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Billiard Game Parameters Calculation Using a Depth Camera for Augmented Reality Applications

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Abstract

The billiard game presents a challenge for players who have to imagine the ball paths, this game raises an issue that requires the application of the classical mechanical physics. The objective of that work is to generate a tool that calculates the ball paths on a billiard table, using an infrared camera as a depth sensor and a projector to indicate the results of the calculated path; using the balls and the cue contours, the principles of mechanical physics are applied dynamically to diagram the possible move in real time. A projected image is obtained over the table, which generates an absolute realism feeling, also the opening angle and use of the depth sensor raise on the surface of the table, which allows to calculate 4 rebounds of the projected path, all this with less than a one second delay, which generates the fluidity feeling for the simulation. A prediction system for the billiard game was obtained, however it does not guarantee the success of the play through external conditions, nevertheless it can give a good idea of the behavior and interaction of the balls. regarding the acquisition of the image, the system due to the changes of environmental light conditions.

Keywords: Augmented Reality, Image segmentation, Machine vision, Object recognition

1 Introduction

Augmented reality applications use a series of artificial intelligence techniques such as: neural networks [14], Vector support machines [9], Machine learning techniques [3], color segmentation [4], to achieve results that increase the user experience in different areas [10] [13], either by mixing reality with the interaction of objects with augmented reality [8] or just by performing projections of images, symbols [7], information or simple lines projections that simulate the possible balls trajectories in the billiard game.

There have been some augmented reality developments applied to the billiard game [6], [5] some others use robots that have the ability to play this game autonomously [11], on the other hand, systems of augmented reality were implemented, which use laser projections to draw on the bed cloth the route the balls will take after being hit[1]. In addition, developments have been made using augmented reality through spectacles which allow the trajectory to be traced, taking into account the player's point of view.

The system presented here uses an infrared camera [15], which allows to obtain depth information of a scene as a sensing mechanism. A calibration process is performed to obtain the information in real spatial coordinates reducing the possibility of errors by illumination or textures change [12]. Processes based on morphological operations are performed for the extraction of the characteristics, and finally a projector is used [2], to trace the possible path that the balls will follow according to the intention of the player. The selected strategy allows a high performance regarding the processing speed, in addition, it allows a powerful calibration of low computational cost. The improvement offered by the use of the depth camera is reflected in the ease of segmentation for the scene and total independence of the lighting conditions.

2 Methodology

For the development of this work a series of tests were carried out to guarantee the focus, angle and resolution indicated for this type of artificial vision systems using as input, a system of infrared sensors. After this, an analysis of the image processing was made, necessary to ensure correct detection of the cue, balls and corners of the bands. After having an image with the appropriate characteristics, morphological operations techniques were applied to remove effects and artifacts of the image, after this, mechanical physics laws are applied to calculate up to 4 possible rebounds of the balls in the table.

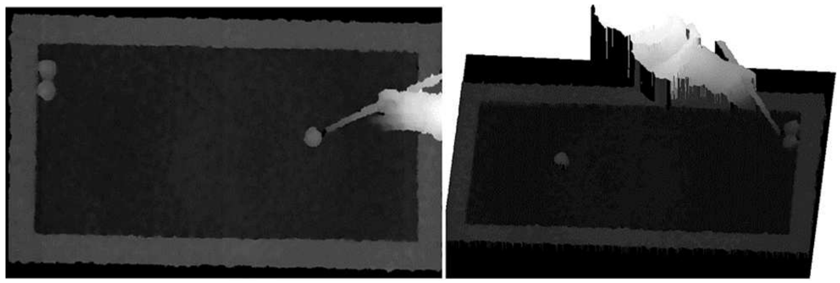

Figure 1: Depth information obtained with the 3D camera, grayscale intensity varies proportionally to the height.

2.1 Embedded system

The system consists of 3 fundamental parts, a projector, a depth camera and a pool table. The projector is placed on the table at a height of 1.5 Meters so the projection will be able to cover the entire surface. The depth camera is located right next to the projector, making sure that it does not interfere with the projection and ensuring that it is also capable of covering the whole surface of the table including the bands, a depth camera is used to measure distances from 50 cm up to 4.5 m with a resolution of 1mm.

2.2 Description of the algorithm

The algorithm performs the depth image processing, obtained with an infrared camera (shown in figure 1), from which the information related to the location of the balls on the table and the position, orientation and angle of the cue are extracted. The algorithm needs certain constants that are calculated in the calibration process. This process is performed once the system is built, it is not necessary to calibrate every time it is restarted, it is only necessary to do so if the camera changes position regarding to the table. The calculation elements position, the determination of possible collisions and the trace of trajectories is performed cyclically until the process finishes. The description of each of the parts of the algorithm is presented below.

2.2.1 Calibration

The calibration mechanism consists of an algorithm to detect rectangles in a depth image. For that the following steps are taken:

-An average image is extracted. 100 images of the table depth are taken, without being any object intersecting the lines of the bands or the playing surface, afterwards an average is made, between the images values, this average result is called matrix A, which would represent the background of the scene.

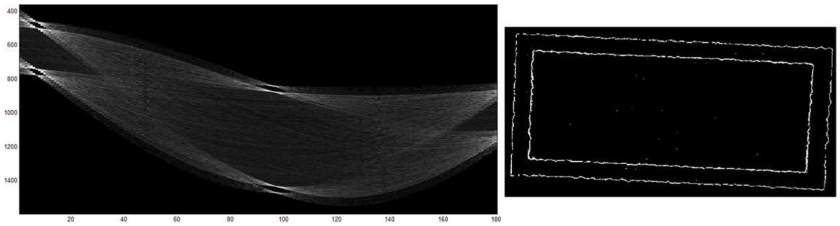

Figure 2: Hough's transform to the binary image containing the edges

-The outline of the table is extracted. An edge detection process is performed using the convolution operation on the thresholded image of the average image. In the convolution process two different masks are used, the mask matrix M=[0-1 1] to find the vertical lines and its transposed for the horizontal ones.

-The Hough parametric transform is applied to extract the equations of the contours lines. In the result accumulator the four main peaks are sought. The peaks found represent the equations of the contour lines.

-The points of the corners are found. Solving the equations system formed by the equations of the lines obtained in the previous step, the corners of the table can be found. With this information from the corners, it is possible to find the location of the table regarding the camera and thus find the matrix of projective transformation T, which allows to make coordinates changes to find the position in spatial coordinates, of any object on the table, regarding the camera, this allows to obtain images without unevenness, even when the camera is not aligned with the table.

The strategy of finding the rectangle in the image allows to find the corners of the table with great precision, this strategy works very well regarding other techniques, since in some cases the points of the corners are lost by the depth sensor.

Finally, to conclude the calibration it is necessary to define two threshold values **Ud** and **Ub**. **Ud**. representing the width of the cue in pixels while **Ub** is the diameter of the balls measured in units, determined by the resolution of the depth of the camera. Figure 2 shows the results of applying the Hough transform to the depth image of the pool table, which corrects the possible defects in the edges detection of the acquired image. In the right part the binary image is presented, at the left, the accumulator resulting from the Hough transform where the x-axis represents the angle and y-axis the perpendicular distance from the line to the origin.

2.2.2 Location of the balls and the cue in the image

Initially the objective is to find the position of the balls within the depth images, this is made through the subtraction between the matrix that is ob-

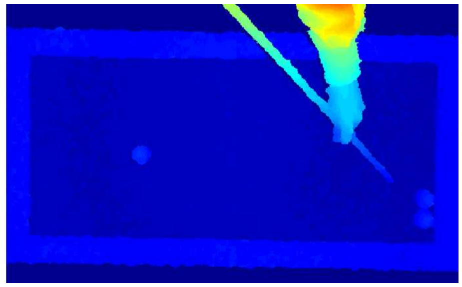

Figure 3: Depth image obtained in a capture cycle

tained when performing a capture with the depth camera P and the matrix A, obtained from the calibration. The result of the subtraction is converted to binary through a process of thresholding according to equation 1. Where r is the result of the difference between $P - A.d = 0.1$, this value is taken empirically and is dependent on the accuracy of the depth information determined by the sensor.

$$f(r) = \begin{cases} 0, & (1-d)U_b < |r| < (1+d)U_b \\ 1, & (1-d)U_b \geq |r| \geq (1+d)U_b \end{cases} \tag{1}$$

In this resulting binary matrix, the 3 elements with a greater area are the balls, which, once identified made possible to find their centroid and with this the coordinates of their location. The interest now focuses on finding the location of the cue, for this binary morphological techniques described below are used. Initially a thresholding of the matrix r is generated, according to the equation in 2

$$g(r) = \begin{cases} 0, & |r| < U_b/3 \\ 1, & |r| \geq U_b/3 \end{cases}. \tag{2}$$

In this case it is sought to find the marked differences, it is considered that the values lower than $U_b/3$ are noise and the rest, elements to be segmented. In order to find the cue, the morphological transformation Opening is performed with a structuring element in the shape of a disc with a diameter **Ud**, the result of this operation is subtracted from the difference matrix r. The entire process is illustrated using the depth image shown in Figure 3, the result obtained is shown in Figure 4.

2.2.3 Determination of possible collision

Once the location of the cue is identified, a linear regression is performed in order to obtain its orientation and slopes; to improve the speed of the algorithm, only a proportion of the points in the cue is taken. The equation of the cue is expressed in vector notation as $X = O + \lambda L$ Where X are points on

(a) Subtraction thresholding of matrix Pk with C

(b) Opening morphological operation

(c) Threshold - Subtract with morpho operation

Figure 4: Binary images of the process to find the cue

the cue, **O** represents the coordinates of the tip, **L** represents a unitary vector with the direction in which the cue points, and λ represents the distance on the line L from the point O. On the other hand, each ball found is expressed in vector notation as a sphere according to $\|X - C\|^2 = r^2$ Where **X** represents the points on the surface, **C** is a vector with the center coordinates and r represents the spheres radius.

Once the elements are represented, the move intention can be sought, since only the trajectories are drawn if certain conditions are met, which are: that player aligns the cue in the direction of a ball, close enough to hit it. The first step for detecting the move intention is to calculate the distances from the center of the cue to each of the balls, the nearest one is sought, and if it is below a minimum distance threshold, the next step is to determine if there is a possible collision between the elements, for that, it is enough to combine equations which will result in equation 3.

$$\|O + \lambda L - C\|^2 = r^2 \tag{3}$$

Expanding, arranging the terms and taking into account that **L** is a unit vector, we get equation 4.

$$\lambda^2 + 2\lambda(L(O - C)) + (O - C)(O - C)^2 - r^2 = 0 \tag{4}$$

Now, a quadratic equation becomes evident, which solution is presented in equation 5.

$$\lambda = -L(O - C) \pm \sqrt{(L(O - C)^2 - \|O - C\|^2 - r^2} \tag{5}$$

Solving λ generates 3 possibilities, where only if the radicand value is higher than 0, it implies that there is a collision between the line and the sphere, being the smaller value the one representing the point, where the cue would contact the ball. Figure 5 shows the graphical representation of the evaluation of the intersection.

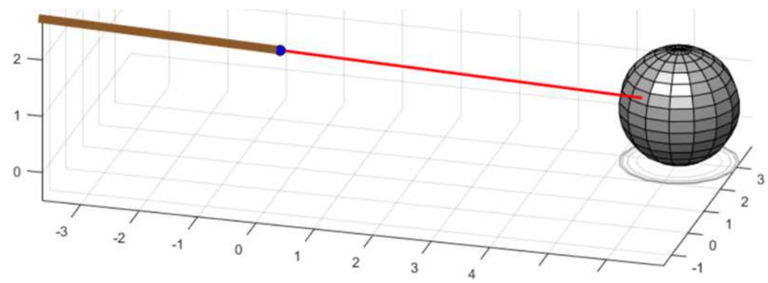

Figure 5: Collision determination between the cue and the balls.

Figure 6: Trajectories projected on the table with the final result of the algorithm

2.2.4 Trajectories generation

It is necessary to determine which will be the point to which the ball will be contact with the cue, by using the last step of the previous section, the point in spherical coordinates can be found. The generation of the possible trajectory is made by the algorithm developed and explained by [1], this algorithm is able to follow the trajectory until n hits, being these with the bands or with the other balls, although as n grows, reliability is lost, for this particular system n = 4 was taken into account.

3 Results and Discussion

Although the results obtained by the trajectory generator algorithm are more than acceptable in terms of the number of hit points calculated with n = 4 and a refresh speed of the projected image, more than acceptable, it is possible to improve the speed of the algorithm in 2 ways: by sub-sampling the depth image obtained in each cycle; in this case, precision is lost in the moment of obtaining the coordinates of the elements, on the other hand, it is possible not to divide the sought tasks of the balls and the cue in two processes not related, preferably, it was made independently to improve the identification of the balls location with a specific process that offers better results in the segmentation, which improves the performance of the system.

4 Conclusion

Although the possible trajectory is traced, it does not guarantee that the ball follows it, this is because it cannot be determined if the player will make the movement as expected, which means, it could hit the badly and fail the carom shot. This system could be easily implemented to encompass other modalities of the billiard game, not just the current proposal, but also it could include pockets and multiple balls. This platform would have the potential to be used to conduct training on the billiards game, particularly for basic levels. As the system uses a camera with infrared depth to obtain information about the conditions of the game, the system does not depend on the intensity of the light that surrounds it, so abrupt changes in the intensity of illumination may occur and the system will continue to function without affecting its performance.

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