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METHOD OF OBJECT TRACKING IMPLEMENTED IN MULTISENSOR SECURITY SYSTEM

Abstract: Recent military conflicts revealed the need to increase security for military convoys and bases. More and more sophisticated techniques of camouflage and warfare are utilized by for example terrorists. This situation demands a development of sensor systems for automatic detection and tracking of threats. In article the concept of multi-sensor system for detection and tracking objects is presented. System is built of radar, visual and thermal camera. Radar is used for wide area monitoring, detection and preliminary localization. Visual and thermal camera is used for precise localization and tracking of objects being potential threat. In article the principles of system operation are described. In article the visual object tracking algorithm used in the system is described. The security system described in this paper can be used as an early warning system for mobile units or temporary bases.

METODA ŚLEDZENIA OBIEKTÓW ZAIMPLEMENTOWANA W WIELOCZUJNIKOWYM SYSTEMIE OCHRONY

Streszczenie: Doświadczenia z ostatnich konfliktów zbrojnych ujawniły potrzebę zwiększenia bezpieczeństwa konwojów oraz baz wojskowych. Coraz bardziej wysublimowane techniki kamuflażu oraz walki stosowane na przykład przez terrorystów wymagają rozwoju systemów wieloczujnikowych do detekcji oraz lokalizacji zagrożenia. W artykule przedstawiono koncepcję wieloczujnikowego systemu do wykrywania i śledzenia obiektów składającego się z radaru, kamery rejestrującej obraz w świetle widzialnym oraz kamery termowizyjnej rejestrującej promieniowanie podczerwone. Zastosowanie radaru umożliwia detekcję zagrożenia oraz wstępną lokalizację, natomiast czujniki w postaci kamery dziennej i kamery termowizyjnej zapewniających obserwację obiektu oraz jego śledzenie. W artykule przedstawiono zasadę działania systemu, oraz omówiono algorytm do śledzenia obiektów na obrazie zastosowany w urządzeniu. Wieloczujnikowy systemu ochrony zrealizowany według zaproponowanej koncepcji może stanowić swoisty system wczesnego ostrzegania przed zagrożeniem.

1. Introduction

Recent terrorist attacks and possibilities of such actions in future have forced to develop more reliable and intelligent security systems for critical infrastructures. One of the common targets of terrorist attacks is a critical infrastructure like airports, harbors, nuclear power plants, pipelines, encampments and other sensitive sites. Countermeasure for terrorist and criminal threats is a physical protection system, which integrates people, procedures and equipment. Popular and widely-used concepts of perimeter protection with double fence and zone sensors [1, 2, 3] supported by area illumination and daylight visual cameras are now replaced by multi-sensor platforms. Multisensor platform can integrate (i) day/night cameras for luminosity and color contrast detection, (ii) infrared cameras[4] for thermal contrast detection and (iii) millimeter-wave radars detecting the electromagnetic radiation reflected from the target. Efficiency of the system operator can be increased by enabling automatic detection of intruders using different detection methods. On the other hand, increased amount of information form multi-sensor platform can decrease operators' efficiency therefore the proper visualization information from sensors have to be employed. Advanced visualization methods of an observed scene and video tracking of an intruder can effectively increase operator reaction efficiency enabling faster threat suppression. The key element of a multi-sensor security system is adaptive, intelligent image analysis module. The use of advanced image processing methods makes it possible to automatically detect the intruder and launch automatic tracking of its movement. The important advantage of multi-sensor system is scalability, which applies to both observation range and the size of protected area.

2. Concept of security system

The sensor platform integrates millimeter-wave radar (STS-1400 by ICX) and camera system (PTZ 50MS by FLIR Systems). PTZ 50MS module consists of two cameras for daylight operation and thermal vision. Radar is used as a wide area sensor for preliminary detection and localization, while movable cameras with narrow field of view are used to identify objects, precisely locate them and track them while they move. The area coverage of such platform is schematically presented in Fig. 1.

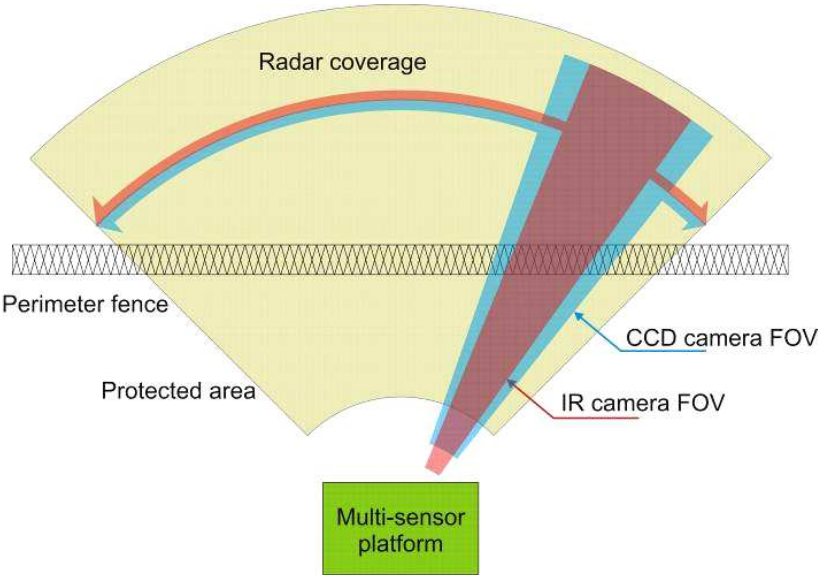


Fig. 1 Observation areas of particular components of a multi-sensor platform.

Radar STS 1400 can detect a human moving at the velocity of about 2m/s at the range of 800 m, under normal atmospheric conditions. Radar is a primary sensor of the security system. During the operation of the system, the radar data are analyzed. When the radar detects that the intruder trespasses the protected area, the control module of the system calculates location of the object and moves cameras so they can observe the invaded area. The movement capabilities of the cameras (visible and infrared) are +30°/- 45° in elevation and 360° in azimuth. Sony's FCB EX-980SP visual camera used in the system has a CCD imager with 800 000 effective pixels, zoom lens with a FOV changing from 42° to 1.6° and 26x electronic zoom. From these parameters we have estimated effective human detection range to about 880 m, and a vehicle detection range to about 2.2 km. Second camera is a thermal camera unit with uncooled focal plane array (FPA). It has 8-14 μm spectral range and 320 x 256 pixel resolution. Cameras lens provides FOV of 14° in horizontal axis and 10° in vertical axis. This camera can detect a human from 650 meters and a vehicle from about 2 kilometers.

The software instrumentation of the system is based on FLIR Nexus system [5], which provides software interface to both cameras and ICX radar. However, the Nexus system does not fulfill all assumed functions. Image processing, target detection, tracking and sensor data merging are performed by separate software.

3. Multi-sensor platform design

A complete multi-sensor unit is mounted on height to provide proper visibility to all sensors. A model of sensor carrier platform is presented on figure 2.

Fig. 2 Design of the multi-sensor platform: radar dome (above) and cameras (below).

As mentioned earlier the radar is a preliminary detection system used to guide cameras to focus on the area of interest. Both visible and infrared cameras are moved synchronically and their areas of view are overlapping. Nevertheless the fields of view of these cameras are not identical, the visible light camera can cover wider range. A view from both cameras composed to one image presented on figure 3 shows the actual area coverage monitored by image processing unit.

Fig. 3 The composite image obtained by fusion of visible camera image and thermovision camera image.

4. Tracking procedure

Tracking algorithm is performed by separate computing module. Automatic tracking module ensures that the intruder won't be lost from the sight of the cameras. In order to track an object, first the detection has to be performed. Object detection is performed by radar and the preliminary localization of the object is obtained. The cameras are moved to the interested location. Then the visual detection can be performed, but in this concept of multisensor platform, visual detection was omitted, and object localization was taken from radar data only. After object localization, the tracking algorithm has to define an object and its fundamental parameters like size. In this concept of multisensor platform a fixed size of average human was used. After object definition the tracking algorithm can be performed.

Multi-sensor security system is expected to have fast guaranteed reaction time; therefore it can be treated as a real-time system. Consequently, emphasis was put on the suitable tracking method capable of real-time operation. Several tracking algorithms were considered, like target feature-tracking Mean-Shift algorithm [6, 7, 8] and Sum-of-Squared-Differences (SSD) gradient algorithm [9, 10]. During the simulations, Mean-Shift approach was inefficient when the tracked object covered small number of pixels. As a result, modified version of SSD algorithm was adopted to perform the tracking task in a security system.

Gradient SSD algorithm analyzes the differences between two consecutive frames to find the target location. The target movement is estimated by calculating spatial and temporal gradients.

SSD coefficient defines the difference between two consecutive fragments of the image. Both analyzed fragments have to be of the same size and they are usually rectangular. Assuming, that the two fragments (called "windows") are ($2h+1$) by ($2h+1$) in size and that they centers have the coordinates (x,y) and (u,v) respectively, the SSD coefficient can be calculated according to the following relation:

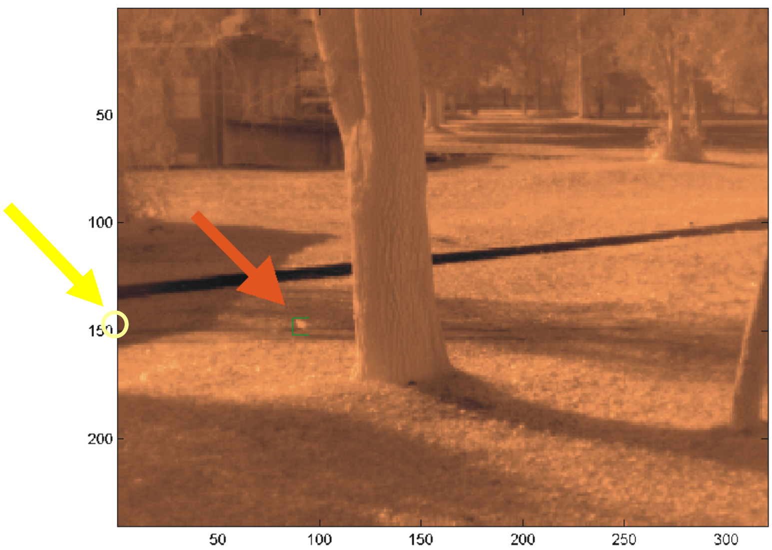
$$SSD = \sum_{i,j} \left[\left(f_{n-1}(x+i, y+j) - f_n(u+i, v+j) \right)^2 \right], \qquad (1)$$

where:

$i, j \in [-h, h]$ - point coordinates with respect to the centers of compared fragments, h – target size coefficient.

If we assume that the tracked object is present on the fn-1 frame and is centered around (x,y) coordinates, then finding this object on the consecutive frame means, that the point (u,v) is to be found, for which the SSD coefficient has minimal value. The point (u,v) is then the center of the tracked object on the fn frame. The search for the minimal value of SSD coefficient is performed in the neighborhood of the past location of tracked object. The size of the search area depends on the assumed object's dynamics. It means that the frame-to-frame movement range should be estimated. Maximal value of the movement (in pixels) should correspond to the tracking range. The bigger is the tracking area, the more calculations must be performed. To minimize the required number of calculations the frame-to-frame movement should be small. For constant observation parameters and object's dynamics it can be accomplished by increasing the frame rate.

As a result of calculations, the values of SSD parameters are obtained for the elements of the image. This set can be presented as a matrix having the same size as the search area. Sample results for a tracked object are presented in Fig.5. The 3-D plot shows the SSD values as the function of the position of corresponding image fragment. Minimal value of SSD coefficient indicates the greatest resemblance to the model object.



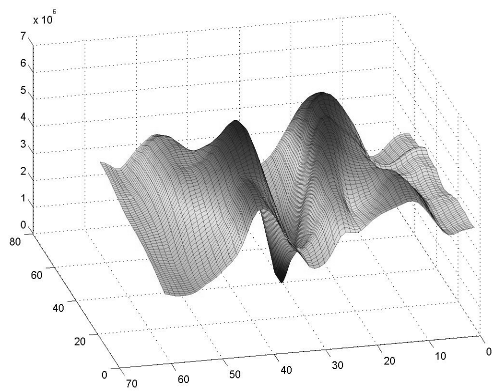
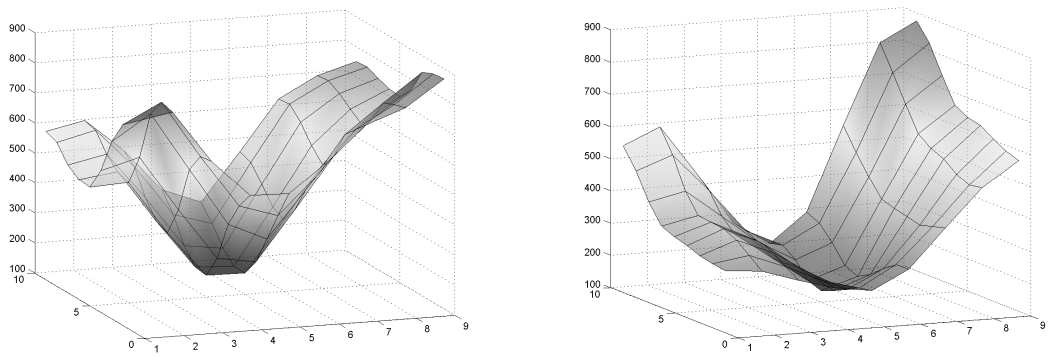


Fig. 4 SSD coefficients (right) for the image areas in the neighborhood of tracked object (left).

The tracking procedure described above is then repeated for the consecutive frames. The area, where the object was found is treated as a reference model object for the movement calculations on the next frame. If the algorithm derives the next location incorrectly, then for the following calculations an empty area (not containing the object) becomes the reference model. The model object is updated unconditionally traditional version of SSD algorithm, so it may happen that the original shape will be forgotten and the tracking lost. Similar effect may occur when the object becomes partially covered, and then due to information loss the next location will not be successfully calculated. It is clear then, that this algorithm has good frame-to-frame efficiency, but long-term effectiveness could be less impressive. Small disturbances, coverage, collisions or noise may lead to the loss of tracking.

This disadvantage of the algorithm was suppressed by developing a conditional model update procedure [10]. During standard SSD algorithm operation, the set of SSD coefficients around previous object position is calculated. The area with smallest SSD coefficient contains the tracked object. In modified version of SSD algorithm the information about ambiguity of object localization is also estimated. To do this, besides finding the smallest SSD coefficient, the whole set of calculated SSD coefficients is analyzed. It turned out that for undistorted objects, the set of SSD coefficient shows sharp and distinctive minimum that indicates object localization, but for distorted noisy objects image the minimum is not so clear. The example of calculated SSD sets for undistorted object a) and distorted one b) around objects localization is shown in fig. 5.



a) b)

Figure 5 Set of SSD coefficients calculated for area in objects neighborhood for undistracted object a) and for partially obscured object b).

To distinct reliable position estimation from noisy one the special SSDVar coefficient was developed:

$$SSDVar = \sum_{i\in\langle -h,h\rangle,\, j\in\langle -h,h\rangle} \left[\left(SSD[i,j] - \min(SSD[i,j]) \right)^2 \right], \quad (2)$$

This coefficient can be used to evaluate the quality of objects localization. High SSDVar indicates that the minimum of SSD coefficient was clear. Low SSDVar indicates that the estimated localization is not so reliable. This coefficient was used to determinate the model update procedure. When the SSDVar parameter was higher than arbitrary threshold, model update procedure is made like in traditional version of SSD algorithm. When SSDVar is lower then the threshold, the model update procedure is skipped. This prevents the algorithm to forget the object model when the new estimation of object localization is unreliable.

Tests revealed, the modified SSD algorithm is quite effective when used on thermal images. The example of object's tracking is presented in Fig. 6.

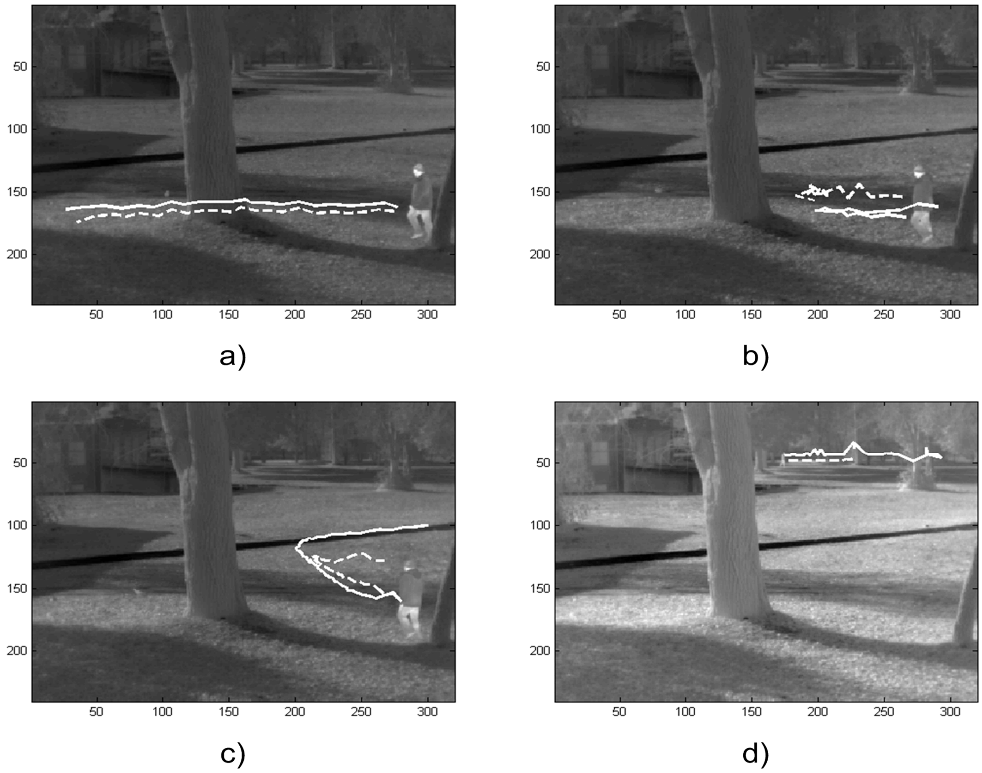


Fig. 6 Results of tracking using traditional SSD algorithm (dashed line) and modified SSD algorithm (solid line)

5. Conclusions

Research on tracking algorithm proofed that it can be adapted to multisensor security system for thermal vision tracking greatly improving its capabilities. It can provide tricking of object previously detected by another sensor, here the radar. The next step of the research will involve using estimated objects trajectory to allow camera to follow object of interest.

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