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Application of the Hough Transform to Aid Raised Pavement Marker Detection on Marked Roadways

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Abstract

A machine vision system is proposed that will identify and locate GPS co-ordinates of defective Raised Pavement Markers along road lane markings. This system will comprise of a mobile data acquisition system, and a separate offline image analysis system. In this paper we present a method for road lane marking identification, using a Hough Transform based technique. This paper describes the implementation of the Hough Transform for line detection. Using the Hough Transform algorithm road lane markings are automatically identified, given a scene acquired from a digital camera system. This knowledge is intended to be used to aid current research in the area of defective Raised Pavement Marker detection at ITB. Results of a sample dataset are presented and discussed

Keywords Machine Vision System, Hough Transform, Raised Pavement Marker, Accumulator, Global Positioning System

1. Introduction

The National Roads Authority (NRA) in Ireland is responsible for the installation and maintenance of Raised Pavement Markers (RPMs), on all roadways throughout Ireland. The main focus of this research is to develop a working prototype for the NRA that can automatically identify and locate defective RPMs. This research can be sub-divided into four parts: Image Acquisition; Image Processing/Analysis; and Fusion with GPS data, with the end goal being a fully functioning practical prototype. Currently, a stereo vision image acquisition system is under development, synchronously capturing image data via two firewire digital cameras. In this paper we focus on the image processing stage of our research, primarily concerned with a technique that can help solve the problem of defective RPM detection.

2. The Hough Transform

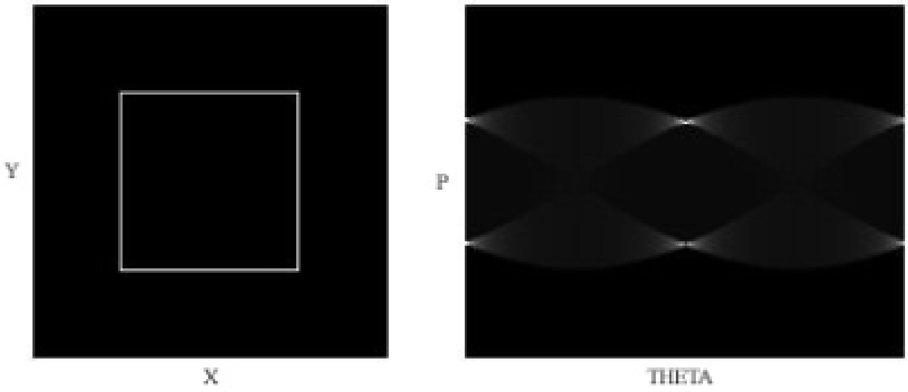
2.1 Introduction

In the field of image processing it is essential to be able to find and identify various objects within image sequences. Objects of interest account for various shapes (road lane markings) with straight and circular edges, that project to straight and elliptical boundaries in an image. One method of identifying features of interest within an image is the Hough Transform.

The Hough Transform (HT), developed by Paul Hough in 1962 [1] [2], has become a standard tool in the field of computer vision for the recognition of straight lines, circles and ellipses. The HT is a technique which can be used to isolate features of a particular shape within an image.

Using some curve representation, this technique transforms a set of points defined over the image space to a set of points defined over some parameter space (known as Hough space). Points in Hough space represent particular instances of a curve in the image. Therefore, the strategy used by the HT is to map sets of points from a particular instance of the considered curve, i.e. the parameterized curve, to a single point representing the curve in Hough space and, in effect, cause a peak to occur at that point [3]. The main advantages of the HT technique are that it is relatively unaffected by image noise while it is also particularly robust to missing and contaminated data, tolerant of gaps in feature boundaries.

2.2 Implementation of the Hough Transform



(a) **(b)**

Figure 1: Hough Transform from (a) image space to (b) Hough space

The motivation for the HT technique for line detection is that each input measurement (i.e. the co-ordinate point) indicates its contribution to a globally consistent solution (i.e. the physical line which gave rise to that image point). To illustrate how the HT technique works, consider the common problem of fitting a set of line segments to a set of discrete image points (i.e. pixel locations output from an edge detector). A simple square is used as an example, illustrated in Figure 1(a), above. The corresponding Hough space is shown in Figure 1(b). In Figure 1(b) above the intensity represents peak size, ρ is represented by the vertical axis, and θ is represented by the horizontal axis.

When interpreting the information contained in Figure 1(b) it might seem that six peaks have occurred to the trained eye when in fact only four true peaks have occurred, since Hough space is periodic. This point-to-curve transformation, from image space to Hough space, represents the HT for straight lines. When viewed in Hough parameter space, points which are collinear in the Cartesian image space become readily apparent as they yield curves which intersect at a common point. Hence each of the four peaks identified in Hough space correspond to each of the four lines that represent the square in our image space.

A straight line in an image has two ends, but the Hough transform (see Figure 1(b)) does not find end-points. Rather it finds the infinite straight lines on which the image edges lie. A part of a line lying between two end-points is called a line segment, note that all references in this paper to the term line will mean an infinite straight line. These infinite lines are worth extracting, since once found they can be followed through the image and end-points located if necessary.

2.2.1 Parametric Representation of HT

Consider a single isolated edge point (x, y); there could be an infinite number of lines that could pass through this point. Each of these lines can be characterized as the solution to some particular equation. The simplest form in which to express a line is the slope-intercept form:

$$y = mx + c \qquad (1)$$

where m is the slope of the line and c is the y-intercept (the y value of the line when it crosses the y axis). Any line can be characterized by these two parameters m and c. Each of the possible lines that pass through point (x, y) can be characterized as having coordinates (m, c) in some slope-intercept space. In fact, for all the lines that pass through a given point, there is a different value of c for m:

$$c = y \,.\, mx \qquad (2)$$

The set of (m, c) values, corresponding to the lines passing through point (x, y), form a line in (m, c) space. Every point in image space (x, y) corresponds to a line in parameter space (m, c) and each point in (m, c) space corresponds to a line in image space (x, y) [2].

2.2.2 Accumulators

The Hough Transform works by quantizing the Hough parameter space into finite intervals (i.e. letting each feature point (x, y) vote in (m, c) space for each possible line passing through it). These votes are totaled in an *accumulator*. Suppose that a particular (m, c) has one vote, this means that there is a feature point through which this line passes. If there are two votes, this means that two feature points lie on that line. If a position (m, c) in the accumulator has n votes, this means that n feature points lie on that line. Lines for which a high number of votes are accumulated result in the occurrence of peaks in Hough space.

2.2.3 The HT Algorithm

The algorithm for the HT can be expressed as follows:

1. Find all of the desired feature points in the image
2. For each feature point:
3. For each possible line, in the accumulator, that passes through the feature point (ρ, θ)
4. Increment the (ρ, θ) position in the accumulator
5. Find local maxima in the accumulator

2.2.4 Polar Representation of HT

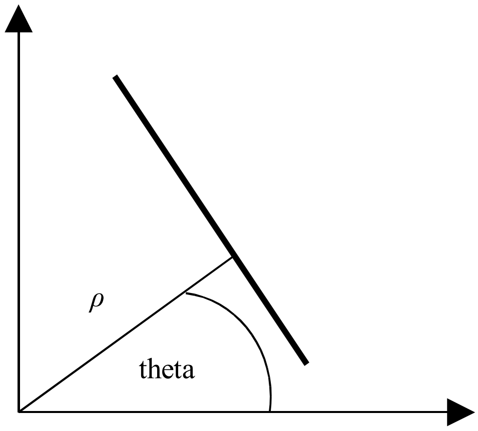


Figure 2: Parametric representation of a line

The slope-intercept form of a line has a problem with vertical lines: both *m* and *c* are infinite. Another way of expressing a line is the *normal parameterisation form*, or (ρ, θ) form:

$$x \cos \theta + y \sin \theta = \rho \qquad (3)$$

One way of interpreting this is to draw a perpendicular line from the origin to the line (Figure 2). θ is the angle that the perpendicular line makes with the x-axis and ρ is the length of the perpendicular (bounded by the diagonal of the image). If θ is restricted to the interval $[0, \pi]$, then the normal parameters for a line are unique. With this restriction, every line in the x-y plane corresponds to a unique point in the θ - ρ plane [2]. Given some set $\{(x_1, y_1), \ldots, (x_n, y_n)\}$ of n figure points. By transforming the points (x_i, y_i) into the sinusoidal curves in the $\theta - \rho$ plane, one can calculate the set of lines that fit the n figure points.

Curves generated by collinear points in the image space intersect and form peaks in *Hough space*. These intersection points characterize the straight line segments of the original image [2]. Instead of making lines in the accumulator, each feature point votes for a sinusoid in the accumulator. Where these sinusoids cross, there are higher accumulator values. Finding maxima in the accumulator still equates to finding the lines. There are a number of methods which one might employ to extract these bright points (peaks), or local maxima, from the accumulator array.

3. Experiments and Results

A sample dataset was collected on a national roadway. A single frame of the data used is illustrated in Figure 3(a) below. It was decided that the camera position was set as close to driver eye level as possible to allow for realistic measurements and realistic data analysis of the driving scenario. For the purposes of the HT technique all image data had a threshold function applied to convert it to a binary image, and a Sobel edge detector [6] was then applied to each frame of the image sequence. Figure 3(b) illustrates the edge map, of the original test image data Figure 3(a), returned (using a threshold level of 40).

Figure 3: (a) Test image

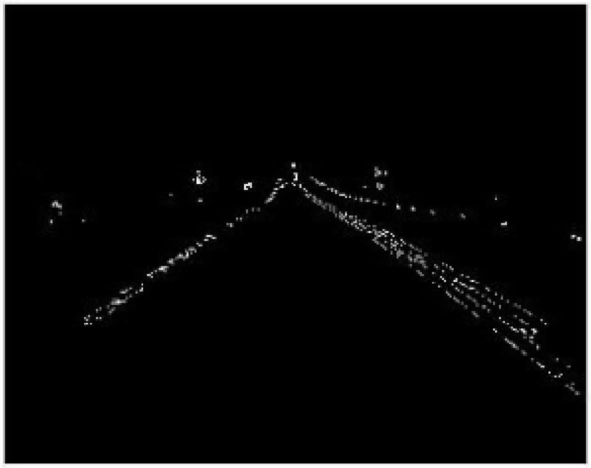


Figure 3: (b) Sobel edge map of test image

After the edge map was generated, the HT function was applied to the edge map rendering a Hough parameter space plot. Some of the noise was eliminated by thresholding the peaks in *Hough space*. Hence the number of legal peaks found, to be plotted was reduced to 100 in order to reduce the amount of information to be processed.

To aid our analysis of the test data Hough space was represented as a 3-D mesh of peaks, see Figure 4. It can be clearly seen from this Figure where the strong and relevant peaks lie. The strongest peak representing the centre lane of the roadway can be clearly seen as a light blue/yellow peak.

In order to allow individual identification of each road lane, the approximate angle of each line was computed in relation to the camera position, in the image space. An angular threshold was set to extract peaks corresponding to the individual lane markings.

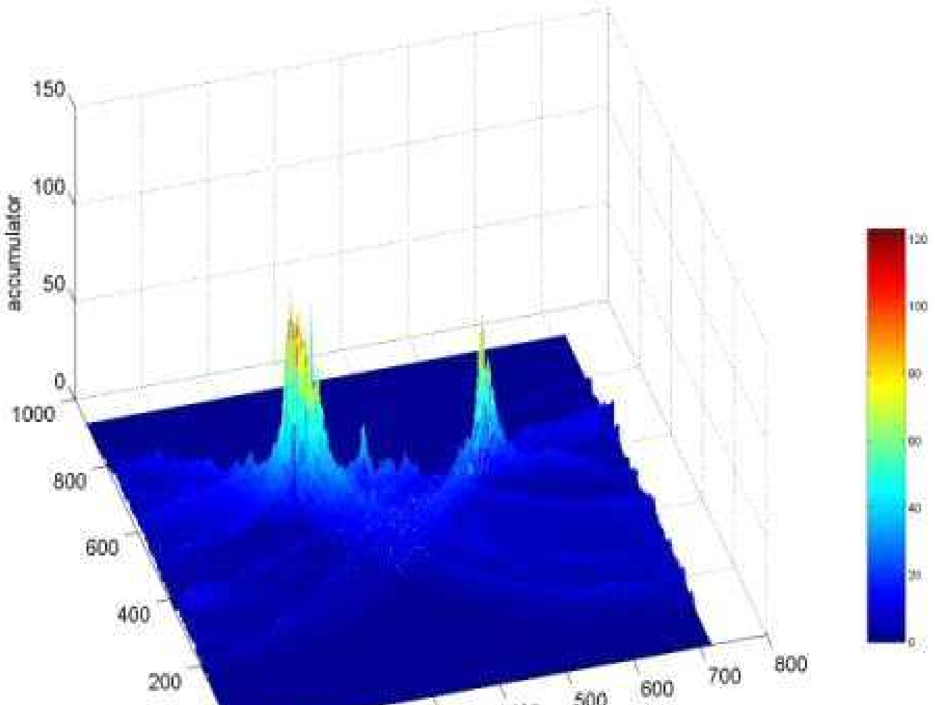


Figure 4: Hough space illustrated in a 3-D mesh

The HT technique discussed above was applied to other datasets collected from minor roads. As expected, when this technique was applied to some of the data sets acquired, the results for the right road lane were inadequate. The cause of this error was related to the camera position.

Hence these problems can be over come by introducing a second camera to concentrate on the right hand side road marking. This was due to the fact that the angle of the right hand road marking is greater (closer to horizontal) than the left and centre road markings in terms of the camera position, hence other feature points in the image (noise etc.) were causing incorrect peaks being created in Hough space.

3.1 Conclusions

This paper details a method of identifying road lanes, with the intent to reducing the image processing complexity when identifying RPMs along a roadway. The method involves applying the Hough Transform to the input data, with the result rendering the identification of the road lane(s). Knowledge of where the road lanes are will greatly reduce the amount of information needed in the data set, and allow for image analysis to be focused on a subset of the data set. It is planned to develop this prototype technique to take into account faded or defective painted road lanes, in order to identify roadways that need immediate maintenance.

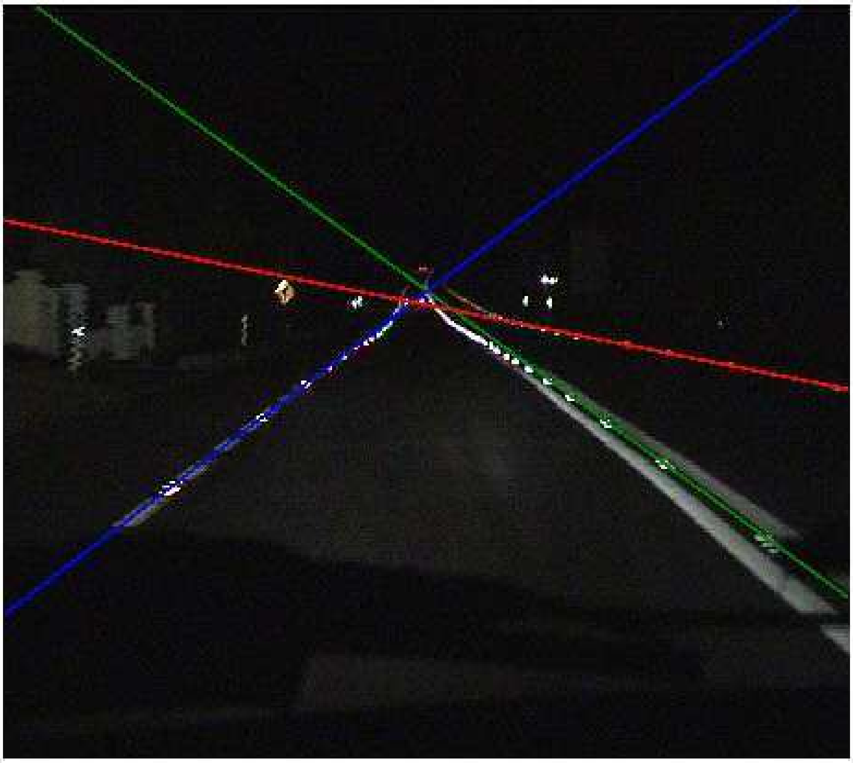


Figure 5: Inverse Hough Transform result

4. Future Work

It is planned to develop this technique further and acquire road data using a stereo vision system, which is currently near development completion. With this system it is envisaged that the right hand road marking will produce a greater peak in Hough space allowing for more straightforward identification, and separation from unwanted noise.

The next stage of research will involve developing a robust RPM locator algorithm which can traverse along road markings and identify all defective RPMs along those lines. In order to detect RPMs along the road, a threshold must be set to allow for the contour changes in the ground plane levels of the road. Therefore a segment of the road data image will be used, where the contour of the ground plane is constant. Once the RPMs have been identified and located in relation to the vehicle (on which the stereo vision system will be mounted) this data will be fused with vehicle GPS position information to allow extraction of global RPM co-ordinate information. With this GPS co-ordinate information it is hoped that as an extension to this research initiative, a database of defective RPMs can be catalogued.

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