A Mobile Robot / Thermal Camera System For Intrusion Detection In Nocturnal Environment

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Abstract: This paper introduces the integration of a perceptual capacity for a mobile security robot in order to detect a possible intrusion in nocturnal environment. A thermal Camera is used to extract possible intrusion. An algorithm based on the calculation of the optical flow of the scene is proposed in order to differentiate between a real intrusion and an existing heat source (Computer, Machine, ... etc.).

Index Terms: Mobile Robot, Thermal Camera, Optical Flow, Histogram equalization.

1. INTRODCUCTION

Robotics has experienced significant expansion in recent years. Applications using robots are more and more varied and the physical limits between humans and the robot decrease. Surveillance and security robots are therefore emerging in this field. Cartography and navigation, artificial intelligence, video analysis, networks ..., the Embedded technologies instill unparalleled capabilities in these gatekeepers. A powerful security robot is one that responds to the four decisive missions of the surveillance: monitor, detect, alert and remove doubt for an effective intervention. It must also be able to differentiate a human or an animal, from a vehicle or any other fixed object. Thus, any risk of intrusion will be eliminated. For this, before considering the movement of the robot, it is essential to guarantee its ability to perceivesuitably its environment. Many methods exist to extract real moved objects from motion created by the robot/camera displacement. [1] uses block matching to compute dominant movement. The current image is divided into "macro-blocks" non-overlapped of identical sizes which are seen as independent blocks where the pixels component each block has the same pace of movement. In a second step, authors search, for each block, the "most similar" block in a search window: they deduce the motion vector from the block. In order to determine the best of similar blocks, the algorithm compares the difference between the source block and other blocks using a quality criterion such as the absolute mean error or quadratic error [2]. The HOG - Histogram of Oriented Gradients – is used locally to create vector descriptor and perform matching between successive images. [3] describes the hardware architecture for selected object tracking on an embedded system. The LBP and HOG feature extraction algorithm is combined with motion detection to compute and compare the features vectors with captured once only when the target moves. $LBP_{8,1}$, $LBP_{16,2}$, and $HOG_{8,1}$, $HOG_{16,2}$ are used to create the feature vector. [4] computes dominant motion for each pair of images. This motion is computed using wavelets analysis on optical flow equation and robust techniques. Interesting areas (areas not affected by the dominant motion) are detected thanks to a Markov hierarchical model. In [5], authors use omni-directional camera to estimate robot/camera position and velocity. In this case, it is a sensor-based motion estimation. In order to compensate the motion introduced by the dynamic behavior of the camera, [6] estimate geometrical transformations which stabilize consecutive frames. The system is based on the use of Mutual Information as a criterion to find an affine model which relates a frame to a reference one. Then, moving regions are extracted using residual motion. This paper introduces an algorithm based on the calculation of the optical flow of the scene to differentiate between a real intrusion and an existing heat source (Computer, Machine, ... etc.). The originality of this work lies in the nature of the processed images. These are thermal images hence the need for a pre-processing which highlights the initially low contrast. The structure of the paper is as follow: Optical flow theory is described in Sec.2. Section 3 shows our proposed approach including pre-processing step. Experimental results are given in section 4.

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2 OPTICAL FLOW

The technique that comes closest to motion estimation is optical flow whose vectors correspond to perceived motion at the pixel level: This is a pixel-based estimation. Optical flow can be defined by the apparent movement of objects, surfaces and contours of a visual scene, generated by the relative movement between an observer (eye or camera) and the scene. All the methods for estimating the optical flow are based on a fundamental assumption: the light intensity is preserved locally between two successive images I(t) and I(t+1):

$$I(x+w, t+1) – I(x,t) = 0 \quad (1)$$

Where w is the displacement. A differential form of (1) gives:

$$(\nabla I)^T * w + It = 0 \quad (2)$$

This constraint is insufficient to determine the complete flow w because the problem is badly posed: one linear equation for two unknowns. We must therefore make an additional hypothesis. The methods detailed in the following offer different solutions to the problem.

- Horn-Schunk (HS) [7]

This is the global method. It is the first method of calculating the optical flow which was developed in 1980 by Horn & Schunck while assuming that the optical flow along homogeneous elements of the scene must also be invariant, Horn & Schunck propose to consider a constraint smoothing, presented as the square of the velocity gradient. The Horn & Schunk method is then based on the search for a velocity field (Vx, Vy) allowing to minimize the cumulative errors of the change in luminosity and of the square of the velocity gradient.

- Lucas-Kanade (LK) [8]

The Lucas – Kanade method is a differential method used for the estimation of the optical flow. This method was developed by Bruce D. Lucas and Takeo Kanade. It assumes that the flow is essentially constant in a local neighborhood of the pixel considered, and solves the optical flow equation for all the pixels in this neighborhood by the method of least squares. By combining information from nearby pixels, the Lucas-Kanade method can often resolve the ambiguity inherent in the optical flow equation: the aperture problem. However, since this is a purely local method, it cannot provide information about the flow within a uniform region of the image.

- Combined Local-Global Method (CLG) [9,10]

This is a method that takes advantage of the previous two methods. It is an approach which takes both the advantages of the assumption of constant luminosity as well as the constraints of spatiotemporal regularity. A new nonlinear cost function is designed with these constraints. However, dense and precise optical flow estimates are usually computationally expensive and one of their main problem is the slow execution of existing algorithms. Also, optical flow is not an exact measure of actual changes as stated. This is the perception by the vision system of changes in the scene. This perception may be noisy by varying lighting conditions, or else be completely absent in some cases, which limits the performance of this technique.

3 PROPOSED APPROACH

Fig. 1. shows an overview of all steps of our proposed approach. From the thermal images acquired, two processes are launched in parallel: the first consists of a histogram equalization with the aim of enhancing the contrast of the image which will make it possible to avoid singularities when solving the equation of the optical flow using The Lucas – Kanade method. The second process consists of a thermal binarization of the image. in fact, the goal being the search for intrusion, only the pixels whose temperature exceeds 30 ° C will be considered.

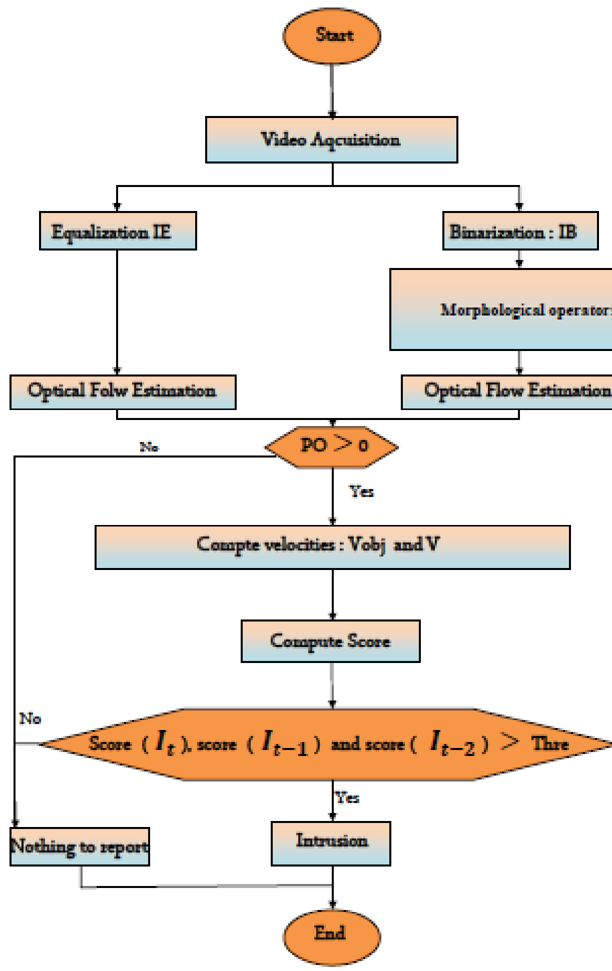


Fig. 1. *Overview of all steps of our proposed approach*

Once the thermal binarization and the histogram equalization have been carried out, a calculation of the dominant average velocity V is done on the equalized image. If the thermal binarization gives rise to one or more objects (PO> 0), a calculation of the velocity of each object is carried out: Vobj. If the velocity Vobj is very close to the dominant velocity V (that generated by the movement of the robot) then the object is considered to be part of the scene to be monitored. Otherwise, it is a human intrusion. Numerically, we propose to calculate a score (Threshold = Thre) beyond which the difference between Vobj and V shows an intrusion:

$$Thre = |Vobj-V|/max(Vobj,V) \qquad (3)$$

A final decision on intrusion is only declared if the score exceeds the threshold (Thre) on three successive images. The smaller the sampling step, the greater the number of images needed for the final decision. the choice of the threshold is experimental and depends mainly on the quality of the histogram equalization.

4 EXPERIMENTAL RESULTS

We use a mobile robot/thermal camera system which navigates in a predefined way while calculating the dominant velocity generated by its movement and projected on the video scene as well as the velocity of objects whose temperature exceeds 30 ° C. We use The Lucas – Kanade method to compute pixel velocities in both cases. The camera used is a thermal camera (FLIR A15) providing a flow of 60 thermal images per second of dimensions 160x128: Resolution in pixels: 160 x 128 with different display option fields. Detector type: Vox uncooled micro-bolometer. Spectral range: from 7.5 µm to 13.0 µm. Frame rate: 60 Hz. Standard temperature range: from -40 to + 160 ° C. Accuracy: ± 5 ° C (± 9 ° F) or ± 5% of reading. Available lenses: 9 mm. Digital data: FLIR Tools. Power supply: 12/24 VDC, TBA W max absolute. Weight: 0.2 kg (0.44 lb). Size (L × W × H): 106 × 40 × 43 mm (4.2 × 1.6 × 1.7 in). Figures Fig.2, Fig.3, Fig.4 and Fig.5 show experimental results obtained for 4 scenarios. We add in each case a red or green rectangle on the video to mention if there is or not an intrusion (Red rectangle: intrusion; Green rectangle: Nothing to report). Fig.2 show results for scenario 1 when no intrusion exists or machine or fixed object having a high temperature. Fig.3 shows scenario 2 with a human intrusion. Fig 4. Shows the third scenario with human intrusion and fixed object (computer) with high temperature. Finally, fig. 5 shows scenario 4 with fixed object (computer) with high temperature. We can see easily that the proposed approach is very robust, mainly when thermal camera gives a suspicious object (computer) but velocity computing in both suspicious object and all image gives a very near values and so very low score.

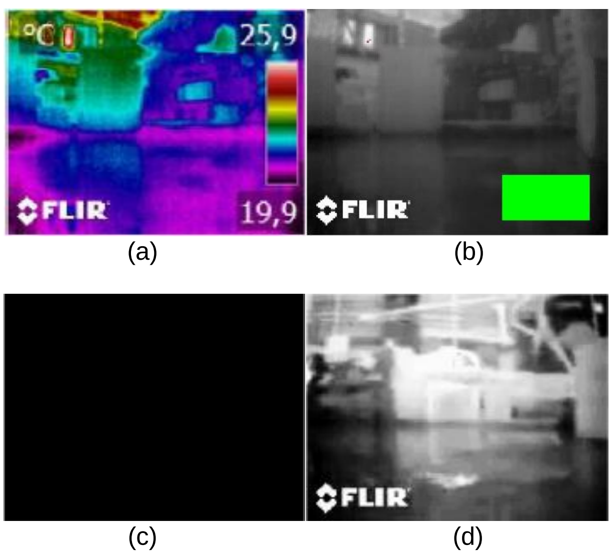
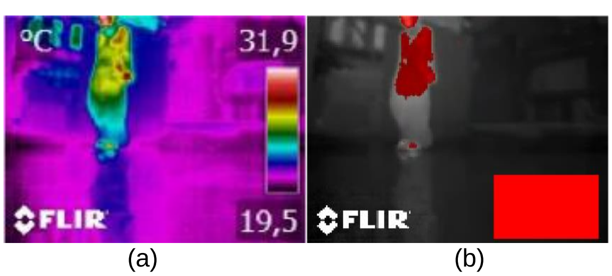


***Fig. 2**. Scenario 1. Frame 8. (a) Original image, (b) Final result, (c) Thermal binarization, (d) Histogram equalization.*



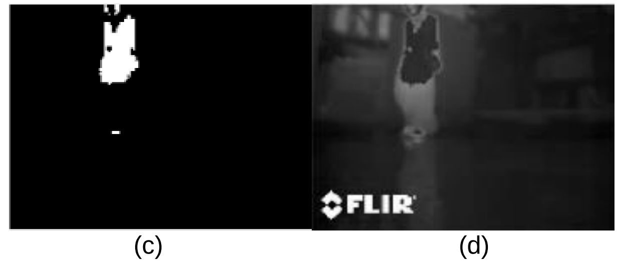


***Fig. 3**. Scenario 2. Frame 650. (a) Original image, (b) Final result, (c) Thermal binarization, (d) Histogram equalization.*

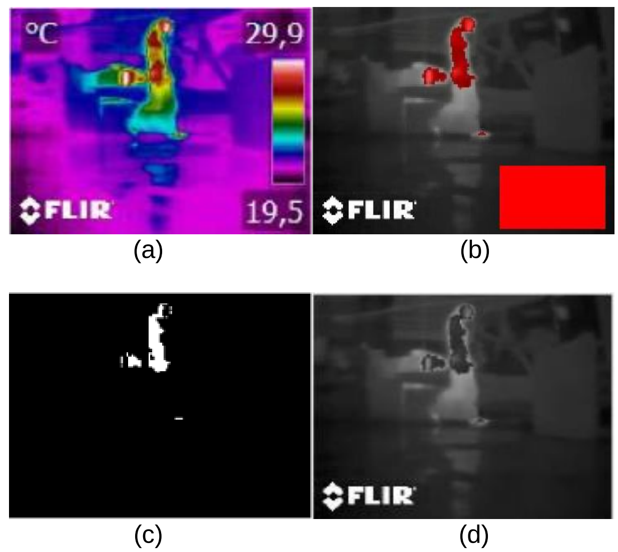


***Fig. 4**. Scenario 3. Frame 1700. (a) Original image, (b) Final result, (c) Thermal binarization, (d) Histogram equalization.*

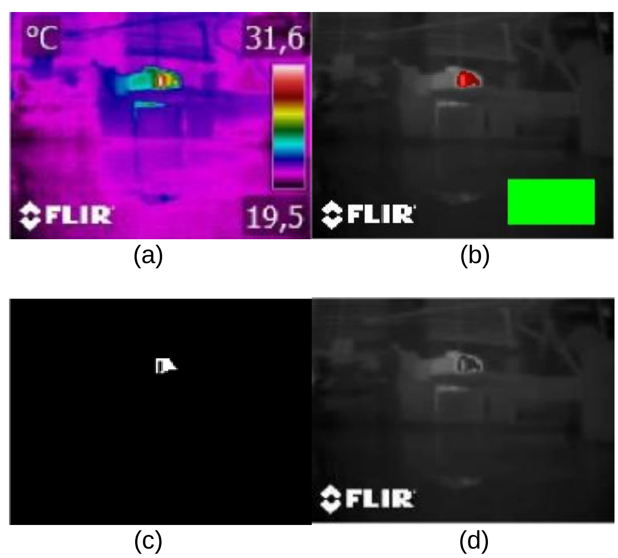


***Fig. 5**. Scenario 4. Frame 1780. (a) Original image, (b) Final result, (c) Thermal binarization, (d) Histogram equalization.*

5 CONCLUSION

In this paper we introduced the integration of a perceptual capacity for a mobile security robot in order to detect a possible intrusion in nocturnal environment. A thermal Camera

(FLIR A15) is used to extract possible intrusion. An algorithm based on the calculation of the optical flow (with Lukas-Kanade method) of the scene is proposed in order to differentiate between a real intrusion and an existing heat source (Computer, Machine, ... etc.). Due to the very low contrast present in thermal images, we proposed to perform a pre-processing step based on histogram equalization. The idea is to avoid any possible singularities when we solve the optical flow system of equations. To valid our new approach, experimental results on real cases are presented. These results show that the proposed approach is very robust mainly when thermal camera gives a suspicious object (computer) but velocity computing in both suspicious object and all image gives a very near values and so very low score. The proposed system uses wireless communication to send images to main computer. Instead of this, we can perform an embedded code using FPGA platform. To improve the software part, some test should be performed with other optical flow resolution methods like Combined Local-Global Method (CLG) or stochastic methods.

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