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An optical method for a bomb scoring system

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***Abstract*— This paper discusses an optical method for a bomb scoring system. It is based on two arrays of fixed camera, used as sensors, and it employs trajectory estimation to compute the point of impact of ballistic bombs. It is designed according to the accuracy and speed requirements established by the Garabato Test Range in Argentina. The performance of the designed system is tested with scaled experiments and the results are shown.**

***Keywords*— video processing, weapon scoring system, digital processing, computer vision, object detection.**

1. INTRODUCTION

The automatic detection and localization of objects is a challenging problem, studied by many research groups [1, 2]. One of the applications that has boosted this line of investigation is the automatic determination of the impact points of bombs during the training of military pilots. It is desirable for the trainee to have scoring information of an attempt before launching the next bomb so as to correct the aim. The information of the impact points of the bombs is also useful to eventually recover the ordnance once the exercise is over, thus minimizing costs and contamination [3]. Applications for civilian purposes have also been found for this system [4, 5, 6].

Several kinds of approaches have been used for object localization up to the present, using different sensor technologies (acoustic, optics and radar) [7, 8, 9, 10]. The analysis of the very high frequency radio waves reflected from their surfaces used for the detection and localization of distant objects is a common method in military applications as well as in navigational systems [11]. A mayor problem of this method is the cost of the sensor used (radar). The acoustic localization method uses two or more microphones to determine by triangulation the impact point location [12]. The disadvantages of this approach are the heavy computational load involved and the need for constant professional re-calibration, especially when the terrain is exposed to heavy rains and/or wind which modify the acoustic propagation conditions. Most optical location methods depend on the visual detection of the practice bomb when it hits the projected target with a binocular camera system. However, since a certain minimum distance is required to guarantee the safety of the personnel, a smoke cartridge is used. Consequently, the wind and the vegetation may affect visual conditions. This led to the design of the method described in this paper.

The object of the research carried out is to develop an automatic scoring system with an accuracy of less than 1 meter and real-time data feedback to the pilot to be used in a test range in Garabato, Argentina Other factors that have to be taken into account are the following: due to the need to preserve the native vegetation, visual contact with the target surroundings is not possible; furthermore, the system should not require that the personnel using the scoring system have extensive mathematical, computational, or procedural knowledge, and the costs for the execution of the project have to be kept low. This paper describes the optical impact point localization method based on the trajectory of the bomb developed on the basis of the above-mentioned factors. First, the system requirements and specifications are described. Next, the proposed method is explained. Finally, the experimental results are given to validate the efficiency of the method proposed.

2. SYSTEM REQUIREMENTS AND METHOD

2.1. System requirements

The system began to be developed in order to improve the functionality of the Garabato Test Range which is part of the Reconquista air base (28º54′29″S, 60º09′00″W), in the province of Santa Fe, Argentina. The Test Range that belongs to that air base is used to train the aircrew in the skills necessary to handle ballistic bombs. To accomplish this purpose, during training missions, practice bombs of 11 kg and 65 cm (Fig. 1) are dropped from a flying aircraft (Pucara) towards a target marked on the ground.

Figure 1: MK-76 Practice Bomb Mod.5.

The Garabato Test Range is a four-kilometer by six-kilometer rectangular air field. The target is a circular area with a 25-meter radius. Two observation towers, located at 1000 meters from one another, are at a distance of 800m each from the target. The tropical vegetation is very dense on the Test Range, increasing the difficulty of the observation and maneuvers. To improve observability, pathways have been created from each tower to the center of the target (Fig. 2). Nevertheless once on the ground, it is hard to localize the practice bomb from the towers mostly because of the vegetation.

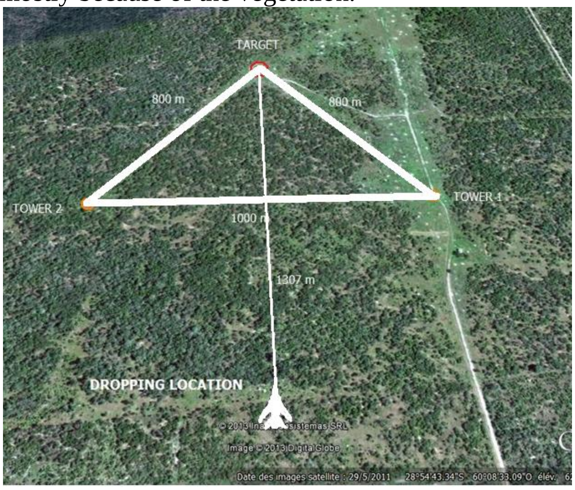

Figure 2: Garabato Test Range.

In order to guarantee a good shot, the Pucara planes have to fly at an altitude ranging between 380 m and 500 m, and at a 460 km/h velocity. The dropping position should be at a distance of about 1300 m from the target, on the axis referenced in Figure 3. The final velocity of the ordnance is estimated to be around 100 m/s.

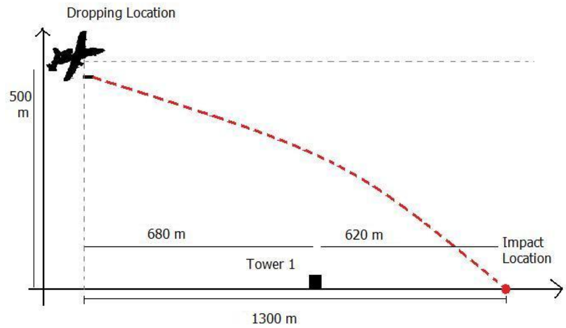

Figure 3: Trajectory of the bomb and location of the tower (lateral view).

During the firing practice, it is desirable for the pilot to have the scoring information of the previous shot, in order to rectify his/her aim. Currently there are two methods available in the Test Range, an acoustic method and a manual method. The acoustic one is not functional at the moment due to lack of availability of trained personnel to calibrate it in the area. The other method consists in two witnesses, located in the towers, observing bomb impact and measuring its angle relative to a fixed direction. Then, the impact location is determined using trigonometric calculations. To allow for the observation of the impact point, the bomb emits a smoke signal.

Even when this method allows at times the determination of the location of the impact, it lacks precision and sometimes, it is difficult to observe the smoke coming from the cartridge (the height of the vegetation hinders smoke detection from the towers). Furthermore, the time required to calculate the scoring does not allow real time correction of the pilot´s aim.

In view of the above, a new method is required in order to improve precision and to shorten the data processing time. More specifically, if it is to enable the bomb recovery, the method error should be less than 1 meter. Moreover, the data processing should not take longer than a minute if it is to be used for real time practice for the pilots. Another factor that had to be taken into account was the need to keep the costs low and the development of a method simple enough to be used by people with little background knowledge on the system operation.

2.2. Proposed method

The selected method, considering all these requirements, consists in putting two arrays of fixed cameras in two different observation places (the towers of the Garabato Test Range can be used for instance). The aim is to record the bomb hitting the ground. Then, after applying an image processing algorithm, the bomb trajectory can be estimated and impact location determined.

This method requires two main stages. First, the video data is processed, obtaining the position of the bomb in the image (in pixel coordinates). Then this data is translated into absolute geometric measures, and, the trajectory and the point of impact are estimated.

2.2.1. Video processing stage

In applications that employ fixed cameras, background subtraction is a widely used method to enable target detection and localization in specific image frames. Several approaches are known to separate foreground from background. If the background image is known, a simple thresholding yields the foreground. Another way of solving this is the difference picture method [13], i.e. the foreground is detected by subtracting each pixel of different frames of the sequence and then thresholding is used.

This approach assumes that the objects in the foreground are moving continuously because the foreground cannot be detected when there is no motion between different frames. This is similar to approaches based on the optical flow [14]. The calculation of the optical flow is computationally expensive, and special hardware is often used for real-time applications.

To ensure the system's data processing speed, a basic difference picture method is used. This method should suffice given the characteristics of both the background and the bomb visual aspect and dynamics. It is worth noticing that in most frames, when using an interlaced scan image sensor, the bomb may appear twice; and, once the difference method is applied, four different locations of the bomb can be detected (Fig. 4). Each of these locations can be used to reconstruct the trajectory.

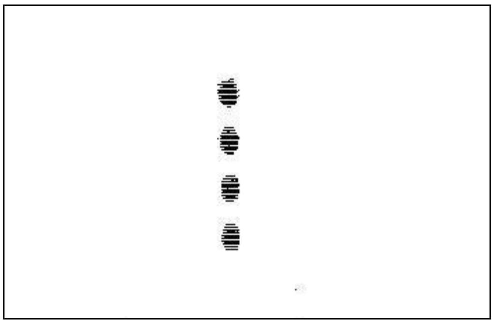

Figure 4: Foreground detection with the difference picture method.

Once the foreground is detected, a template matching algorithm is applied to detect and localize the bomb [15]. Generally, to guarantee a correct matching of the template, the target template should have at least 8 pixels. In view of this restriction, each camera field of view at the target distance should cover 50 meters or less. Therefore, in order to get a wider field of view, two camera arrays are needed.

Figure 5: An array of video cameras.

The information generated by this stage is only useful if the camera position and attitude are known. The relationship between pixels and angles is also needed in order to translate the pixel position to an absolute angle. To identify this information, at least two reference marks within the field of view of each camera need to be provided. These marks are supplied by surveying sticks (that should be positioned near the target in the Test Range).

2.2.2. Geometric estimation stage

During this stage, the system calculates, for each camera, the half-lines extending from the camera to the position of the bomb at various times. These half-lines are used to define a plane for each camera. These planes contain the positions of the bomb detected in the images mentioned before. Then, the trajectory is estimated as the intersection between the two planes (one per camera) that fits best all the half-lines. At this point, a simplification is applied, modeling the last stage of the trajectory of the bomb as a straight line. Given the duration estimated of the portion of the trajectory captured (0.33 seconds maximum) and the direction (maximum 20 degrees of inclination from the vertical position) and velocity (100 m/s) of the bomb at this final stage, this simplification will not add any significant error to the estimation of the point of impact.

In the first step of this stage, two angles (αpitch, αyaw) are calculated to define the half-lines containing each location of the bomb detected. Both angles are not measured from the camera optical axis, but from an absolute frame of reference (Fig. 6 and 7).

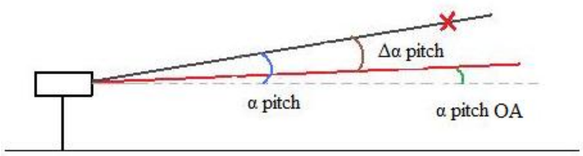

Figure 6: αpitch for a given position (lateral view)

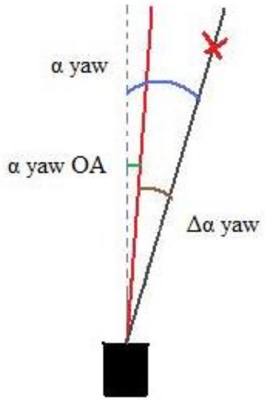

Figure 7: αyaw for a given position (top view).

The half-lines calculated in the previous step are the only location information provided by the image processing stage, because depth cannot be extracted from the video data. That is the reason why a second camera is needed. The exact location of the bomb can be calculated by the intersection between the lines of each camera. Nevertheless, this does not guarantee that a picture of the bomb is taken at exactly the same time. That is why two planes are calculated (each containing one camera and the bomb trajectory), and on the basis of the intersection of those two planes, the bomb trajectory will be computed (Fig. 8). Then, the intersection between this trajectory and the ground topography gives the estimated impact location.

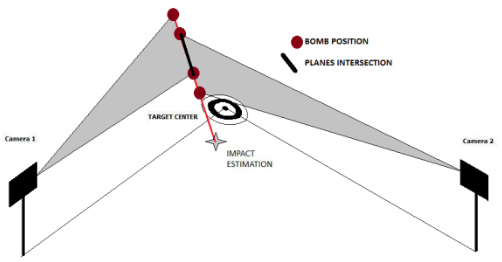

Figure 8: Method used for impact location estimation with two fixed cameras

2.3. Experimental results

To test the feasibility of this system in Garabato and its performance, a scaled experiment was performed. During this test, a 5 cm ball was recorded while falling at a distance of 50 meters from two fixed cameras for a total of 15 times. The positions of the correct impact points were marked to enable the calculation of this method error at a later stage. The positions were measured taking one of the impact points (12^{th}) as reference.

Within the cameras field of view, five stakes were placed to perform the camera calibration (Fig. 9 and 10). From those reference points positions in the picture, the attitude of the camera (αpitch and αyaw of the optical axis) was calculated and IFOV (angle per pixel) was estimated (Ec. 1 and 2).

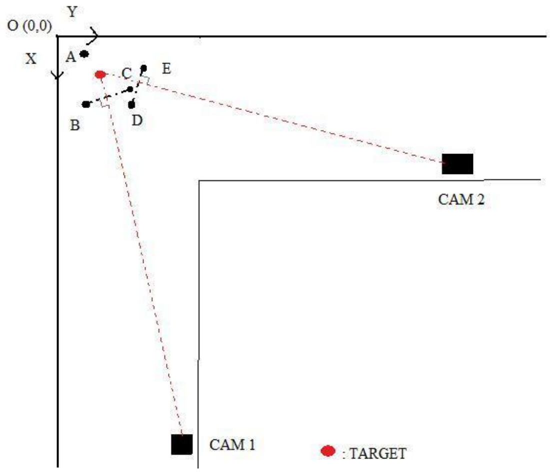

Figure 9: Cameras and stakes distribution for the experiment (top view)

Figure 10: Stakes positions in the picture

$$IFOV_h = \frac{\Delta angle}{\Delta pixels} = 0.0052 \qquad (1)$$

$$IFOV_v = \frac{IFOV_h}{1.15} = 0.00457 \qquad (2)$$

Next the images obtained from the videos were processed in a program developed in Matlab that also solved the plane estimation and intersection, yielding the impact points estimation. The average time needed to process the data was of 0.8 second per shot in an Intel(R) Core(TM) i7-2600 CPU 3.4 GHz. The results obtained are shown in table 1.

Table 1: Distance between the estimated and real values

Number of shot	error [cm]
1	5.8
2	4.4
3	5.9
4	3.3
5	3.8
6	1.7

7	2.3
8	7.2
9	5.0
10	2.9
11	2.7
12 (ref)	0
13	2.1
14	1.1
15	3.8
Mean	3.47
Standard deviation	1.96
Maximum error	5.9

If the scale is taken into account, and considering that the most important scaling factor is the field of view, the mean error would have been of 53 cm with a maximum error of 90 cm at real scale.

3. CONCLUSION

The proposed system for automatic bomb scoring in the Garabato Test Range is accurate and fast enough to accomplish the requirements needed for the application. The extrapolation of the results of the tests at scale allows for a prediction of the impact point with an estimated mean accuracy of 53 cm and processing times of less than a few seconds. It could be programmed, so as not to require specially trained personnel (even for the calibration stage) and it would improve the functionality of the Test Range. The system shows an effectiveness of 100% with good illumination and a target template of 11x11 pixels.

Before proceeding with the implementation of this system, more tests are needed in location. The determination of the optimal camera field of view is essential to achieve the best cost/effectiveness ratio.

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