PERFORMANCE CHARACTERIZATION OF MOTION SENSORS EMPLOYING STEREOSCOPIC TRACKING

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Abstract: This work describes a method for automatic quantification of the detection performance of passive infrared motion sensors by using a stereoscopic tracking system. This method enables one to compare the performance of different sensors available in the market by employing the same criteria. A test protocol developed by UL/Sandia Labs was used.

Keywords: Passive infrared sensor, stereoscopy, engineering applications.

1. INTRODUCTION

Passive infrared (PIR) motion sensors have been extensively used in domestic and corporative electronic security applications. Its principle of operation is based on the employment of a pyroelectric detector, which is responsible for transducing the incident IR radiation to an electric signal [1].

Associated with the photodetector and conditioning circuitry, there is a multi zonal Fresnel lens array, which monitors different spatial zones and collects the IR radiation from a body that moves inside the monitoring volume [2], as shown in figure 1. When a human corporal mass moves through the volumetric monitoring field of the sensor, different Fresnel lens element focuses the IR radiation on the pyroelectric detector, generating an electrical signal at its output [2].

In order to validate the functional performance of the sensor, a climate-controlled test laboratory facility (10 m by 14 m by 3.5 m size) was constructed, following a standard procedure published by the Interagency Advisory Committee on Security Equipment – Intrusion Detection Subcommittee (IACSE protocol), developed by UL (Underwriters Laboratories), Sandia National Laboratories e SIA (Security Industry Association) [3]. A typical test to quantify the functional performance of a PIR sensor is the so-called “walk through test” (figure 2b). The goal is to determine the location of a human target moving along the detection range of the sensors. The test consists of mapping the detection range of the sensor (distance and field of view). Beginning outside the detection area, along the arc nearest the sensor, the person (test target) shall move forward along the arc until the sensor is triggered, and the target position must be recorded and displayed by the system.

Figure 2 shows the test facility used to evaluate the sensor’s performance. Figure 2a shows a schematic view of the pattern used for mapping the volumetric detection of the sensor, extracted from the IACSE standard; figure 2b is a photography of the a climate-controlled test laboratory facility used in the experiments, showing a comparative test to determine the detection zones among several sensors (inset). The output data of such a test is of a map for a detection range of the sensor, as shown in figure 3.

A low-cost suitable way to perform the test in an automated manner is to track the target position by using stereoscopic technique. Stereovision is a method that uses same properties that human vision and is one of the main technologies for future distance measurements techniques, from mobile robots to intelligent vehicles [4-9].

In most stereovision applications two main issues must be addressed: high speed image processing and minimization of...
the impact of distortions on a stereo systems, introduced by the image acquiring optics. The main effort is to implement algorithms, which can compensate image distortions as well as be able to process 3D information in real time systems. In many cases a natural choice is implement the solution by using embedded systems such as a field-programmable gate array (FPGA) [4][5].

Although the extraction of 3D information from 2D digital images is a relatively old technique - the first works was made by 1838 by C. Wheatstone with binocular images to simulate three-dimensional effect [6] - it is still used in several applications where distance measurements are of major importance. In automotive applications Bhownick et al used an improvement of a well known triangulation method to track specific points from both camera images [7]. Surgailis and co-workers present a stereo vision based traffic analysis system where the stereovision system is part of an environmental analysis system embedded in a intelligent vehicle, with laser (LiDAR) and RADAR sensors, and ultrasonic sensors [4]. Mrovlje et al implemented built in functions from a distortion model in order to correct image distortions [6]. Baek and co-workers present an improvement of distance measurement algorithm on stereovision system when an object is located outside the optical axes in the overlapping area of the two cameras [8].

Sun and co-workers have developed a binocular system to measure distance of vegetation to power lines [9].

In this application the time responses are relatively slow, allowing one to employ a solution on microcontroller based hardware and C# language software. Another feature of this application is that the tests are performed in well-controlled indoor environment, with discretized points in the sensor’s detection domain (figure 2b). The main goal is to determine the location of a human target moving along the detection range of the sensors, and synchronize it with detection events generated by the sensor.

2 METHODOLOGY

In this work we used two low-cost cameras (model SPC230NC from Philips), attached to servomotor positioner which received their displacement by USB communication between the Computer (PC) and a hardware based on microcontroller (model 18F4550 from Microchip). The cameras are also used to provide USB communications to image capture system using a toolbox from OpenCV by Intel corporation [10]. The routines for calculating the distances were made in C# language, using Visual Studio development environment by Microsoft. Since the cameras move to cover all the distances, some changes to the method proposed by Baek et al. [8] was performed. Because cameras are not aligned with the target base and are not positioned at the center of the images, distances calculations based on the procedure described in section 2.1, were performed.

2.1 DISTANCE MEASUREMENT BASED ON BINOCULAR STEREO VISION

Figure 4 shows a schematic view of the experimental setup. The reference position was used to find inclination angles of cameras:

$$\theta_{1R} = \tan(h/d_{1R})$$
$$\theta_{2R} = \tan(h/d_{2R})$$
Fig 4 - Schematic view of experimental setup cameras. The goal is to find inclination angle of the cameras $\beta_1$ and $\beta_2$.

and

$$\alpha_{1R} = \frac{y_2}{2} + \tan^{-1}\left(\frac{\left(res/2 - x_{1R}\right)\tan(y_2/2)}{res/2}\right)$$

$$\alpha_{2R} = \frac{y_2}{2} - \tan^{-1}\left(\frac{\left(res/2 - x_{2R}\right)\tan(y_2/2)}{res/2}\right)$$

(2)

Then

$$\beta_1 = \theta_{1R} + \alpha_{1R}$$

$$\beta_2 = \theta_{2R} + \alpha_{2R}$$

(3)

With camera inclination evaluated, it is possible to find the target positions:

$$\theta_1 = \alpha_1 + \beta_1$$

$$\theta_2 = \alpha_2 + \beta_2$$

(4)

(5)

By using the initial reference $(0,0)$, it is possible to estimate the distances:

$$\hat{x} = d_{1R} - \frac{d \cdot \tan(\theta_2)}{\tan(\theta_1) - \tan(\pi - \theta_2)}$$

$$\hat{y} = h_{1R} - \tan \theta_1 x$$

(6)

where:

- subscript R: about reference
- res: horizontal pixel resolution from camera
- $\gamma$: open angle from camera
- $\beta$: camera inclination
- $x$: pixel position of target
- $\hat{x}$ and $\hat{y}$: real position estimated

3. RESULTS AND DISCUSSION

Initially we analyzed the tracking done by the algorithm camshift, [10]. He found the center of mass presented by target, which was established by an orange rectangle placed on the person who is traveling the circuit. The stereoscopic sequences and segmentations made by the algorithm to find the center of mass of the target is shown in figure 5.

Fig 5. Stereoscopic images of the target and their segmentations to find the center of mass.

For this tests the target moves along the camera longitudinal distances, starting from the beginning of the field of view of both cameras up to the maximum length of the room. Three repetitions were performed for the three latitudinal distances chosen, all of which are kept 0.85 m apart, due to pre-existing marks on the floor where the validation tests were performed.

In Figure 6 we plotted the average of three measures. The
standard deviation of the measurements was very low, with the highest value of 0.09m (2.9%).

Two polynomial adjustments were performed: for the vertical coordinates (x), a first order polynomial fitting was used, and for the horizontal distances (y) a second order polynomial fitting was used. In future works we will test the routines proposed by [11][12], where the distortions made by cameras are corrected before distance evaluation.

4. CONCLUSIONS

A method to perform distance measurements from a human target with respect to a PIR sensor employing the technique of binocular stereovision was proposed. The precision of distance measurements was evaluated for targets at large distances. It was observed that when the target is closer to the edges of images, position error increases due to optical aberrations in the camera optics. These errors were corrected by using polynomial fit. Despite the observed errors, a good reproducibility was observed (standard deviation of 2.9%). These errors can also be corrected by keeping the target located near to the optical axe of the camera, assuring a paraxial regime during image acquisitions. Finally it was observed that the methodology used with the appropriate adjustment will be able to make measurements with precision appropriate for use in the procedure of measurement of PIR sensors according to the IACSE protocol.

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REFERENCES


