Marine Buoy Detection Using Circular Hough Transform

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Marine Buoy Detection using Circular Hough Transform

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A low cost method for buoy detection in maritime settings is presented using inexpensive digital cameras. In this method, the circular Hough transform is applied to an edge image to circular objects in the image. The center of these circles will signify the locations of each buoy. The known color information of the buoys is also used to enhance the performance by removing false detections. The algorithm is compared to an approach that locates buoys purely on color information. In order to validate the method, we test the approach synthetically and also with real images captured from a small surface vessel. This approach is unique in that it combines the use of shape and color information for buoy detection. It is found that by using both color and shape, the buoy detection is improved from using either feature independently.

INTRODUCTION

In recent years, there has been a great deal of interest in autonomous marine navigation particularly in unmanned surface vessels. A self reliant system for these craft can potentially be used in many applications from use as a military scout to an improved recreational autopilot. A problem that arises in automated marine navigation is the detection and recognition of buoys. These buoys are important in marking important areas in the marine landscape such as shallow regions, no wake zones, and channel locations. In this paper, a real-time methodology to be able to identify and locate red and green buoys commonly used to outline the boundaries of channels through the use of digital cameras is presented. This computer vision approach is much less costly than using lasers or rangefinders for detection. An inexpensive web camera may be purchased for under $50 while a SICK laser measurement sensor commonly used for navigational purposes are over several thousand dollars. One computer vision method to detect solid colored buoys is to color segment the known color regions and find the centroid pixel location. This method is highly sensitive to lighting variations and requires careful calibration. Also, other regions or objects in the image may share the same color characteristics, thus the method is prone to error. If the buoys are assumed to be circular, the color sensitivity can be reduced by incorporating a shape component in the detection thus making the detection more robust to color variations.

The circular Hough transform was implemented in order to find round objects in the image. The center of these circles will signify the locations of each buoy. The main steps in performing

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the detection involves first finding the contours of objects using edge detection, then using the circular Hough transform to extract shape information, and finally trimming false detections by using the known color information of the buoy. This method combines the use of shape and color information to enhance the capabilities of either approach individually. This method was found to be more robust to color similarities of the buoys and background than the color-centroid approach while producing real time processing. Also, the use of color information along with the circular Hough transform was found to reduce the number of false detections.

METHOD

A number of computer vision methods are applied to the input images. In this section, each component that leads up to buoy detection is discussed.

Edge detection

In this buoy detection method, the shape of the buoy is restricted to be circular. With this assumption, the known shape information can be used to detect the location of the buoy. In order to perform this feature extraction within the image, the first step is to find the contours of objects. This is a fundamental problem in computer vision known as edge detection which has been researched heavily in the computer vision literature. As such, there exist many different algorithms including the Sobel, Prewitt, and Canny edge detectors.[5,7] In general, these algorithms trace areas in an image that have sharp discontinuities in intensity value which are commonly present at the borders of objects.

The Canny edge detection is used for this implementation. This is a popular edge detection technique for its robustness to noise and its good localization of edges.[7] In Canny edge detection, the horizontal and vertical gradient of each pixel location is calculated. The sum of these two components is compared to a threshold to determine if an edge exists at that location. For pixels that have high edge strength, an edge direction is computed which is used to trace edges. An example of this step is shown in Figure 1. As can be seen in the Figure, the Canny edge detector creates a fairly circular boundary for the single buoy. Also, the resultant image is binary such each pixel is either labeled as an edge (white) or not an edge (black).

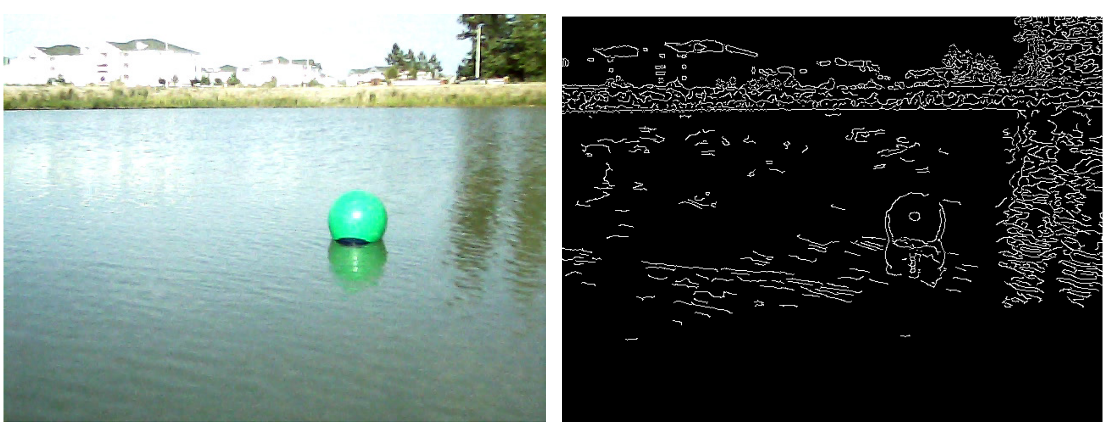

Figure 1. Edge Detection. a) Field Image. b) Canny Edge Detection

Circular Hough Transform

Once an edge image is obtained, the next step is to determine the location of round objects in the image that can then be labeled as buoys using the circular Hough transform.[1] This technique employs a voting mechanism that can overcome minor imperfections in shape. This is useful since in real world implementations, the edge detector may not produce a perfectly round boundary for the buoys due to many factors including reflections of light, occlusions, and partial submersion of the buoy. These imperfections can be seen in the coarse outline of the buoy in Figure 1b.

The circular Hough transform takes advantage of the fact that besides the center location, a circle's only parameter is the radius thus limiting the parameters to adjust while searching for the shape. First, take the assumption that the radius of a particular circle is known. Given an edge image of the circle, its center can be found geometrically by drawing circles with similar radius centered at the edge of the original circle. Consider the example shown in Figure 2. The original circle is shown in Figure 2a. In Figure 2b, eight secondary circles are drawn centered at various locations on the edge of the original circle. As can be seen, the secondary circles will intersect each other at the original circle's center. The edges of the secondary circles can be seen as potential areas that the original circle center can be. Furthering this notion, the secondary circle edges can be seen as "votes" for the circle center. In image processing, an accumulator will store the number of votes at each pixel location. After all edge pixels are considered, accumulator locations that contain more than a specified threshold of votes is determined to be a circle center.

This can be extended to the more practical case where the actual size of the circle is not known by simply iterating through every suspected radius. In image processing, this can be from 1 to ½max(height, width). In the implementation using low cost webcams, the maximum size of the image is relatively small (640x480 pixels) and the processing can be completed with a frame rate of 6 fps even if all possible radii are tested. It was found that radii that are too small will produce many false detections while large radii can be omitted to reduce computation cost. The implementation limits the radii to be between 20 and 75 pixels.

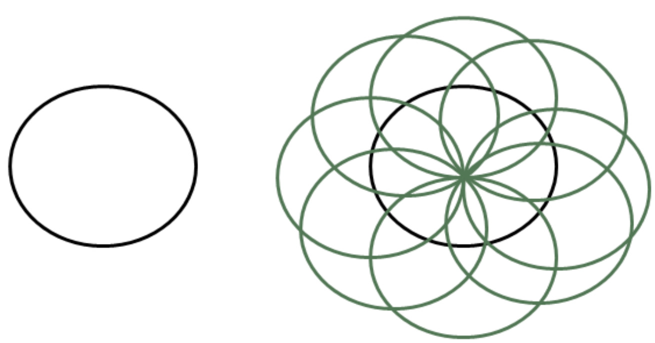

Figure 2. Circular Hough Transform. a) Original Circle. b) Secondary Circles

False Detection Trimming

False detections can occur at areas of high edge activity. This occurs since the density of accumulator votes will be much higher in these locations. To reduce the number of false detections, the known color information of the navigational buoys is also used. Once a potential buoy is found with the circular Hough transform, the ratio of pixels within the detected circle that meet the color criterion is computed. If the correct color ratio is too low, the circle detected is not labeled as a buoy. In the implementation, a ratio of 35 percent was used. This number is relatively low since the color segmentation of the buoys generally does not encompass the entire buoy due to lighting variations.

EXPERIMENTAL RESULTS

In order to test this algorithm for buoy detection, two experiments were conducted. The first experiment is under synthetic settings while the second is performed on real images.

Synthetic Setting

The purpose of the first experiment was to obtain preliminary results and to validate the algorithm. The circular Hough transform method to detect buoy locations is compared to a simple mean color method that relies only on color information. The compared method finds the centroid of all pixels that have the same color as a potential buoy and labels the center of the buoy as the centroid found. This approach is expected to fail if other objects with the same color characteristics appear in the image. One red circular object is drawn randomly in the image along with a red polygon. In Figure 3a, an example of a synthetic image is shown. Figure 3b contains the predicted center for the two algorithms. The green circle is the circular Hough algorithm's predicted center. Using the radius found in the algorithm, an outline of a circle is overlaid over the original image. As can be seen, the predicted center is very close to the true center with an exterior outline that is only slightly offset from the contours of the original circle. This variation can be attributed to the accumulation of errors in edge detection along with the errors in approximating circles in a pixilated image. The prediction using the centroid color is shown as the white "+". As expected, this method is greatly affected by the presence of similar color objects.

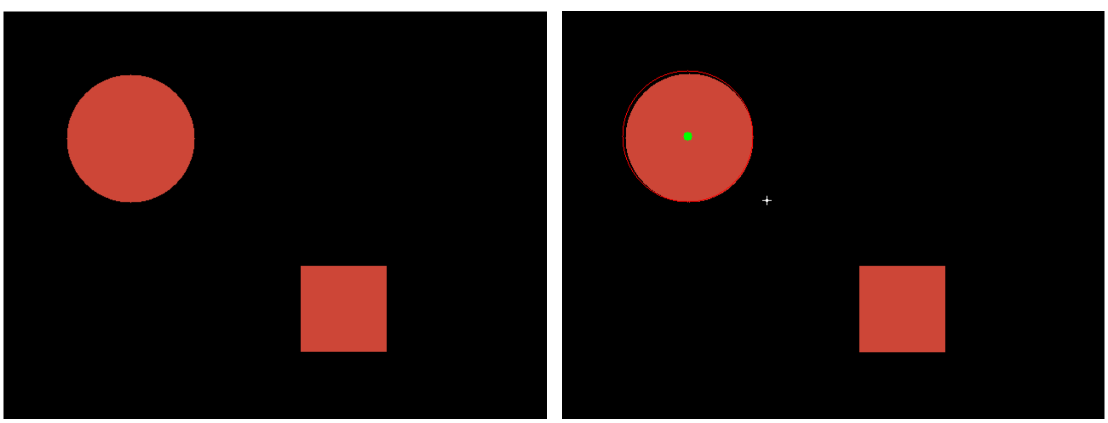

Figure 3. Synthetic Test. a) Original Image. b) Predicted Centers

Maritime Setting

In order to test the algorithm's usefulness in real settings, images are taken of a course of red and green navigational buoys in a maritime setting. An example of a scene is shown in Figure 4. In Figure 4a, the original image is shown taken of two red and green floating buoys. Figure 4b is a color segmented image using the known color information. As can be seen, the color of the green buoy is similar to the background causing the color segmentation to include high levels of noise. This would certainly cause a strictly color based method to fail in detecting the green buoy. Figure 4b also shows four circles as potential buoy locations found from the circular Hough transform. In this case, the ripples on the water produce areas of high edge activity and a few unwanted detections are found. False detection trimming was then performed as described in the Method section. The false detections, shown in gray in Figure 4b, contain a low ratio of pixels compared to the location of actual buoys. Here, the algorithm correctly detects the locations of the green and the red buoy. It is shown by the Figure that by using the color information for false detection trimming, the buoy detection is improved from just using shape information. The buoy detection algorithm was found to have a frame rate of 10 fps from live video captures thus allowing its use in real-time applications.

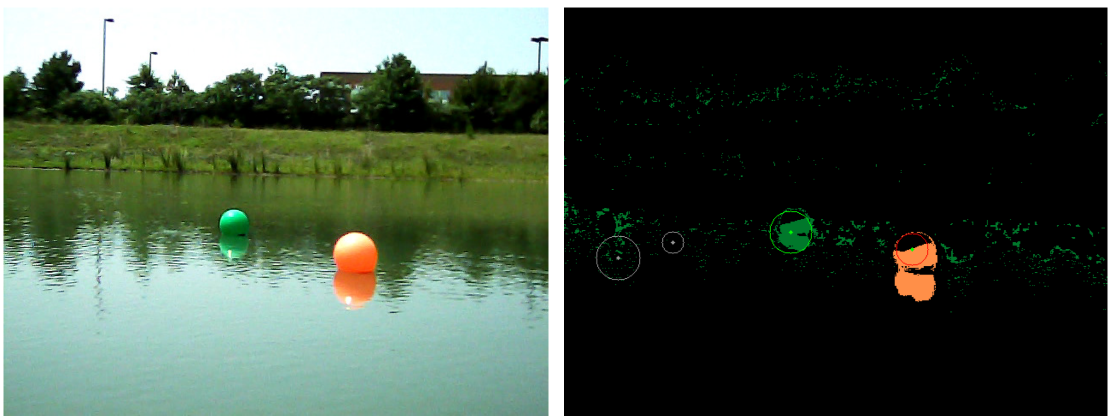

Figure 4. Maritime Test. a) Field Image. b) Buoy Prediction

CONCLUSION

A system for the detection of navigation buoys in a maritime setting must be efficient enough so that decisions can be made in real time. While lasers and range finders can provide accurate estimations, their high cost may be prohibitive. An alternate approach is to use low-cost web cameras and extract information from the video stream. Here, a method for detecting round navigation buoys using the circular Hough transform is presented. The method is more robust to background color similarities that just using a color segmenting approach. Also, the color information was found to be useful in reducing the number of false detections. This approach of using both the color and shape information of the navigational buoys was shown to be more effective at buoy detection than by using either approach independently. A disadvantage to the presented method is that the detection is very parameter sensitive. The threshold in the edge detection step may vary between scenes and requires calibration to restrict the amount of unwanted edges. This becomes a problem since false detections occur at regions of high edge activity. False detections may also occur if the accumulator threshold for the Hough transform is not calibrated. The presented method restricts the shape of the buoys to be circular. This is to take advantage of the fact that a circle's only parameter other than the center location is the radius. This limits the use of the Hough transform for other shapes since the inclusion of many parameters may be computationally prohibitive.

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