A New Efficient Real-Time Arbitrary Colored Ball Recognition Method for a Humanoid Soccer Robot

Jiteng Mu*,1, Yunxuan Li*,2

1 School of Mechanical Engineering, Shandong University, Jinan, China (mujiteng@outlook.com)

2 School of Optical and Electronic Information, Hua Zhong University of Science and Technology, Wuhan, China (yunxuantonytony@outlook.com)

*These authors contributed equally and should be considered as joint first authors

***Abstract*—The ball recognition algorithm in Robocup is challenging with regard to the computing complexity and false positive rate. This paper proposes a new method to deal with the real-time arbitrary colored ball recognition for a humanoid soccer robot. At the beginning, the image is matched with a look-up table under the HSV color space. After we get the edge pixels information, the ball is recognized by the contour feature method (CF) or the modified Gradient Circle Hough Transform method (GCHT) based on different contour conditions. The CF approach proved to be fast and effective in non-intersection condition. While the modified GCHT as a complementation is more reliable under intersection condition. The novelty of this ball recognition method is the combination of the CF and modified GCHT method and taking advantages from each of them. In addition, the new ball recognition method focuses on the arbitrary colored ball recognition rather than the single uniform colored ball detection. Besides, the variance of illumination, the shadows and occlusion have also been considered. A great number of experiments have been carried out showing that the proposed new method achieves a balanced point with the consideration of timeliness and efficiency.**

Keywords*—*ball recognition, Circle Hough Transform, soccer robot, Robocup

I. Introduction

Robocup is a worldwide popular robotic competition attracting thousands of teams competing together every year. In order to meet with the goal which is to make robots able to compete with human-beings in the year of 2050, the committee improves its competition rules every year. In 2015, the color of the balls [1] used in the Humanoid Kid-size League became arbitrary compared to using the single uniform orange ball in the past few years, which certainly increased the difficulty.

To win the champion, a fast, effective, reliable ball recognition method is needed, which means that the method should have a good timeliness as well as effectiveness. Thus, the approach should have a low computing complexity and short average recognition time. However, for the competition, we are not trying to eliminate the misdetection with some complicated computing methods as that is not necessary for the real application in the Robocup. The aim of our work is to find a balanced point between the timeliness and efficiency, so that the robot can have a good sensitivity to the ball.

A couple of methods for circle detection have been studied in the past years for various image processing applications, including the soccer robot. The application considered in this work is the soccer game. For the specific case in the Robocup, the Robocup committee has made concrete rules for the colors and sizes of the court. Thus it is possible for the participants to use the color as the first choice to recognize the ball. Some researchers use the color feature to recognize the ball [2], [10]. In the meantime, some others [3] combined the shape and the color together to achieve the goal. However, though such methods are fast and effective in most cases but can be easily affected by the illumination. In addition, most of previous work dealt with a uniform single colored ball.

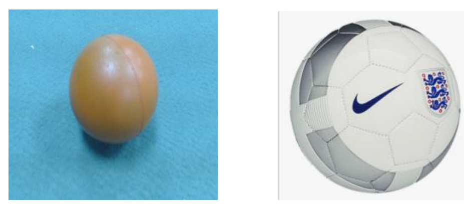


Fig. 1. Balls used in Robocup. The uniform colored ball on the left used previously is substituted by the arbitrary colored ball on the right.

Some other researchers use the Hough Transform to do the identification. One significant drawback for the Standard Hough Transform is the computing complexity, as it computes in three dimensions. To get a well performance in the Robocup competition, the timeliness for the ball recognition method is of crucial consideration. To overcome this problem, a number of approaches are put forward to improve this method, reducing from three dimensions to two dimensions, like Randomized Hough Transform (RFT) [7] and the probabilistic Hough Transform (PHT) [8]. Besides, many other researchers have contributed to improvement of the Hough Transform, like 2D Hough Transform and radius histogram [5], Segment Hough Transform (SHT) [11] and Hough transform and neural classifier [12]. OpenCV uses another advanced Circle Hough Transform, which is called Gradient Circle Hough Transform [6] to meet the timeliness requirement. But it is used for more general cases and thus cannot be directly used, so we, based on it, made some specific modifications to give a better performance. So in order to recognize the arbitrary colored ball, a new advanced method needs to be introduced.

The main contribution of this work is the innovative combination of two different techniques in order to take advantages from each of them. One is a fast circle detection algorithm, contour feature method (CF), based on contour information. While another one, modified gradient Circle Hough Transform (GCHT) is introduced as a supplement for the CF.

In this paper, we propose a new efficient real-time arbitrary colored ball recognition method based on OpenCV for a humanoid soccer robot, combined with the shape features and the color features, for the Robocup competition. The following parts are organized as follow: In Section Ⅱ, we give the full algorithm method with four coherent parts, which are overview, preliminary image processing, the ball recognition under non-intersection condition and the intersection condition. In Section Ⅲ, we show the experimental results based on the HFR robot with the similar configuration as the DAR-Win model. Finally, we concluded our work in Section Ⅳ.

II. The Proposed Method

A. *Overview*

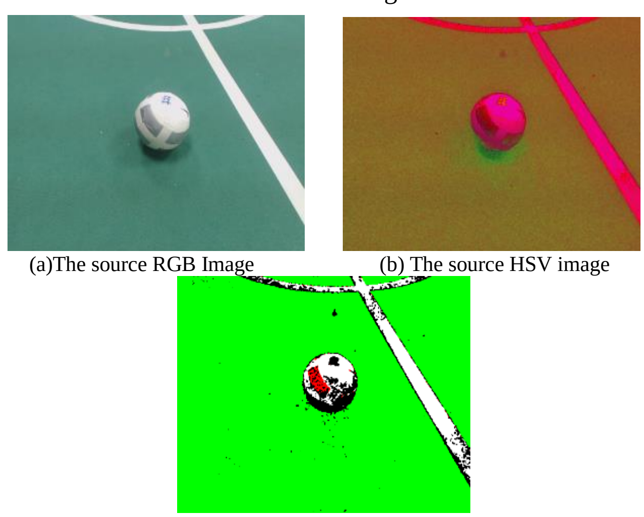
The image from the camera is represented in the RGB color space. So first of all, after an image is captured, we change the color space from the RGB to the HSV color space. Then we make a matching between each pixel on the image with the look-up table (LUT) prepared previously, which can give us the segmentation image with the field information. Next, we use the canny operator to get the edge image. The edge image can be divided into two categories. One is non-intersection condition, which is shown in Fig 3.d and another one is intersection condition, which is shown in Fig 5.d. Then we use the CF method to recognize the ball. If this method failed, the GCHT will run automatically to check again for this edge image. So the non-intersection detection is used every time, while the intersection detection based on GCHT is used only when the CF method cannot give the information of the ball.

There are many advantages for the combination of these two methods. One benefit is the low computing complexity. As the non-intersection condition is often the case, once CF method achieves the goal, the modified GCHT will not operate. With the regard of the high efficiency of CF method, the computing complexity is reduced. Another advantage is the complementation. As this is often the case when the ball is close to the goal or occluded by the robots, the intersection condition cannot be ignored. The modified GCHT can be a good supplement with respect to the overall ball recognition, especially when the first method fails to locate the ball for some rare unknown problems. The combination makes full use of the different advantages of the two separated approaches. In our experimental results, the combination shows reliable performances with the consideration of false positive rate, efficiency and timeliness.

B. *Preliminary image processing*

For the color space, there are a variety of choices. RGB is the most common used one, but it is sensitive to the variance of the illumination and cannot promise a stable recognition. However, the HSV color space represents the colors in hue, saturation and value. The hue channel has a resistance characteristic to the illumination changes [9] and this is tested in our experiments.

To recognize the ball in the field, we need to split the image at first. Some popular methods to get the image segmentation are region growing, connected domain and etc. However, for the simple regulated field features in the Robocup, the look-up table method (LUT) [10] is a more appropriate choice because of its timeliness and efficiency in the actual conditions. Therefore it is widely accepted and applied. The color classes are documented in LUT offline. A look-up table is constructed for fast indexing of a color in HSV. We choose three colors in our look-up tables which are green (color of the field), white (main color of the ball) and other specific colors on the ball. In this paper, we assume white is the main color based on the ball used for the 2015 Robocup. In fact, white can be replaced by any other color except for green, which will never be the main color of the ball according to the rules. So the proposed method is not limited to the ball mainly in white. After an image is captured, the algorithm will automatically check the color of each pixel and make a comparison between the values of colors on the image and the look-up table. After this approach, all of the pixels uninterested are set to a certain color and the finally LUT matched image is shown in Fig2.c. Although the look-up table is needed to update frequently due to the variance of the illumination as well as the reflection, the condition during a match do not change a lot. So this method is reliable for the competition purpose. Thus we use the look-up table to split the image in order to get rid of the irrelevant pixels outside the field. This step is of paramount significance as all of the following image processing approaches are based on the image here. One issue needs to be considered is that a look-up table cannot be perfect which means there are still some pixels on the images which are hard to be classified. Nevertheless, this algorithm is robust enough. Therefore, little noise will not influence the final recognition result.



(a)The source RGB Image (b) The source HSV image

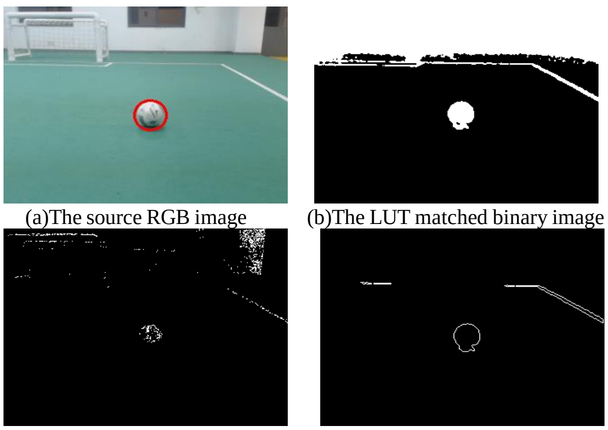
(c) The LUT matched image

Fig. 2. Preliminary image processing

There are several ways to get the edge of the image. Some common leading edge detection methods are Sobel operator, Canny operator and etc. In this paper, we chose the canny operator because it is able to correctly find the majority of the edges and therefore will not miss much important edges. Though it sometimes give the spurious edges [4], that will seldom be our case with the regard of the simple back ground subtraction image. Canny operator showed a good performance in our real tests and experiments. The edge image is shown in Fig.3.d.

C. Ball recognition under non-intersection condition

Under the non-intersection condition, the contour of the ball is easily distinguished by the features of the contours. Besides, the computing complexity for the finding of contours on the edge image is acceptable. So we proposed the contour feature (CF) method as the first ball detection method.



(a)The source RGB image (b)The LUT matched binary image

(c)The matched white pixels (d)The edge image

Fig. 3. Ball recognition procedure under non-intersection condition with CF method. The red circle in picture (a) means the estimated ball position and radius with CF method.

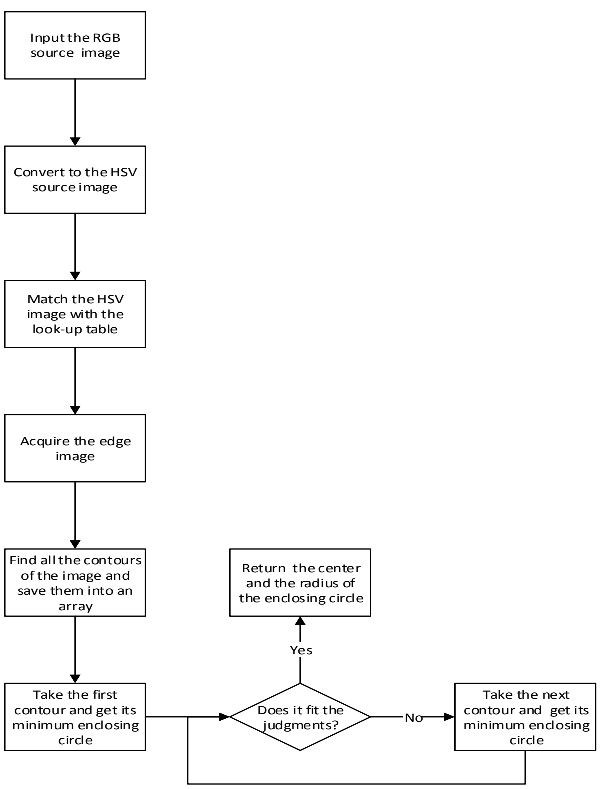


Fig. 4. The CF method algorithm flowchart

However, the false positive rate is a problem. To solve this problem, we further introduced and integrated the color feature into the CF method. The CF method with details is showed in the following part.

At the beginning, the CF method gets the minimum enclosing circle based on Open CV for every contour in the edge image. Then for every minimum enclosing circle estimated, it is justified by several separated judgments. We determined to use the range of radius, circle similarity, color distribution in the contour as the judgments after a couple of experiments.

The range of radius is given as parameters beforehand. The given radius range is not only useful to exclude the misdetection, but is of great significance to improve the timeliness. The circle similarity means the ratio between the area of the contour and the area of the enclosing circle. The more close to one the ratio is, the more round the contour is.

Not like the above judgments which are about the shape features, the color distribution has taken the color feature into account. The CF method uses the white pixels ratio and green pixels ratio to make further judgment. The white pixels ratio means the ratio between white pixels (main color of the ball) within the range of the enclosing circle over the pixels of the enclosing circle. Green pixels ratio means the number of green pixels (color of the field) in the enclosing circle and the number of pixels of the enclosing circle. Only when that estimated circle can meet with all of these judgments, is the ball thought to be recognized.

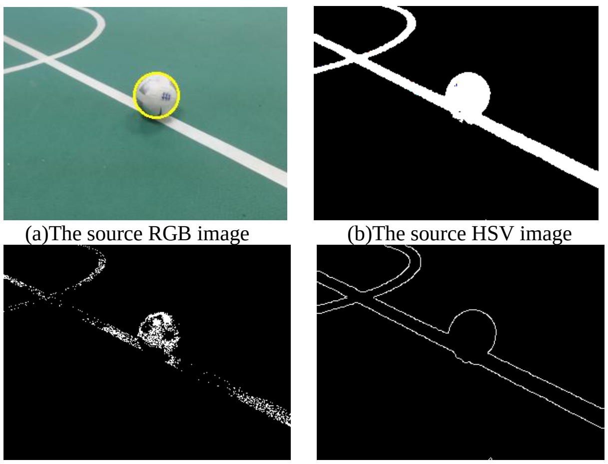
D. Ball recognition under intersection condition

If the CF method fails to detect the ball, the program automatically starts to call the second function, which mainly contains the modified GCHT. OpenCV implements the Gradient Circle Hough Transform (GCHT) method [6] to realize the circle detection. The GCHT is a two dimensional Hough Transform. Compared to the three dimensional Hough Transform method, the memory requirement is reduced and the computing speed is improved significantly. However, for the soccer game consideration, the false positive rate remains high and the efficiency remains to be improved. In addition, this method focuses on the shape feature and doesn't take color feature into consideration. Thus, to improve the performance of the method under the Robocup condition, some modifications are needed. Based on the experimental testing results, we put forward the modified GCHT combined with the color feature. The detailed modified GCHT is described as follow.

Firstly, the algorithm computes the local gradient for every edge point in Fig.5.d. Then based on the gradient calculated, every point along the line as well as within the radius range is incremented in the accumulator. The radius range is given as parameters beforehand. Next every pixel is sorted in a descending order of the accumulator values counted. The higher accumulated value means the higher likelihood for that pixel to be the real ball center. A center is kept if it has sufficient support from the edge pixels in the edge image and if it is a sufficient distance from any previously selected center. So until now we have got several real circle center candidates.

Started from the real circle center candidate supported by most pixels, the algorithm calculates the distances from the center candidate to the edge pixels within the radius range given. Working out from the smallest radius to the largest radius, the best supported radius is selected.

This ball candidate is then considered for the color aspect. With the center and the radius estimated previously, we can get a fitting circle. We use two criteria to verify the color information. One is white points (main color of the ball) ratio mentioned before and anther one is the ratio of green points (color of the field) on outer circumference. As is used previously in the CF method, the ratio of white pixels in the fitting circle is to avoid objects similar to the ball but with different colors. The ratio of green pixels on outer circumference is the ratio between the total number of the



(a)The source RGB image (b)The source HSV image

(c) The matched white pixels (d) The edge image

Fig. 5. Ball recognition procedure under intersection condition with modified GCHT. The yellow circle in picture (a) means the estimated ball position and radius with modified GCHF

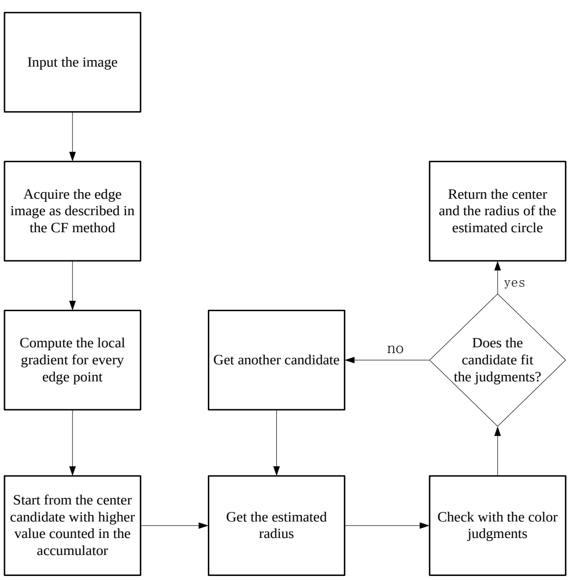


Fig. 6. The modified GCHT algorithm flowchart

green pixels and the circumference of the fitting circle. It is to make sure the radius of the estimated radius is accurate enough, because the contour of the ball on the edge image is easily influenced by the shadow or contours of grass. If one ball center candidate is well supported by all of these criteria, it is thought to be the real ball center. However, the disqualifications for any criteria will repudiate this ball candidate. If all of the candidates are repudiated to be the real ball, this image is considered to be an invalid image and will be discarded.

III. Experimental Results

We do all the experiments based on the HFR robots shown in Fig. 7. which participated in the 2015 Robocup and made into the final eight. The height of the robot is 56cm with 21 freedom degrees. The camera has been placed on the top of the HFR robot. The camera used is Logitech C920 with the resolution of 640*320. The main controller is a PCM-3363 with the ubuntu 14.04 system environment.

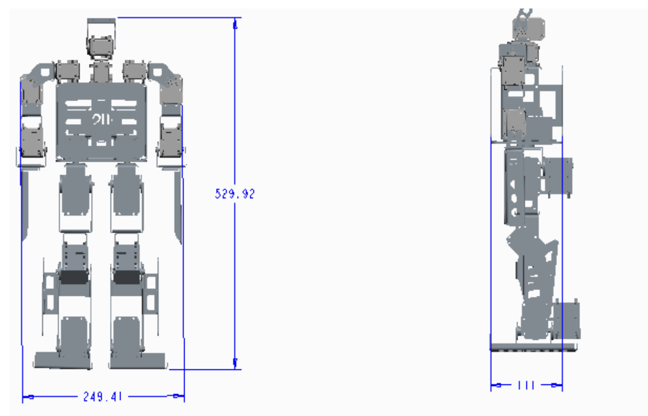
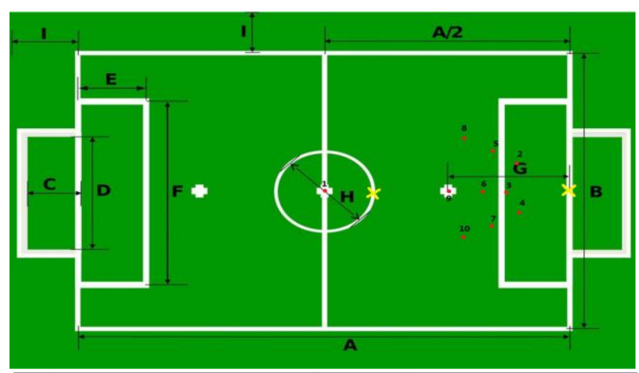


Fig. 7. The model represents the configuration and dimensions of HFR Robot (in mm)



		KidSize	TeenSize & AdultSize
A	Field length	900	900
B	Field width	600	600
C	Goal depth	50	60
D	Goal width	180	260
E	Goal area length	60	100
F	Goal area width	345	500
G	Penalty mark distance	180	210
H	Center circle diameter	150	150
I	Border strip width (min.)	70	

Fig. 8. Kid size Humanoid Robot Soccer Field and Dimensions (in cm)

All tests have been carried out in a standard humanoid robot soccer field for KidSize shown in Fig. 8. under artificial light condition. A set of key points, explicitly exhibited in Fig.8, are chosen for the experiments. Red points marked by points 1 to

10 represent the positions for the ball and the yellow X mark represent the robot. These positions are crucial during a match. Point 1 is the place to kick off, whereas the others are close to the goal. With the aid of PID method, the ball is always locked in the middle area of the robot's vision field.

TABLE Ⅰ
THE PERFORMANCE OF THE CF IN 10 SECONDS WITH ARTIFICIAL LIGHT CONDITION

NO	Distance (cm)	Total frames in 10s	CF detected ball	False Detected	False Positive rate(%)	Effective frames per second
1	75	266	0	1	0.4	0
2	50	261	0	2	0.8	0
3	50	268	0	2	0.7	0
4	50	266	0	0	0.0	0
5	100	261	261	0	0.0	26
6	100	262	256	2	0.8	26
7	100	262	262	0	0.0	26
8	180	263	263	0	0.0	26
9	180	262	258	0	0.0	26
10	180	263	263	0	0.0	26

TABLE Ⅱ
THE PERFORMANCE OF THE ORIGINAL GCHT IN 10 SECONDS WITH ARTIFICIAL LIGHT CONDITION

NO	Distance (cm)	Total frames in 10s	GCHT detected ball	False Detected	False Positive rate(%)	Effective frames per second
1	75	229	95	10	4.4	10
2	50	277	82	20	7.2	8
3	50	278	146	9	3.2	15
4	50	268	146	14	5.2	15
5	100	279	159	59	21.1	16
6	100	279	165	53	19.0	17
7	100	287	153	59	20.6	15
8	180	286	178	37	12.9	18
9	180	286	124	46	16.1	12
10	180	286	183	42	14.7	18

TABLE Ⅲ
THE PERFORMANCE OF THE NEW EFFICIENT METHOD (NE) IN 10 SECONDS WITH ARTIFICIAL LIGHT CONDITION

NO	Distance (cm)	Total frames in 10s	NE detected ball	False Detected	False Positive rate(%)	Effective frames per second
1	75	285	193	10	3.5	19
2	50	274	108	0	0.0	11
3	50	280	181	3	1.1	18
4	50	264	106	9	3.4	11
5	100	283	283	0	0.0	28
6	100	286	286	0	0.0	29
7	100	283	283	0	0.0	28
8	180	286	286	0	0.0	29
9	180	234	127	1	0.4	13
10	180	285	285	0	0.0	29

As improving timeliness and reducing false positive rate are the major concerns of our algorithm, so we tested the performance of different methods in 10 seconds performance. The new method has been compared with the independent CF method and the original GCHT algorithm used by OpenCV. In order to get the false positive rate in terms of efficiency and the effective frames per second in terms of timeliness, the total frames, frames with real detection and frames with false positive detection have been recorded.

To get a good performance of the new method, a number of trials were necessary to acquire the best LUT and decide the proper threshold of Canny operator. In addition, both algorithms are implemented on the edge image acquired through our preliminary image processing algorithm.

The experimental testing results using the CF method are shown in Table Ⅰ. The results using the original GCHT are shown in Table Ⅱ and the results with the new recognition method are shown in Table Ⅲ. The results in Table Ⅰ indicates that the CF method completely fails when the ball is under intersection condition (at point 1, 3, 5, 7, 9). So the CF method is limited to non-intersection condition and therefore can not be used independently. However, it does perform well under the non-intersection case. From the results of original GCHT in Table Ⅱ, it can be seen that it can be used in both conditions but the performance is relatively not good enough.

For the results of the new proposed method shown in Table Ⅲ, it is clear that the new recognition method not only can be used in both conditions but also shows a higher efficiency and timeliness. For one thing, compared to the CF method, the new method can be applied in broader conditions. For another thing, compared to the original GCHT method, the efficiency referred to the effective frames per second is higher. As is shown, effective frames detected per second of the new recognition method are almost twice than the original method. Besides, the original GCHT method gives more false positive detection under non-intersection condition whereas the new recognition method gives nearly no false positive detection under the same condition.

IV. CONCLUSION

The aim of this work is to put forward a new method dealing with the arbitrary colored ball recognition based on OpenCV for Robocup. The new method not only combines color features and the shape features together, but also has taken the illumination as well as occlusion into consideration. In order to improve the performance in timeliness and efficiency, this method uses specific ways to recognize the ball under different conditions, CF for non-contour intersection and modified GCHT for contour intersection. Multiple of experiments have been implemented with the robot HFR. As the encouraging experimental results shows, this method accomplishes a good balance among timeliness, efficiency and false positive rate with the regard of the Robocup competition.

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