Soty-Segment: Robust Color Patch Design to Lighting Condition Variation

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Abstract. Significant developments have been seen over the last few years in the robot soccer domain. Considerable improvements have been made in the areas of robot control, strategy generation, vision processing, etc. In particular, in the vision area, there have been many researches aimed at decreasing processing time. However, many other issues remain in the development of ideal vision system. Despite MiroSot being a well established competition, development of a vision system is still considered as a difficult task. In global vision systems, the development of insensitive system to lighting condition variation is an important issue. This paper proposes a novel color patch design which possesses some advantages from the vision processing viewpoint. It is insensitive to lighting variation, greatly reducing vision setting time as well as providing improved recognition. The effectiveness of the proposed Soty-Segment color patch is demonstrated through real experiments.

Keywords: Color patch design, localization, MiroSot, robot soccer.

1 Introduction

Micro-Robot World Cup Soccer Tournament (MiroSot) has witnessed considerable technical improvement as well as continuous development of robust system over the last decade. MiroSot development is based on the standard architecture for robot soccer, which is composed of cameras, robots, color patches and RF transmission modules [1]-[4]. MiroSot has expanded to the Middle League MiroSot (5 a-side) and Large League MiroSot (11 a-side) with the progress in the related technologies [5]-[9]. The most important issue associated with these expansions is the processing time for the vision system. It is not easy to obtain optimal digital camera performance completely for larger playground. Most previous researches focused on this problem and a wide variety of solutions was developed.

The vision system of Large League MiroSot shares many common elements with that of the Middle League MiroSot. The vision system recognizes each robot with color patch through the camera located on top of the field. Field lighting condition is thus an important factor, as the lighting condition is not uniform continuously. If lighting condition varies during the game, the vision

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system confuses colors such that it may not be able to recognize the robots. Therefore, during vision setting time, all colors are sampled considering various lighting conditions on the field. It is obviously a tedious and time consuming task.

These days color patch design usually comprises of a team color and a combination of ID colors for distinguishing each robot. Accordingly, with an increase in the number of robots, more independent ID colors are needed and consequently this makes vision setting time longer. Many teams implement a wide variety of strategies, depending on their experience and know-how, for reducing this time-consuming effort. For example, a simpler and more comfortable interface is programmed and utilized or alternately a large number of color patches are placed on field during vision setting time. Nevertheless, these have been no ideal solutions.

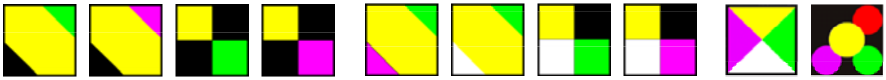
The proposed novel color patch design on top of robot uses the state of each segment representing an identification (ID) number of each robot to distinguish each other, where the ID number is placed on team color. Lens distortion revision, perspective distortion revision and image conversion algorithm in image preprocessing are employed to calculate the correct position of each segment. The heading direction of the robot is calculated by simply detecting the orientation of the direction color region.

Proposed design reduces the number of patch colors and saves time for vision setting and processing time. Also, the vision system becomes more stable than the existing ones and is independent of lighting condition variations due to the increased number of margins that are allowed in RGB color space with less number of colors. Moreover, its human friendly design leads to much easier operation of human operators as it can be easily identified by the number on top of robot. Additionally, as the robot soccer system can be utilized as a test bed for experiments in mobile robot navigation, multi-agent cooperation, and so on, the proposed design will be useful in the research of mobile robot.

This paper is organized as follows: Section 2 explains the previous and recent color patch designs. Section 3 proposes a novel color patch design and its recognition algorithm. Section 4 presents experimental results and concluding remarks follow in Section 5.

2 Previous Color Patch Designs

Fig. 1(a) shows two representative types of earlier color patches for soccer robot. These color patch designs used ID colors to identify each robot. Fig. 1(b) shows the modified color patch design which uses just two ID colors. To the best of the authors knowledge, this is the first attempt at reducing the number of ID colors. This color composition became a basic idea for later color patch designs. Fig. 1(c) is a recent color patch design used in Middle League MiroSot and Large League MiroSot. The characteristic feature is the usage of more than two colors with increase in the number of robots. Such color patch designs are considered as a relatively effective method. However, in Large League MiroSot, the number of robots is more than twice of Middle League MiroSot, and two cameras



(a) (b) (c)

Fig. 1. Various color patch designs. (a) conventional ones, (b) improved ones and (c) the most recent ones.

should be set up. Therefore the conventional color patch design proves inefficient in Large League MiroSot. Setting up one more ID color is not a trivial issue. As the size of a ground increases, the lighting conditions become more variable. Consequently, the possibility of failure to recognize exact color is greater. This is the principal reason necessitating much time consumption for the preparation of Large League MiroSot. The problem is further compounded due to the usage of two camera systems. Furthermore, the conventional color patch design presents another problem. It is difficult for the human operators to identify the robots quickly and intuitively. Distinguishing robots by various compositions of colors is an inconvenient task for human operators. This further complicates the communication among human operators.

3 Soty-Segment Color Patch Design

As described above, a fundamental problem of conventional color patch designs is the usage of too many ID colors. To solve this, the color patch design for distinguishing the robots should be based on a specific pattern. At the same time, the algorithm must be simple to avoid impeding the performance of the system.

Fig. 2 depicts the proposed color patch design, the Soty-Segment color patch. Each robot can be distinguished by the segments on team color instinctively. The heading direction of the robot is calculated by simply detecting the orientation of the direction color region (white), which thus makes the algorithm faster and simpler.

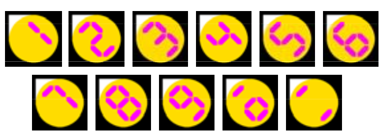


Fig. 2. The Soty-Segment color patch design

3.1 Preprocessing

The image through a camera is distorted image due to lens. Image distortion also occurs in the case that a camera is not installed horizontally. This distortion has to be revised to suitably recognize small patterns like the color patch of soccer robot.

1) Revision of Lens Distortion: A camera, which can cover wider range, has larger distortion near the edge region. For this reason, a pixel in an image is not exactly located at a real position in the image. It is known as radial distortion. To recover the distortion, One of well-known method is mapping the camera image position r to the perspective image position r' through 2^{nd}-order or 3^{rd}-order polynomial in polar coordinates (Fig. 3) [10] as follows:

$$r' = R_{lens}(r) \tag{1}$$

To use this method, lens parameters should be examined. However, in the absence of this knowledge, the parameters should be found experimentally.

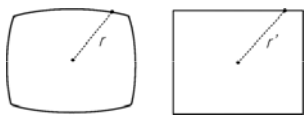


Fig. 3. Relationship between camera image position and perspective image position

2) Revision of Perspective Distortion: Because of imperfect alignment of a camera, an image from a camera suffers perspective distortion. This paper proposes its restoration using 2D homography. 2D homography is a transformation between 2D planes in images. It includes translation, scaling, rotation, perspective transformation, and also general 2D transformation. The transformation can be represented as a 3×3 matrix whose degrees of freedom (DOFs), is eight [10]. To use the matrix, position of pixels should be represented by a homogenous coordinate (x,y,w), where w is a scale factor, which is generally 1 in an image. One missing DOF results from its scale-less property, that is, scalar multiplication of the matrix makes the same transformation. To transform an arbitrary plane to a desired rectangular plane, the homography, that is, the 3x3 matrix should be evaluated. Generally the (normalized) four-point algorithm can be applied, and it needs four pairs of corresponding points. Each pair of corresponding points has a constraint as follows:

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = H \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \tag{2}$$

Therefore four pairs are enough to estimate the matrix H. Using DLT (direct linear transformation), the matrix H can be calculated as a solution of homogenous linear system of equations [10]. Fig. 4 shows the result of revising perspective distortion.

3) Image Conversion Algorithm: Revising distortion of all pixels in the image consumes too much operation time. Therefore applying image conversion algorithms to the necessary pixels only is effective for robot soccer system which needs fast operation (Fig. 5). It will be demonstrated in following section.

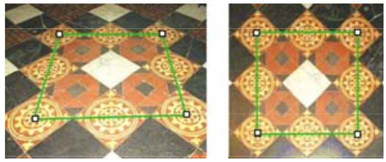
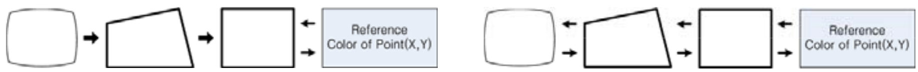


Fig. 4. Relationship between perspective image position and real location



(a) (b)

Fig. 5. Revision process for lens and perspective distortion. (a) revise entire image, (b) revise just only reference points.

3.2 Algorithm of Color Patch Recognition

Table 1 describes the colors used in the recognition algorithm of the Soty-Segment color patch, composed of the Position-color, Direction-color and Team-color regions.

1) Pixel Sampling: Two-dimensional image information is recorded in a one-dimension array. To reduce time required for scanning of the entire image, color information is only extracted from every kth pixel. Fig. 6 shows extracted points when k is 180.

2) Locate Position-color Region: If the extracted color is Position-color, begin locating the Position-color region by flood-fill algorithm which searches the circumference color region in order.

3) Locate Direction-color Region: During locating Position-color region, if the extracted color, which is the detected contiguous position of the Position-color, is Direction-color, then Direction-color region is located with the same method as in locating the Position-color region. This method prevents the spurious detection of Direction-color, extracted from opponent team color patch or noises on field.

4) Calculate Position and Orientation of Robot: The position and orientation of the robot are calculated by using center positions of the Position-color and Direction-color regions. However, these two center positions are from distorted

Table 1. Types of colors used in Soty-Segment color patch design

Type	Color
Position-color	Team-color + (Segment-color)
Direction-color	WHITE or ALL–(BLACK+Position-color)
Team-color	Yellow or Blue

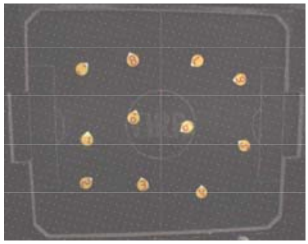


Fig. 6. Image scan with k-pixels jumping (k=180)

image, due to which the actual center positions must be calculated from a revised image. Each position should be revised by an image conversion function. Direction-color region of the proposed Soty-Segment color patch is placed 45 degrees counter clockwise. Therefore the positions and the orientations are calculated as follows:

$$\begin{aligned} &Q_{pos} = H(R_{lens}(P_{pos})) \\ &Q_{dir} = H(R_{lens}(P_{dir})) \\ &V_{dir} = Q_{dir} - Q_{pos} \\ &Orientation = Direction\ Of\ Vector(V_{dir}) - 45^{\circ} \end{aligned} \tag{3}$$

5) Identify the Segments: When the position and the direction are calculated, the exact locations of each segment are determined. Circumference colors are extracted from each segment to increase accuracy of detection, as shown in Fig. 7. ON/OFF condition of segment is decided as follows:

```
NumberOfSegmentPixels = 0
For Each pixel of 9 pixels
   IF pixel does not belong Team-color
   THEN NumberOfSegmentPixels++

IF NumberOfSegmentPixels >= Threshold
   THEN Segment is ON
   ELSE Segment is OFF
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Threshold value is appropriately controlled according to the environment. When the states of segments are decided, the identification number of the robot is also decided by the predefined table as shown in Table 2. The decision accuracy

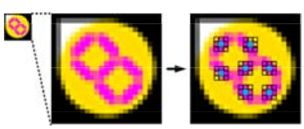


Fig. 7. Segment state decision with nine circumference points

Table 2. States of seven segments for each robot

State of 7 Segments	Robot ID										
(ON:○, OFF:×)	1	2	3	4	5	6	7	8	9	10	11
1	×	○	○	×	○	○	○	○	○	○	○
2	×	×	×	○	○	○	×	○	○	×	×
3	○	○	○	○	×	×	○	○	○	×	×
4	×	○	○	○	○	○	×	○	○	○	×
5	×	○	×	×	×	○	×	○	×	○	×
6	○	×	○	○	○	○	○	○	○	○	×
7	×	○	○	×	○	○	×	○	○	○	○

can be also increased by using the whole shape of Soty-Segment color patch. However, referring to the corresponding color in each segment is more efficient from the viewpoint of processing time.

3.3 Color Demarcation

Demarcation methods of Position-color, Direction-color and Team-color differ depending on their usage in the algorithm. Position-color is assigned as the summation of team color and segment color. It has the widest possible region in RGB space because it is the most fundamental color for identification of robot position. Direction-color can be assigned in two ways. One is to simply extract the white color, while the other is to extract the rest part excluding black color, boundary color of color patch, and Position-color in RGB space. A characteristic of Direction-color is applied, which is only dependent on the circumference of Position-color region and independent of its actual color itself. Since Team-color is only used for identifying the state of the segment, it is arbitrarily assigned in region excluding the segment color. The black and white regions are the easiest colors to be demarcated. Thus the only critical factor in color demarcation is to identify the Position-color region in RGB space.

4 Experiments

To test the proposed methods, many images were captured at various heights and angles. Images were captured in the environment of Small League MiroSot game field using a UNIQ vision UC-685CL digital camera which further utilized a PANTAX 6.5mm C-mount lens. The camera was installed at a height of 2.5 meters above the field. In order to capture whole rectangular game field at once, the field for Small League MiroSot was used for testing. The proposed Soty-Segment color patch design proved its applicability and effectiveness in Middle League MiroSot and Large League MiroSot at FIRA Robot World Cup 2008.

4.1 Revision of Distortion

Fig. 8 shows revised lens and perspective distortions. For convenience of analysis of the results, all pixels in the image were revised. In practice, however only a much lower number of pixels need to be revised depending upon the color patch recognition algorithm. Fig. 9 shows the located regions of Position-color and Direction-color. The numbers on image mean the number of pixels in each region.

4.2 Color Patch Recognition

Fig. 10 shows segments recognition processing. Fig. 10(a) shows the original patch image. Fig. 10(b) illustrates that the positions of segments are fixed by position and direction of the robot. Only Team-color regions are shown Fig. 10(c). The numbers on image indicate the number of segment pixels, which was described in Identify the segments in Section III. If the threshold is set to seven, seven segments have all ON state. Then, the robot ID number is decided to

(a) (b) (c)

Fig. 8. Revising lens and perspective distortion. (a) original image, (b) revising lens distortion and (c) revising perspective distortion.

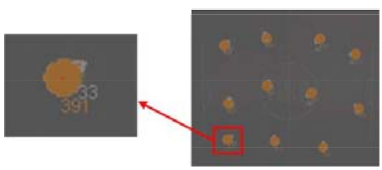
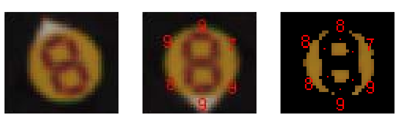


Fig. 9. Position-color and Direction-color region location



(a) (b) (c)

Fig. 10. Segment recognition

Fig. 11. Recognition result with 11 robots

Fig. 12. Possible patch design based on the Soty-Segment patch design

be 8 from Table 2. Fig. 11 is the final recognized image with 11 robots on the playground.

It should be noted that various the color patch design is possible using the same algorithm as shown in Fig. 12. This different design is suitable for the opponent team to differentiate between the two matching teams.

5 Conclusion

This paper proposed a novel advanced Soty-Segment and demonstrated its effectiveness and efficiency through experiment. The Soty-Segment color patch design was able to identify and distinguish each robot by using only Team-color, Direction-color and Position-color. As the number of colors needed is lower, the effort needed in the color recognition process is significantly reduced. Furthermore, this design stabilizes the vision system from variation of lighting conditions. This color patch design is easy for human operators to identify the robots, and thus posses an additional advantage in system management. The Soty-Segment color patch design thus makes the robot soccer game more realistic as the playing robots are easily identified by the ID number like the back number of human soccer players.

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