Automated detection and classification of dice

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ABSTRACT

This paper describes a typical machine vision system in an unusual application, the automated visual inspection of a Casino's playing tables. The SORTE computer vision system was developed at INETI under a contract with the Portuguese Gaming Inspection Authorities IGJ. It aims to automate the tasks of detection and classification of the dice's scores on the playing tables of the game "Banca Francesa" (which means French Banking) in Casinos. The system is based on the on-line analysis of the images captured by a monochrome CCD camera placed over the playing table, in order to extract relevant information concerning the score indicated by the dice. Image processing algorithms for real time automatic throwing detection and dice classification were developed and implemented.

1. INTRODUCTION

The human visual identification of the dice sorted on the playing tables is still the only method in use in Casinos. The SORTE computer vision system was developed at INETI under a contract with the Portuguese Gaming Inspection Authorities to improve on human vision for the repetitive task of the identification of the dice's score in the game "Banca Francesa" in Portuguese Casinos.

There are two major benefits implicit in the required automation. On the one hand, the SORTE vision system eliminates the need for the manual entering of data concerning the dice's scores, since they are automatically transmitted to a central computer after classification, where they are collected for statistical purposes. All the required data is obtained automatically, thus replacing the manual procedure still in use. On the other hand, due to the high speed of the game, which may reach the rate of one throw per second, some doubts are sometimes raised by the players whenever someone witnesses a different result from the one being announced by the croupier. The SORTE system can be used in this context to confirm the last results of the game.

In order to understand the system configuration and the implemented algorithms, it is important to note some of the characteristics of the dice used in game, namely those which make difficult the apparently easy task of identifying the score using a computer vision system.

Each die is a transparent 13 mm plastic cube, very reflective, with a pale colour that can range from violet to red. Their transparency is a visual proof of the homogeneity of composition, so when looking at any surface of the die, the spots on the opposite side are also partially visible. The distribution of spots on the surfaces of a cube is such that the number of spots on each surface summed with the number of spots corresponding to the opposite side, is always seven. The dice are thrown through a cone on to a green table, inside a rectangular area of 0.80 m by 0.65 m. The dice are constrained within a paraboloid area defined by a cushion adjusted by the croupier.

All the six faces of a die have printed on them, one to six clear white opaque spots. Those circles are 3.5 mm in diameter, and the distances between their centres range from 4 to 12 mm, depending on the pattern. Figure 1 presents

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the geometric constraints for the spots, showing all their possible positions. From left to right, we denote the spots on the first row by Q1, Q2, Q3, the three spots on the last row by Q4, Q5, Q6 and the middle spot by Q7. The distances between the spots are given by the following relations:

$$
\begin{aligned}
&A = \text{dist}(Q1,Q2)\\
&B = \text{dist}(Q1,Q3) = \text{dist}(Q1,Q4) = 2A\\
&C = \text{dist}(Q1,Q7) = \text{dist}(Q3,Q7) = 1.5A\\
&E = \text{dist}(Q1,Q6) = \text{dist}(Q3,Q4) = 2C = 3A
\end{aligned}
\tag{1}
$$

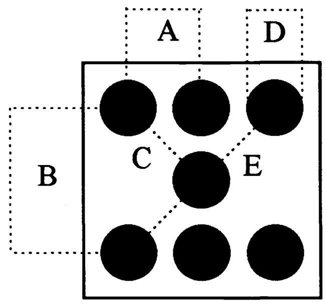

Figure 1 - Spots on a surface of a die.

The diameter of each spot is D=3.5 mm and the smallest distance between spots is A=4 mm. The relations between all the distances B, C and E and A are also presented in (1). These geometric constraints simplify significatively the design of the surface identification algorithm for the dice.

A typical image of the inspection area captured by the SORTE system is shown in figure 2. The three dice can be seen on the playing table, after being thrown through the cone, which sits on the table, as the cushion also does, within the field of view of the camera. Figure 3 shows the six possible isolated patterns of the surfaces of the dice as seen by SORTE.

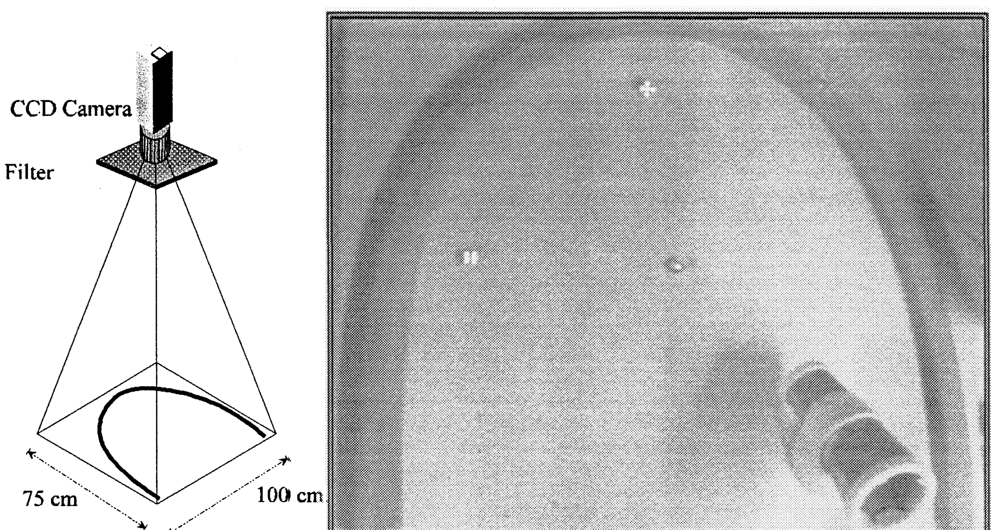

Figure 2 - Image of the playing table of the game "Banca Francesa".

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2. THE VISION SYSTEM

A compromise between spatial resolution and complexity of the algorithms needed for processing the images lead to the development of a configuration for the vision system SORTE based on a single camera covering the complete area of inspection, with carefully chosen lighting and an optical filter.

Since each monochrome image is digitised at 768 horizontal by 576 vertical pixels with 8 bit resolution, the spatial resolution achieved with this system is approximately 1.3 mm/pixel. A spot is seen in the image as illustrated in figure 4, occupying about 2.7 pixels in each dimension. Higher resolution through the use of a multiple camera configuration system implies an increase in the complexity of the algorithms. In fact it would be necessary, on the one hand to combine the information delivered by several cameras, typically four, and on the other hand to perform the detection of spots on the top surfaces while ignoring the spots on the opposite side, since these become too prominent when the resolution increases.

The best lighting conditions are obtained when fluorescent light is used, basically because its emission spectra maximises the contrast between the spots and their surroundings, which includes the green table, the cushion, the cone and the coloured transparent surface of the dice. The use of an optical filter in the blue region of the spectra in front of the camera also helps to enhance the contrast.

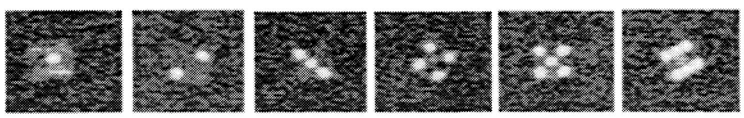

Figure 3 - Magnified images of the six faces of a die.

It is not desirable to have direct light reflected from the dice towards the camera, because it may produce a false spot detection situation. In practice, the system has been successfully tested with several artificial lighting conditions, including the use of incandescent and halogen lamps. The only requirement is to have the lamps distributed in such way that there is no possibility of having specular light reflected towards the camera from the playing table.

The calibration of the system is processed automatically and only requires that the four spot surface of a typical die be presented to the camera. The calibration procedure has been developed to be very easy to perform and involves the automatic classification of a surface of a die with at least four spots. In fact the four extreme white circles on that surface, Q1, Q3, Q4 and Q6 will be used to evaluate the reference distance A (figures 1 and 3). From the distance A, several values are computed, namely the expected mean measurements B, C and E and the ranges ΔA, ΔB, ΔC and ΔE allowed for the variations around the mean values. Once the calibration process has been completed, the acquired images provide all the information needed concerning the dice's surfaces, in terms of distances between spots.

The asynchronous image acquisition and consequent processing are triggered by an automatic throwing detection procedure, whose purpose is to determine the exact instant when the dice have stopped their rolling movement on the playing table, after having been thrown. The real time detection implies a continuous monitoring of the presence of the dice on the playing table.

3. DICE IDENTIFICATION

The images obtained with the implemented configuration of the SORTE vision system present low spatial resolution, where each spot on the surface of the dice is seen as a one point local extreme. With such images, the image processing algorithm for dice classification can be seen as based on a sort of template matching approach, if we allow any position and any orientation within the images for the objects to be matched. Those objects are simply the patterns of spots. As illustrated in figures 3 and 4, it is required to perform with subpixel accuracy, the precise detection of the

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centre coordinates of the spots and the distance measurements between spots. The implemented algorithms for the real time automatic throwing detection and dice classification involve the sub-processes described in the next paragraphs.

3.1. Real time automatic throwing detection

It is based on a continuous monitoring of the presence of the dice on the playing table through image surveillance, in order to trigger the image acquisition of dice in their final positions.

The automatic detection of throwing the dice gives a trigger signal to grab and classify the final image containing the dice whenever some significant movement occurs inside rectangular windows of parametrizable sizes. Those predefined areas are small enough to allow fast grey level image comparison along the time and subsequent thresholding. The image surveillance of the referred windows includes movement detection within each window and sequences between windows. The windows are located in positions such that they give information concerning the instants when the cup containing the dice enters the cone and when the dice reach the table.

When the dice have stopped, an image containing the dice can be grabbed and used to classify the dice and give the final score for the play.

3.2. Seed points

Due to the non-uniform grey level distribution over the image several segmentation approaches were refined to accurately distinguish the spots from their surroundings. Since a roughly circular shape is expected for the spots, geometric considerations can be used to define the criteria for their detection. The implemented algorithm performs the detection of all the points in the image that are possible candidates for the centres of the spots. It is not used a global thresholding approach, in order to increase the robustness of the detection method.

Based on a 1-D extreme image analysis, this fast detection process scans all the image from left to right, and top to bottom. Basically, it looks for points where a strong transition occurs in their horizontal neighbourhood, above from the background noise level. Since it is expected not to have too many points in the image in this situation, this iteration through the entire image is performed very quickly.

This procedure results in a collection of local horizontal maxima within each line for all the lines of the image. Each of those peaks is a candidate to be the centre of a spot so it has then to be related to all the neighbouring peaks in the vertical direction in order to choose the local 2-D maxima from all the previously determined 1-D maxima.

3.3. Centres of spots

The centres of spots are first determined as image points from the recursive two-dimensional attraction algorithm that follows the first iteration of the image. In fact, a 3x3 iterator centred on each seed determined in the previous procedure, redefines the position of the maxima if a higher value than the centre occurs within the window. The new centre for the 3x3 search window is then located on the new maxima. This process is recursively repeated and the moving 2-D iterator is evaluated until its centre does not move. This means that the original 1-D maximum has been moved to the highest 2-D maximum of its surroundings.

This first step results in a list of all the image points that can be centres of spots. Some of them may not correspond to real spots so that list of centres has to be filtered through a noise elimination application. For instance, one of the criteria used is related to the average radiometry of the determined centres of spots. The set of centres that survive this filtering constitute a good first estimate for the spots visible on all the dice on the playing table.

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The coordinates of the centres still have to be translated from image point values to coordinates in the real plane. Due to the low resolution of the images used, subpixel accuracy must be achieved if we want to properly identify the position of the centre of a spot between the sample positions. The implemented algorithm begins with the local maximum pixel and determines the grey minimum in a 3x3 neighbourhood. This grey level offset is then subtracted from each pixel value in the 3x3 area under consideration. The grey levels thus obtained are then used in the evaluation of the coordinates for the centre of grey, which is a weighted centroid or centre of mass (if the grey level pixel values are considered to be the masses).

The weighted centroid algorithm is well suited to subpixel location of the centre of a spot. In fact, we simulated fitting the data near a spot to a Gaussian surface, as suggested by the shapes shown on figure 4a) and b), and the resulting position for the peak of the Gaussian is very close to the grey centroid. We did not implement this fitting method for all the spots in the images being processed due to the time consuming processing involved. In fact, the fitting considered was the general multidimensional gradient descent technique and the non-linear dependencies introduced by the Gaussian shape imply that the minimisation must proceed iteratively. Given trial values for the parameters of the Gaussian, the gradient descent method improves the trial solution.

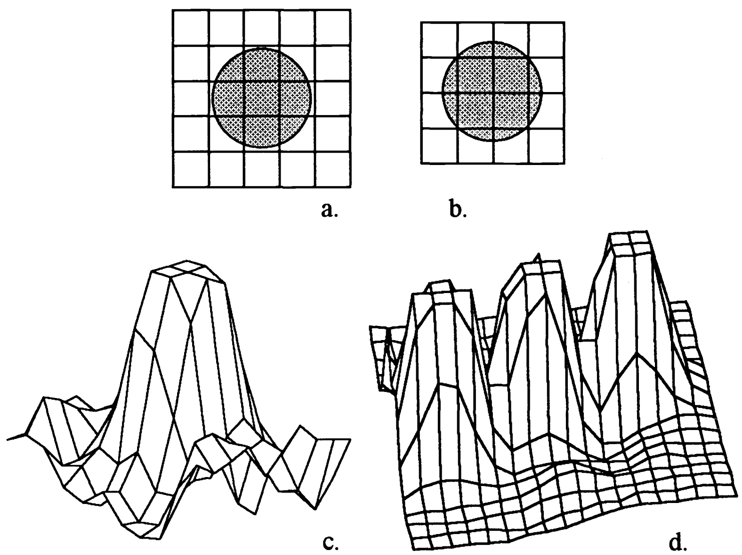

Figure 4 - a) Spot of a dice centred on a pixel; b)Centre of spot over several pixels;
c)Topography of the spot on the one surface of a dice; d)Spots on the three surface of a dice.

3.4. Grouping of spots

Given a list of N spots, each one of them defined by its coordinates in the real plane, a combinatorial method is applied for grouping the spots into valid patterns. It involves the definition of groups of spots, through the application of a proximity criterion that computes a matrix of NxN distances containing valid values only when the related points are close to each other.

Within each group of points defined as the ones corresponding to valid values in the distance matrix, a sort of template matching is performed to classify that group as a die. This process is repeated until all spots have been associated to a die.

Since more than one die are on the table, in order to properly identify the dice involved and to reject false classifications, it is necessary to consider all the possible associations of spots. This is particularly important when two or more dice are close to each other and there is more than one possibility for the association of spots. The

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combinations proceed in such a way that the number of dice is minimised and for each dice the number of spots is maximised, in a process summarised as follows.

For each score S beginning with 6 and going down to 1, look at all the N rows on the distance matrix and search for a spot SP that belongs to a group with at least S spots. Let G be the number of neighbouring spots of SP. Each time one of the spots SP in these conditions is found, get all the valid combinations of S spots Q1,Q2,Q3,Q4,Q5,Q6,Q7 from the available G, which may define the score S. Proceed until all scores are searched. A valid combination is reached when the relations (1) between the candidates to Qi (I=1 to 7) are satisfied for the score S being considered. This means, for instance, if S=4, that Q2, Q5 and Q7 do not exist and dist(Q1,Q3)≈B, dist(Q1,Q4)≈B, dist(Q1,Q6)≈E, dist(Q3,Q4)≈E, dist(Q3,Q6)≈B and dist(Q4,Q6)≈B. To allow reasonable variations for the A, B, C and E measured between the spots, those distances have fairly wide bounds, centred on the values given by (1) after the calibration that determines the value A from the measurements of a few B's and E's.

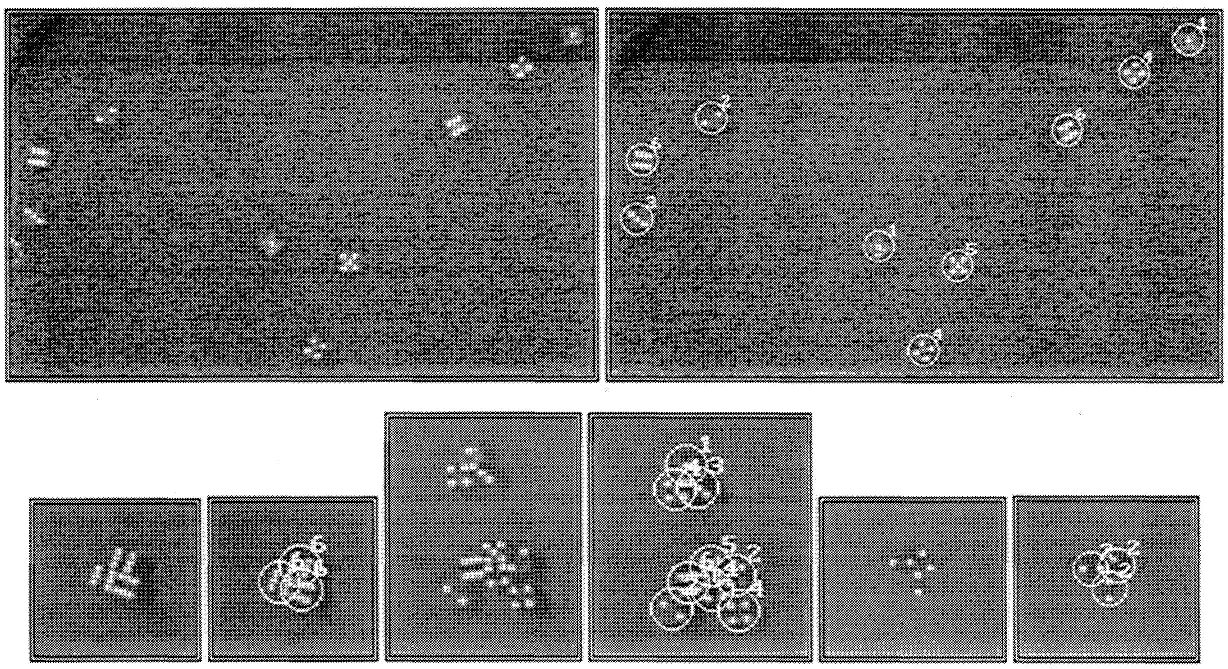

Figure 5 - Results of dice classification.

When a valid combination of S spots is found and G=S, this is a trivial situation since the corresponding dice is far from all the others and there are no ambiguities concerning the dice to which the spots belongs. All that has to be done in this case is to prevent the spots being grouped from being found in subsequents searches. The situation is of course much more complex when two or more dice are close to each other. In that case, G>S and even if S spots from the group of G spots form a valid S score, all the other valid combinations cannot be excluded, even the ones found on the next cycles when a lower S is searched.

This implies that we may get a large list of possible dice, especially if more than two dice are close to each other. In fact, if a six is identified in that situation, all the possible scores included in the six are also considered, such as the four, several twos and ones. The list of dice must then be cleaned. This cleanup process begins with the construction of lists of dice with common spots and from there tries to put the independent spots in the minimum number of dice, considering first the high scores.

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Only after this do we get a collection of valid dice, each of them having the coordinates of all the spots it contains and the corresponding score. Suitable data structures for storing the complete data for all the spots and dice were developed.

The SORTE system allows any number of dice to be used, although the game "Banca Francesa" uses only three dice. By combining the readings for the score of the three dice we obtain the usual output, which is "Small" (whenever the score sum is 5, 6 or 7), "Big" (14, 15 or 16) or "Ace" (three dice with the one score), which are the significant scores of the referred game.

4. CONCLUSIONS - THE RESULTS

The vision system developed is able to read each sorted die and identify the number of dice on the playing table of the game "Banca Francesa". The SORTE system allows an arbitrary number of dice to be used, although this particular game uses only three dice. By combining the readings for the three dice we obtain the result of interest to the Casino, which is "Big", "Small", or "Ace". Of course, the system is prepared to deal with new games that involve more than three dice, since the algorithm for combination of spots into dice does not assume a fixed number.

With regard to the interface with the central computer system installed at the Casino, whenever the information concerning the score is automatically determined, it is transmitted to the central computer, for management, statistical treatment and display purposes.

The SORTE system was developed and implemented on a PC based central system unit. The 80486 PC is equipped with an image processing board without internal processing. The frame grabber used has 2 Mbytes of image memory and contains all the interfaces and the necessary circuitry to digitise, memorise, process, transfer to/from the host and to display images. It was configured in a VGA overlay mode, in order to present the user with an attractive way of interacting with the SORTE system. The identified dice can be visualised on a screen, with a convenient graphics output superimposed on the image.

The system as already been evaluated and successfully tested by professional employees of a Portuguese Casino. Just looking at the images on the computer screen, in an ambiguous situation, such as the last one shown in figure 5, the croupier could not decide the exact combination of dice on the table, which is by 2-2-2 as it is identified on the image, and not 1-4-1 as the croupier thought.

The computer vision system SORTE will be soon installed on the playing tables of the game "Banca Francesa" in Casino Estoril.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. T. Pavlidis, *Algorithms for Graphics and Image Processing,* Springer-Verlag, 1982.

2. D.H. Ballard and C.M. Brown, *Computer Vision,* Prentice-Hall, 1982.

3. A. Rosenfeld and A. Kak, *Digital Picture Processing,* Vol. 2, Academic Press, 1982.

4. G.A.W. West and T.A. Clarke, "A Survey and examination of subpixel measurement techniques", SPIE *Proc. on Close Range Photogrammetry meets machine vision*, Vol. 1395, pp.456-463, 1990.

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