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Automatic Intruder Combat System : A way to Smart Border Surveillance

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ABSTRACT

Security and safeguard of international borders has always been a dominant issue for every nation. A large part of a nation’s budget is provided to its defense system. Beside wars, illegal intrusion in terms of terrorism is a critical matter that causes severe harm to nation’s property. In India’s perspective, border patrolling by security forces has already been practiced from a long time for surveillance. The patrolling parties are equipped with high end surveillance equipment but yet an alternative to the ply of huge man power and that too in harsh environmental conditions hasn’t been in existence. An automatic mechanism for smart surveillance and combat is proposed in this paper as a solution to above discussed problem. Smart surveillance requires automatic intrusion detection in the surveillance video, which is achieved by using optical flow information as motion features for intruder/human in the scene. The use of optical flow in the proposed smart surveillance makes it robust and more accurate. Use of a simple horizontal feature for fence detection makes system simple and faster to work in real-time. System is also designed to respond against the activities of intruders, of which auto combat is one kind of response.

Keywords: Border surveillance; Intruders, Human detection; Fence detection; Optical flow

1. INTRODUCTION

Apart from finance, banking, aviation, technology and science, nation’s security is the important issue, on which every nation places a prime concern. Every country reserves a large component of its budget for the defense system. Defense system safeguards the country’s sea, air and land borders. The focus of our work is to propose a smart surveillance system for land borders only. Surveillance or patrolling is the most common strategy used by the defense system to protect borders from illegal intrusions.

Borders in Indian scenarios have enormous problems of illegal intrusions in terms of terrorism. Indian Army takes care of patrolling these border fences all along day and night. The patrolling becomes even more typical during winter in Kashmir and summer in Rajasthan. Fog, hue, mist and sand storms create inhuman conditions for patrolling parties doing surveillance. Intrusions leading to the militant activities take benefit of these severe climatic conditions. The harsh climatic conditions create the increasing demand of man power for patrolling and as well have consequences of loss of life of soldiers. To overcome these problems being faced by BSF and Indian Army in surveillance, an automatic surveillance mechanism could be a solution.

The task of automatic surveillance involves automatic detection of human intruders continuously in the real-time surveillance scene. In automatic detection, the real-time surveillance video from camera is processed for detecting human intruder and then checking its position relative to the fences. Intruder position could be behind the fence, across the fence or have crossed the fence. Certainly in these three cases, a responsive action can be made such as alarm when intruder tries to cross the fence and firing/auto firing when it actually has crossed. This auto firing is a form of auto combat, which makes border surveillance smarter. The paper proposes a mechanism for automatic detection of human intruder with the auto combat provisions. Here intruder is considered to be a human being only, not any other living or non-living object. Therefore human detection everywhere shall be taken as intruder detection.

Several human detection techniques for applications such as indoor surveillance, robotics, driver assistance or auto car driving, etc have already been proposed in literature. These techniques can broadly be classified into some categories based on the characteristics of scene and region of interest (ROI) for detection. These categories are motion based detection[1,2], features (Haar, HoG, LBP, etc.) and classifier based detection[3,4], and skin colour segmentation based detection[5,6]. The examples of motion based human detection techniques are background subtraction and frame differencing. Elaborated discussion on these human detection techniques is presented in the paper.

2. RELATED STUDY

Issues of illegal border crossing or infiltration lie almost at every international border. Beside Indian borders, the US-Mexico border is yet another example of a very sensitive one. Other borders that stand in same queue are China-North Korea border, Israel-Palestine border, Syria-Turkey border and many others. Reports from Federation for American Immigration

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Reforms (FAIR) on border security measures reveal the fact that around 20000 illegal border crossings were recorded from the US-Mexico border side in 2012[7]. Another report from European Union states nearly the same facts on surveillance[8].

These reports also talks about preventive measures as employment of patrolling, border checks, and supervisory duties by special task forces. In the infrastructural resources provided are regular armaments with night vision devices (NVD's), floodlighting at border side roads and use of drones for patrolling in air[7,8]. But neither of the report talks of the automated usage of this infrastructure for surveillance and patrol.

A report from Department of Border Management, Ministry of Home Affairs reveals the initiatives taken for border surveillance and patrolling at Indian borders[9]. Border side roads, floodlighting, border out posts (BOP's), air support and budget towards communication equipment, surveillance equipment, weapons, bullet proofs, vehicles, etc. accounts to those initiatives. These add to the strength of BSF but a need of automated surveillance and combat system still remains.

Human detection has been achieved by a number of techniques and background subtraction technique[1] is one of those. Frame differencing technique[2] for human detection is derived from background subtraction technique. These two techniques are more prone to noise; shadow and ambient light illumination[10]. The problem of shadow removal for accurate detection is covered in[11]. Some of other techniques use face features for human detection[3-6]. Viola-Jones technique is one of them and it uses texture information of the face for face detection and consequently the human detection[4]. Texture information is coded into features called haar-like features[4]. Cascaded classifier uses these features to classify the face[3]. Viola-Jones fails for tilted and rotated faces. SVM is used with HoG features in[12] for pedestrian's detection.

Skin colour is also used as unique feature to distinguish human being from other class of objects and background. A number of approaches for skin colour modelling[5,6] have been proposed in literature. The approaches using skin colour information for human detection fails if skin portion of human body covered. Intruders are trained enough towards the use of these camouflage techniques. To avoid demerits faced by above discussed techniques, the optical flow[13,14] information is used in proposed technique to detect human being.

3. SYSTEM OVERVIEW

A design for intruder combat system is proposed here and this is made by considering a general scenario of intrusion at border fences. A scene in Fig. 1 pictorially depicts the scenario of intrusion. This figure also shows the mechanism of smart surveillance for automating the intrusion detection and combat.

The intruder or terrorist is behind the border fence. A pan and tilt zoom (PTZ) camera and a gun placed on rotating base are the two main equipment used. The distance of fence from camera is the 'target distance (TD)' and this has to be less than target range of the camera. Target range is specific to a particular camera. Other important specifications of a camera are working temperature, image resolution, angle of

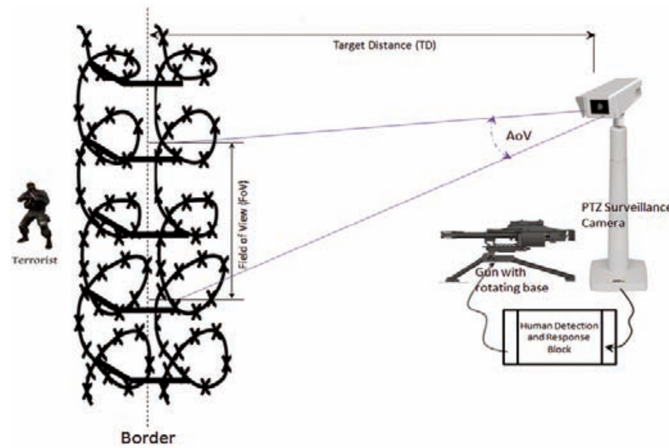


Figure 1. Surveillance scene with proposed design parameters.

view (AoV), field of view (FoV), protection against humidity and water and video interface support. For field setup, PTZ camera should have working temperature between -30 °C to +60 °C. AoV specification is the maximum viewing angle of the camera. Long range cameras generally have smaller value of AoV and it is around 10°. PTZ cameras should have video interface support of VGA, RS232, HDMI and Ethernet. Here, target range of camera is used as the design parameter and the high range PTZ cameras are available with the target range of 1 km to 1.5 km.

Beside other characteristics of gun as weight, length, barrel length, cartridge, rate of fire and muzzle velocity, the effective firing range is more important on the design perspective of intruder combat system. This is one design parameter for surveillance system design. Different guns available with the Indian defense forces such as INSAS, FN MAG, LMG, etc have firing range between 400 m and 800 m. According to our design considerations, the camera and gun are placed at the same distance from the fence. Therefore, TD has to be something 400m for making system compatible to INSAS kind of gun.

The next important part of the setup present in the surveillance scene is the 'human detection and response block'. This is the actual computing and control part of the intruder combat system. The video stream received from camera is processed in the form of video frames (images) after frame extraction and sampling. Processing is done for detecting human subject (intruder) roaming behind the fence. Its position coordinates are calculated. Position coordinates are needed during responsive action. After human detection in surveillance video, what kind of response shall be made is guided by three different cases. These are as follows:

(a) When intruder is behind the fence.
(b) When intruder tries to cross the fence i.e. it is across the fence or above the fence.
(c) When intruder has crossed the fence and reaches our side.

The responsive action for first case is keeping track on intruder. For second case, an alarm is raised while in third case auto firing is the responsive action. These three cases are presented in Fig. 2.

Proposed algorithm for human detection and its positioning with respect to fence is detailed in section 4. The place where above shown setup is made is termed as a 'surveillance point' and there has to be a series of such surveillance points all along the border. The calculation of distance between surveillance point and the border which is same as TD is given below.

Referring to Fig. 3, the FoV has trigonometric relation with TD and FoV also has correspondence to the size of image captured by camera. In order to clearly detect human intruder in the image, the image size should be in sufficient ratio with human size. With image resolution 640 x 480, human width of 40 pixels is minimum bound to clearly detect human being. 640 x 480 is the optical resolution of surveillance camera and 40 pixels is used as minimum bound for human size in image, to avoid false detections arising due to noise. Since the average width of human body in different view of human standing posture is 1 feet, the required image length (which is same as FoV) can be calculated as follows:

FoV = (640/40) * 1 feet

FoV= 16 feet ≈ 5 m

Now since,

$$\tan\left(\frac{AoV}{2}\right) = \frac{\left(\frac{FoV}{2}\right)}{TD} \tag{1}$$

Therefore, with FoV = 5 m and AoV = 10°

TD = 28 m

28 m is much smaller distance and TD as per design consideration shall be near to 400 m. Increasing TD will also increase FoV with fix value of AoV. So, to increase TD without changing FoV, we have to change AoV and this is done by the optical zoom feature of PTZ camera. Optical zoom reduces the angle of view by a factor of magnification i.e. zoom. This means that 5 x zoom will reduce the AoV from 10° to 2°. The calculation for new AoV and/or optical zoom is given by Eqn (2):

$$newAoV = 2 * \tan^{-1}\left(\frac{\left(\frac{FoV}{2}\right)}{TD}\right) = 0.716° \tag{2}$$

On further calibrating the values of AoV and TD, it is found that the TD comes out to be 286 m at AoV value of 1°. 1° AoV means the optical zoom of 10 x. The TD of 286 m also helps in easy selection of gun for auto firing task.

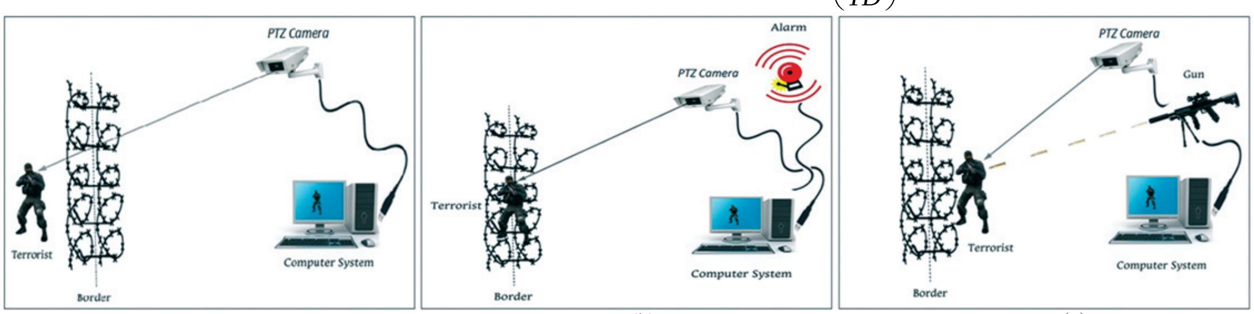
3.1 Human Detection and Response Block

Block diagram in Fig. 4 presents the design of human detection and response block. Detecting human in video stream received from camera is the first task. A person being detected is marked by a rectangle and centroid of the rectangle represents the position of human (intruder). X, Y are the coordinates of the intruder's previous position and X', Y' are the coordinates of next position after the movement. The displacement of intruder from previous to next position is the important information for rotating the camera to keep intruder in focus. The same information is also used for positioning the gun needed for auto firing response. The rotational movement of camera and gun, given by θx, θy is calculated from the linear displacement of intruder, which is given by Eqns (3) and (4), respectively.

$\Delta x = (X' - X)$ and $\Delta y = (Y' - Y)$

$$\theta x = \tan^{-1}\left(\frac{\Delta x}{TD}\right) \tag{3}$$

$$\theta y = \tan^{-1}\left(\frac{\Delta y}{TD}\right) \tag{4}$$



(a) (b) (c)

Figure 2. Three cases of intruder position wrt fence.

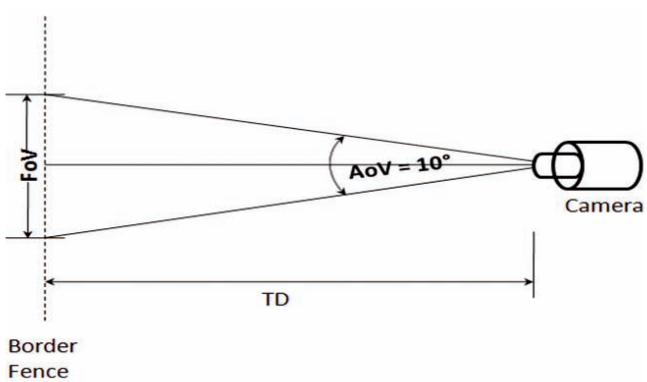


Figure 3. Target distance for camera placement.

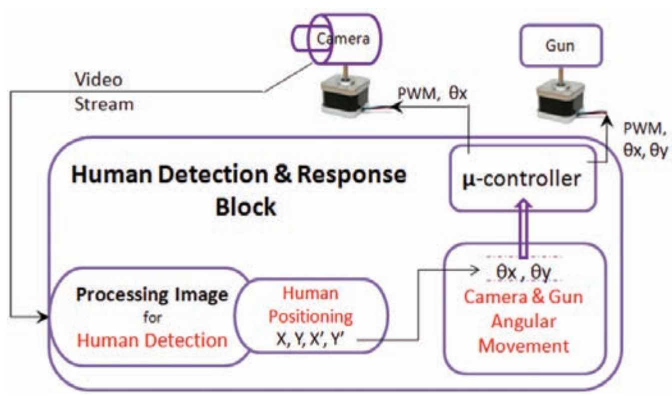


Figure 4. Human detection and response block.

Δx, Δy are the intruders linear displacement in horizontal and vertical direction. Vertical movementis considered in case when intruder climbs the fence. Camera image resolution is enough in vertical direction i.e. around 4.5 m (which very well covers the fence), so camera need not be rotated in vertical direction. Therefore, Δy and Θy are required only for gun positioning. Horizontal rotation i.e. 'Θx' is required both for camera and gun. Negative values of Δx and Θx emphasis the leftward movement of intruder while their positive value emphasis the rightward movement.

The Θx and Θy are fed to microcontroller which generates respective pulse width modulated (PWM) signal for the rotation of motor in either clockwise or anticlockwise direction. Motors are the high torque servos used for rotating base of camera and gun.

4. PROPOSED HUMAN DETECTION AND RESPONSE TECHNIQUE

It is clear from the discussion in the previous section that human detection and positioning is the first task of 'human detection and response block'. In this paper, human detection is achieved using its motion features and is detailed in next subsection. For next part of positioning i.e. locating the detected human being with respect to the fence, the fence detection is required. So, in another subsection a technique is proposed for fence detection. The third part detailed in third subsection is for decision rules that decide the human (intruder) position with respect to fence. This is required for responsive action in three different cases, as provided in system overview section. The flow diagram in Fig. 5 exhibits the process flow of proposed human detection and response block.

4.1. Human Detection

Motion information gathered from optical flow is used for detecting the human being. The motion information derived is the displacement of a point in two consecutive frames, with direction of its displacement. This information is done for every point in the image. The displacement with direction is termed as velocity and for static or non moving portions of the image, velocity is zero. The points having some velocity value are grouped based on their connectedness. Connectedness here implies reachability of one point to another. Such connected points form a group/cluster and there could be more than one such cluster in an image. On binary output, these clusters can be seen as binary large objects (blobs) of white pixels. Whether the blob represents human being or some noise, processing on blob size is performed. The blob that confirms the size parameters is marked as human being in the corresponding videoframe. A short description of optical flow technique is given in the following sections.

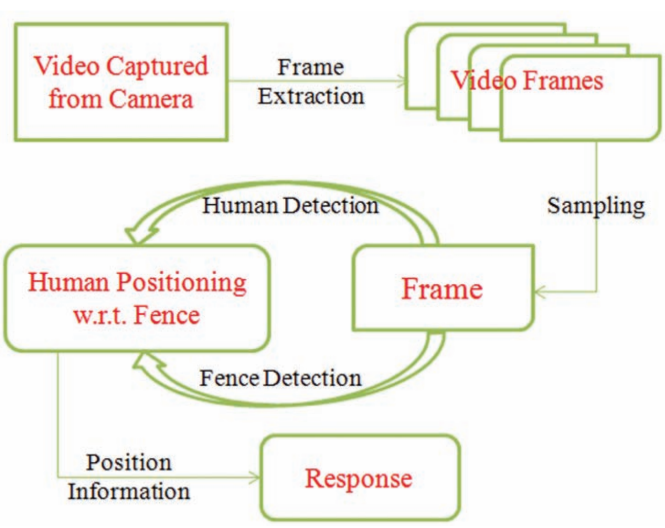


Figure 5. Process flow diagram for human detection.

4.1.1 Optical Flow

Optical flow technique[13] used here for human detection is the motion based technique. This is based on Lukas-Kanade algorithm[15] which detects motion of objects based on change in position of a point in successive frames. Optical flow technique calculates the magnitude and direction of displacement with respect to time at each pixel in the image. This quantity is velocity, given as a vector $[u,v]$ having two components, one in horizontal and other in vertical direction. The algorithmic use of optical flow in our work is detailed in the next subsection.

4.1.2 Human Detection Algorithm

This algorithm is applied to the frames received after sampling from the video captured from PTZ camera, referring process control flow in Fig. 5.

Algorithm: Human Detection

Input: Sampled Frames

Output: Detected Human Being (marked with yellow rectangle)

1. *Optical Flow* (1st Frame, Next Frame) calculation for velocity vectors of moving points
2. The output of Optical Flow shows the motion of large number of points in the frame, but all moving points does not corresponds to the human being, some are due to noise. Finding the points corresponding to human being and locating human position is done by checking connected components and performing thresholding on connected component size.
3. Connected Components are the group of pixels where each pixel of group is well reachable to other.
4. Thresholding is done on size of connected components based on number of pixels. For our setup, an experiment for deciding threshold limit, to detect and position human being is performed in experiment result section of the paper.
5. The human being detected is marked with a yellow rectangle in the final output.

Algorithm: Optical Flow

Input: Two Images (Image1, Image2)

Output: Binary image of optical flow, showing velocity vectors of moving points

Terminologies: *dx* and *dy* are the horizontal and vertical components of displacement of a moving point respectively, *dt* is the time domain difference of two images.

1. Convolute Image1 with matrix M1 to find *dx*.

$$M1 = \begin{bmatrix} -1 & 1 \\ -1 & 1 \end{bmatrix}$$

2. Convolute Image1 with matrix M2 to find *dy*.

$$M2 = \begin{bmatrix} -1 & -1 \\ 1 & 1 \end{bmatrix}$$

3. Convolute Image1 with matrix M3 and Image2 with matrix M4, to find *dt*.
   M3 = [1 1] M4 = [-1 1]
4. Lukas-Kanade algorithm is applied by considering a block of 3x3 pixels to have a system of simultaneous linear Eqn (2) variables. *u* and *v*, the components of velocity vector of a moving point are the solution of Lukas-Kanade algorithm.
5. Step 4 is done for all points in the Image1 having non-zero value in *dt*.
6. Output is binary image showing velocity vectors at only moving points with white. Rest all static points are black.

4.2 Fence Detection

Fence at the border are generally barbed wire fences. The long running horizontal barbed wires are its significant component. The straight and horizontal wires of fence are used as distinguishing feature to detect fence. For our experimentation, due to unavailability of border side patrolling images/videos, we had used grill boundary as fence and created a border intrusion scene. This completely simulates the behaviour of border surveillance.

A simple horizontal feature motivated from Haar-like features[16] is created to detect the fence. The calculation for this feature in an image is done using the concept of integral image[4], same as that done for Haar-like features. Equation (5) shows the transformation of an image to its integral image[4]. The horizontal feature used is as shown in Fig. 6.

$$ii(x,y) = \sum_{x' \le x,\, y' \le y} i(x',y') \tag{5}$$

where $ii(x,y)$.is the pixel value of integral image at (x,y) and $i(x',y')$is the pixel value of original image at (x,y).

Figure 6. Horizontal feature.

The black and white strips in horizontal feature shows change in intensity of nearby pixels. The width and height are the important parameter of this feature. Height is fixed to 2 pixel of which 1 pixel for white and 1 pixel for black. Width of the feature is tuned by an experiment presented in experimental result section. The value of this horizontal feature is used for thresholding the intensities other than fence colour. The value of horizontal feature for a particular pixel(x,y) is calculated by Eqn (6).

$$Val(x,y) = \sum_i \left(p_b(i) - p_w(i)\right) \tag{6}$$

i indicates the number of pixels in width of feature. p_b, p_w are the pixel values in black and white region of the feature, respectively.

The threshold at horizontal feature value to detect the fence is also decided by the same experiment done for width of the feature. The threshold is denoted by *Th*. With tuned value of width and threshold, the fence detection processing generates a binary output when applied on video frames. White pixels in binary represent the detected fence. Classifier in Eqn (7) is the proposed fence detection classifier.

$$oi(x,y) = \begin{cases} 1, & \sum_{y-1 \le y' \le y+1} \left(ii(x,y') - ii(x+1,y')\right) \ge Th \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Top most horizontal boundary detected is the fence top. Similarly lowest point of fence is detected. The position of top, lowest and the centre of fence is calculated, which is required in next phase of decision making for human position in three cases of surveillance provided in system overview.

4.3 Decision Rules for Responsive Action

Depending on the local position of fence and human being, their relative positions are decided. The basic terminologies used for decision rules are Fence top point (FT), fence lowest point (FL), fence centroid (FC), human top point (HT), human lowest point (HL) and human centroid (HC). Decision rules are realised as nested conditional statements and are presented by condition flow graph in Fig. 7.

Assumption: Top left corner pixel is (0, 0) and pixel coordinates increase towards right and down.

The decisions made are for human being position with respect to fence. A responsive action is taken corresponding to a decision made. In case 1, when intruder is behind the fence, the responsive action is simply keeping track of intruder. In 2nd case, when intruder tries to climb the fence or come across the fence, raising an alarm is the responsive action. 3rd case needs auto combat as part of responsive action when intruder has actually crossed the fence and is in front of the fence.

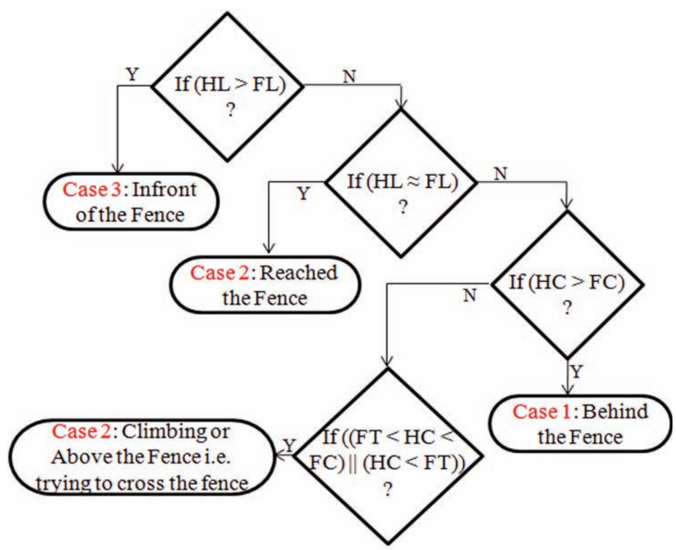


Figure 7. Condition flow graph for decision rules.

5. EXPERIMENTAL RESULTS

The first two experiments are done as a part of training phase of human detection block. First experiment is for deciding the threshold on size of connected components which is used in proposed human detection technique. In second experiment, the width of horizontal feature and threshold on value of horizontal feature is derived. The second experiment is the part of fence detection. These two experiments are performed on a video captured of a created surveillance scene. Fence is mocked by a metal grill in this scene. The last experiment is done for evaluating and analysing the performance of the proposed method.

5.1 First Experiment

First 20 sampled frame of the video are processed for different values of threshold. Threshold or size of connected component is taken in terms of number pixels. In how many frames out of twenty, the human being is correctly detected for each value of threshold is derived and the same is presented in Table 1. The threshold values taken in the table are in correspondence to the image resolution and human size relative to image size.

The tabular result shows that the high percentage of correct detection is achieved around threshold value of 400 pixels. Threshold is not an exact value 400 but a range [390 - 410] of number of pixels.

5.2 Second Experiment

This is done for finding width and threshold value of horizontal feature for maximal correct detection of fence. The same first 20 sampled are used for the processing.

Values in the Table 2 denotes the number of frames in which fence is correctly detected upon using to respective width feature and the threshold value. The feature width of 45 gives the reasonably good result compared to others at almost all threshold values. The selective threshold for high rate correct detection of fence will then be a range around 900 and 1000. Therefore [875 - 1025] is the decided range for threshold value of horizontal feature.

Table 1. Thresholding connected component size for human detection

Threshold on size of connected component	325	350	375	400	425	450	475	500	525
Number of frames with human correctly detected	4	9	14	**16**	15	12	8	2	0

5.3 Experiment of Evaluating the Proposed Approach

This experiment is performed on two different videos of the same surveillance scene. The only difference in two videos is that in one face of human (intruder) is not covered while in other face is covered. The face covered scenario is considered to cover this camouflage technique that intruder generally practice. Figure 8 shows the image results of human and fence detection with corresponding decisions on human position wrt fence, for video 1. Similarly, image results in Fig. 9 are for video 2.

Frames in first row in both the figures are original frames of videos. Second row illustrates processed binary image for human detection. Third row images show rectangle marked on human being. Red asterisk marks in third row images represents the top horizontal line of the fence. These asterisk marks are less visible due to smaller size presentation of high resolution frame. More clearly visible detected fence is presented in Fig. 10. The binary image of detected fence as an intermediate result is as shown in Fig. 11.

In Fig. 10, yellow asterisk denotes centroid and lowest point of the fence. Blue asterisk is for centroid of human being. Caption above each frame is conveying the position of human wrt fence. Additional asterisk at irrelevant position denotes false detection.

Fence detection is done with a horizontal feature of size 2 x 45 pixels i.e. 45 pixels in a row and 2 pixels in a column. Therefore the detected fence has nearly straight lines in the binary image. Use of

Figure 8. Image results of processing on video 1.

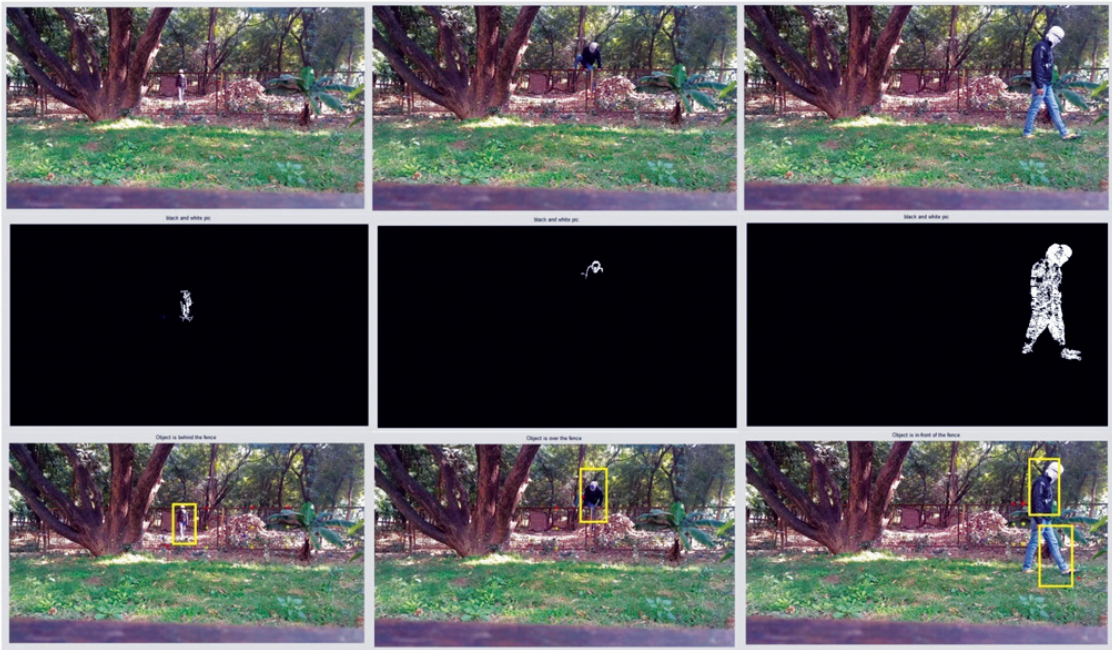


Figure 9. Image results of processing on video 2.

Table 2. Thresholding horizontal feature value for fence detection

Width of horizontal feature	Threshold on horizontal feature value									
	300	400	500	600	700	800	900	1000	1100	1200
20	0	1	1	0	0	0	0	0	0	0
25	0	1	0	2	1	1	0	0	0	0
30	0	0	2	2	4	1	1	0	0	0
35	0	0	1	3	4	7	2	0	1	0
40	0	0	3	8	12	13	7	3	3	2
45	0	1	14	13	16	13	18	19	10	5
50	0	1	8	9	9	12	11	13	7	3
55	0	0	5	7	7	7	6	7	9	2
60	0	0	3	3	2	3	4	3	5	2

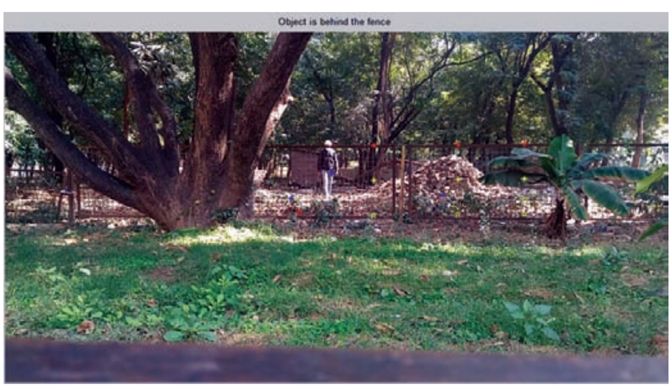


Figure 10. Image result showing fence detection and human position wrt fence.

horizontal feature is done because linear structure of fence distinguishes it from other irregular objects in the image. Detection is fine tuned based on intensity with an experiment on threshold of horizontal feature value. The top white pixels provide fence top position and correspond to red asterisk in Fig. 10, while lower white pixels provide fence lower position which corresponds to yellow asterisk in Fig. 10. These points are then used in decision making.

5.4 Result Analysis

The evaluation parameters used are true positive (TP), false positive (FP), true negative (TN) and false negative (FN). The evaluation metrics based on these parameters are true positive rate (TPR), false positive rate (FPR) and accuracy. These are defined as follows:

TP – number of frames in which human present is correctly detected as human

FP – number of frames in which human not present is detected as human

TN – number of frames in which human not present is not detected as human

FN – number of frames in which human present is not detected as human

$$TPR = \frac{TP}{TP + FN} \tag{8}$$

$$FPR = \frac{FP}{FP + TN} \tag{9}$$

Figure 11. Binary image of detected fence.

$$Accuracy = \frac{TP + TN}{TP + FN + TN + FP} \quad (10)$$

Videos taken are of 2 min duration and frame rate of capturing the video is 10 FPS. Sampling done is 1 out of 5 frames. This way total sampled frames used are 240. The Table 3 presents the performance results for proposed human detection approach. These results are compared with results of other available human detection techniques in Table 4. The same comparison results on two videos are presented graphically in Figs. 12 and 13.

A higher TPR and higher accuracy makes the proposed approach an efficient human detection approach. Proposed approach works better even when the face is covered. In this case pixel intensity based approaches (Viola-Jones & Skin colour modelling) fails while motion feature based approach as three-frame differencing and proposed approach delivers good results. Optical flow based proposed approach outperforms the three-frame differencing approach because frame differencing approach works on difference of pixel intensities, which is addictive to noise. Opposite to that optical flow exploits the movement of image points therefore if noise adds up in any frame does not affect the optical flow of points in previous frame. This results in low FPR and hence a high value of accuracy.

Proposed approach for fence detection works with 100 per cent accuracy on both the videos. Accuracy of decision making of human position w.r.t. to fence is found to be less than 100 per cent. This is 85 per cent and 87 per cent for video 1 and video 2, respectively. This is due to the false detection i.e. FP and fallout i.e. FN in human detection.

The most important outcome of the proposed approach is its real-time implementation on a lab setup proposed by Singh & Singh[17]. The system runs without glitches in the same scene as shown in video 1 and video 2. The camera is able to track the moving intruder. The responses in three cases are also well generated.

5.5 Computation Time Analysis

The computation time analysis is done for algorithm and the complete system as well. The 'human detection and response block' is the main computation block. This performs two different computations, of which one is image processing for human (intruder) detection, fence detection and decision making on position of human w.r.t. fence. Whole of this computation is carried by a single block of code. The second computation is in microcontroller for PWM signal generation for rotating servo motor based camera and gun.

Table 3. Performance measurements for proposed approach

	Performance measures						
	TP	FP	TN	FN	TPR	FPR	Accuracy
Video 1	194	10	10	26	0.881	0.5	0.85
Video 2	199	5	12	24	0.892	0.294	0.88

Table 4. Comparing performance of proposed approach with other state-of-art approaches

	Viola-Jones approach		Three-frame differencing		Skin colour modelling		Proposed approach	
	Video1	Video2	Video1	Video2	Video1	Video2	Video1	Video2
TPR	0.354	0.011	0.677	0.677	0.634	0	0.881	0.892
FPR	0.167	0	0.886	0.868	0.5	0.827	0.5	0.294
Accuracy	0.39	0.07	0.482	0.470	0.621	0.058	0.85	0.88

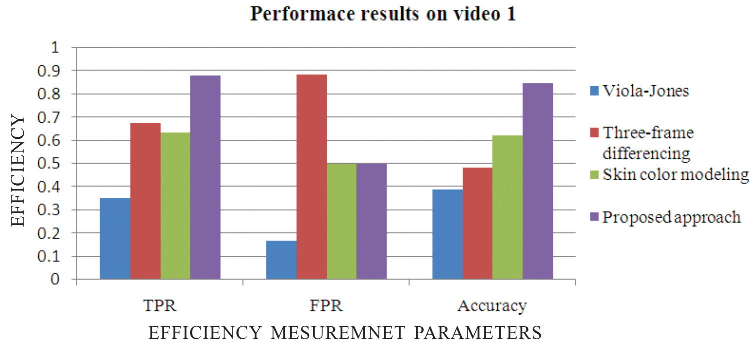


Figure 12. Performance result comparison for proposed approach on video 1.

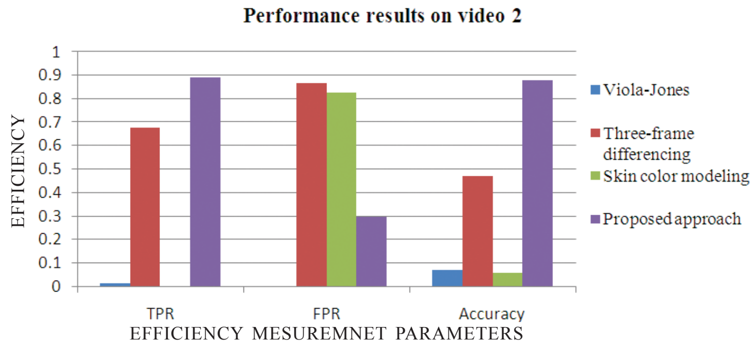


Figure 13. Performance result comparison for proposed approach on video 2.

Beside computation, the system also involves communication of captured video stream to computing block and communication of relative human position information (Δx, Δy, θx, θy) to microcontroller.

Computation time analysis of human detection and decision making is done by 'MATLAB Profiler'. Experiment is carried out on a computer having Intel Core I7 processor and 4 GB RAM. Table 5 presents the timing analysis for both the videos used in experimentation.

For real-time video stream, if rate of capturing is kept same i.e. 10 FPS then time of arrival of every next frame will be (1/10)*1000 ms i.e. 100 ms. This 100 ms time is much more than the time required by our algorithm for computation of human detection and decision making. Therefore, algorithm supports real-time working of the 'Intruder Combat System'.

Time of computation in microcontroller is calculated by the frequency of operation of microcontroller used. In lab setup implementation, the microcontroller used is 'Atmega 32' and this operates at frequency of 16 MHz. Time of execution of assembly code for PWM generation at this operating frequency

Table 5. Computation time analysis of human detection and decision making

	Total time (s)	Average time per frame
Video 1 (240 frames)	8.57	35.7 millisecond
Video 2 (240 frames)	8.43	35.2 millisecond

lies in some microsecond's value. This computation time is negligible in respect of computation time for human detection. Communication time is also found to be negligible since the whole setup is at one point only.

6. CONCLUSIONS

A smart border surveillance mechanism with auto combat facility is proposed. All design and field placement considerations are provided for actual border setup. The algorithms are proposed for human detection, fence detection and human positioning wrt fence. Response block is designed for responsive action in three different cases of surveillance. The whole system is simulated to work in real-time by a model developed as a lab setup.

Human detection achieved by doing connected component size thresholding on optical flow information of movements in video frames. Connected component calculation and size based thresholding is the unique part of the method. Fence detection horizontal feature is completely a new part of work. The use of single horizontal feature makes the fence detection simple and least complex. Training in both human and fence detection and the decision making on human positioning are also the unique contributions to the work. Performance results in terms of TPR, FPR and accuracy confirms the efficiency of proposed methods and algorithms.

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