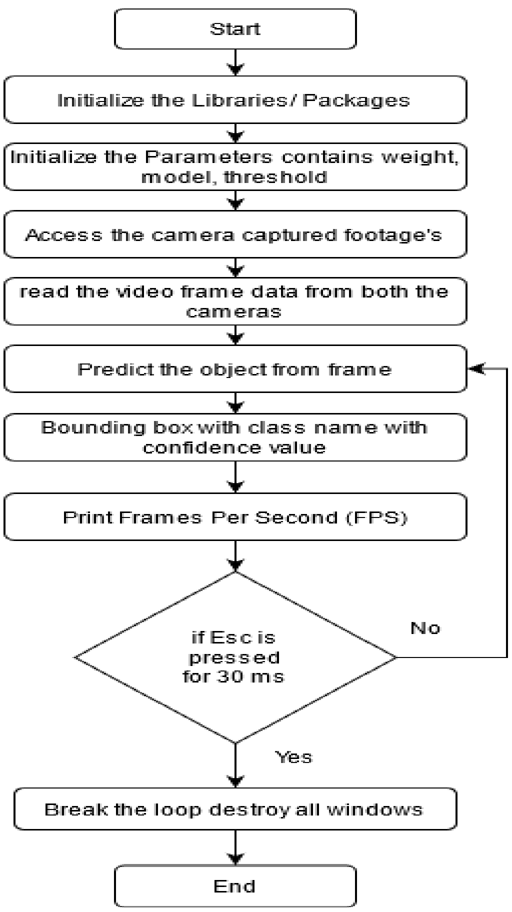
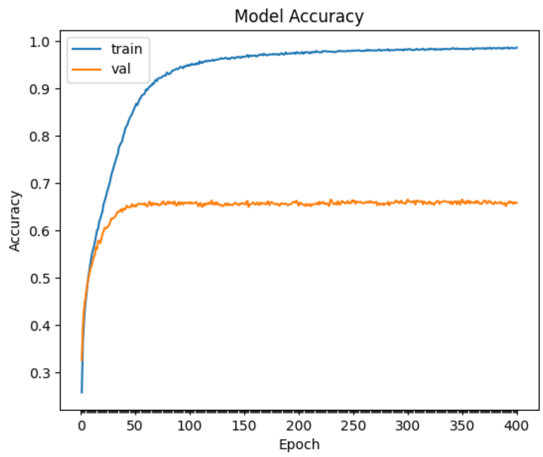



Fig 13. flowchart for MODEL testing using Trained model.

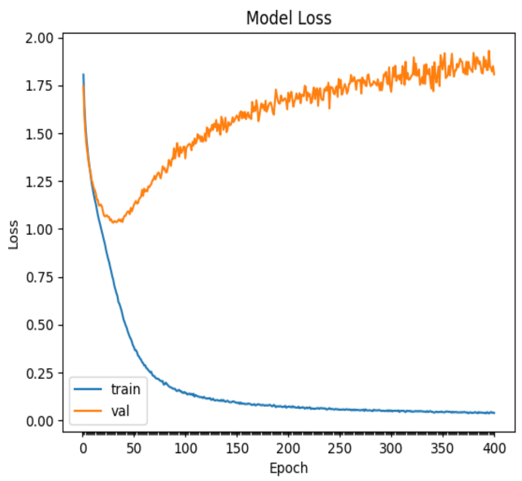
Once the results are generated by prediction models that need to be shown as like on the frames as shown in figure[K]. once the detection and recognition ends to quit the execution user needs to press "q" key from keyboard to break operation

## IV. RESULTS AND CONCLUSION

With our extensive research we have developed an automated border security system which is equipped with day night vision with thermal vision cameras.Our research and study proves that this methodology is completely implementable and a border area for safety and security systems.




(a)




(b)

Fig 14. Model accuracy losses graphs.

With our research and development we come to the conclusion that with a limited dataset our model can give us accuracy of 86% based on the YOLO v3 algorithm. As shown in fig M.

## V. ACKNOWLEDGEMENT

We would like to thank our parents for helping us conceptualise the idea and guiding me throughout its execution.We would like to thank our college Teachers project mentor for giving us their invaluable inputs and highlighting any gaps in the project.

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