

Realtime Image Processing Algorithms for the Detection of Road and Environmental Conditions

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Abstract

This paper discusses image processing algorithms for the recognition of environmental and road conditions from real-time camera images. This research addresses various implementation techniques for and considerations of the implementation of algorithms to extrapolate various features from images taken by stationary traffic cameras. These algorithms have uses in the areas of traffic pattern analysis, emergency response, real-time traffic situation awareness, and homeland security. This paper covers the design and implementation of an automated camera heading detection system to determine the directional components of a camera's position using the current camera image, various computer vision techniques, and a series of classification training images. Image processing topics addressed as part of this research include edge detection, line detection, and two-dimensional filtering.

Introduction

Thousands of traffic cameras are situated along roads throughout the United States. These cameras serve many purposes such as speed enforcement, accident investigation, and traffic flow analysis. In addition, a wealth of information on environmental and road conditions such as weather, traffic flow, and visibility can be obtained from the visual cues in the images. The additional information contained within these images is often very difficult to extract or determine automatically. Therefore, human intervention is usually required to analyze and interpret the images and collect important data. Furthermore, the images obtained from these cameras often suffer from severe noise distortion due to weather conditions and camera characteristics.

Another difficulty in the analysis of these images is the distortion which occurs as a result of perspective projection of lines within the image to a horizon of vanishing points. This perspective distortion is further compounded by the fact that traffic cameras are generally situated at heights of less than 30 meters.

A further difficulty in the harnessing of visual information from traffic images is the lack of multisensor information to detect camera heading or pitch. When translating from camera and image geometries to real world geometries, this lack of directional heading information means that camera observers cannot tell the direction of the traffic flow.

This paper discusses the analysis of 2D images from stationary expressway traffic camera systems. The result is a camera heading feedback mechanism for the detection of the two dimensional rotational angle of a traffic camera based on a single training image and the

analysis of the perspective projection vanishing point of straight path roadways. The core of this paper discusses a method to determine the perspective vanishing point from 2D camera snapshots. The remaining portion discusses a method for determining the rotational angle based on the image vanishing point and a single training image.

This research focuses on the interpretation of low resolution snapshot images from a real-time traffic monitoring system and uses various computer vision and trigonometric techniques to determine the perspective vanishing point and camera rotation angle.

Related studies have analyzed aerial images for the purpose of unmanned aerial vehicle navigation and transportation system mapping (Koutaki and Uchimura 2005, Laptev et al. 2000, Gorte et al. 2005, Kim 2005) using large area, high resolution photographs. The results of these studies do not, however, have direct translation to studies involving low-altitude, low-resolution, stationary camera situations. Therefore, the development of general purpose camera visual feedback algorithms is needed to allow for collection of real world information from traffic camera.

Related Work

A considerable amount of research has been performed on the analysis of 2D images and video to determine various traffic characteristics (Koutaki and Uchimura 2005, Laptev et al. 2000, Zhang et al. 2001, Gorte et al. 2005) for the purpose of traffic simulation calibration and traffic network mapping. Gorte et al 2005 used helicopter image sequences to extract microscopic traffic flow information during traffic congestion. In this case, linear road segments were extracted using various edge and line detection techniques on images taken from a height of approximately 500 meters. Laptev et al 2000 also analyzed aerial images to extract road patterns for the purpose of mapping and navigation. Other research (Kim 2005) has focused on the realtime analysis of aerial images for the purpose of Unmanned Air Vehicle (UAV) navigation. This work instead entails the analysis of images taken instead from low heights by stationary cameras.

Likewise, there has been a great deal of research into the analysis of images to determine the perspective vanishing point (Rother 2002, Shufelt 1999, Cantoni et al. 2001, Tuytelaars et al. 1997). It is well known (Shapiro and Stockman 2001) that the use of common points from multiple images can be used through the process of rectification to determine the angular distance between these images. Using this knowledge, it is possible to determine the 2D rotational angle of a camera based on the location within two images of a common camera point and the projection line from the camera to this point in each image. Additional camera calibration information such as camera height allows for the extraction of 3D characteristics of image scenes.

Traffic images are further complicated by the dynamic nature of the scene vehicles and the somewhat uniform color of road sections. This makes it difficult to distinguish individual points for comparison between multiple images of a single scene. Therefore, a general purpose algorithm for determining reference points or lines within traffic images is needed to allow use of the well known analysis algorithms in computer vision research.

Image Analysis

The images used in this research (see Figure 1) were acquired using stationary traffic cameras mounted at various locations in the metropolitan Chicago area. These 2D images used JPG format and were represented using a two dimensional array such that each value in the array represented the RGB color triplet for an individual image pixel. This section details the techniques used to enhance the traffic images and extract the road direction and vanishing point for use in heading detection.

Grayscale Conversion

The first step in image analysis was the conversion of the RGB image into grayscale using standard techniques. An example grayscale image is shown in Figure 2.



Figure 1: Image obtained from traffic camera (copyright Gary-Chicago-Milwaukee Corridor).



Figure 2: Grayscale converted image.

Median Filtering

After grayscale conversion, the noise within the image was smoothed using a median filter (see Figure 3). A median filter modifies an image pixel such that the new pixel value is selected as the median of the neighboring values within a range. This filtering has the effect of removing random noise in images while still maintaining the overall integrity of image regions and boundaries. This type of filter is typically categorized as a blurring filter in many image processing toolkits.

Thresholding

The next step in processing involves the conversion of the grayscale image into a black and white image through a process called thresholding. This process involves the selection of a threshold value in the grayscale range which acts as a cutoff for determining which pixels should be converted to white or black in the resulting image. The resulting black and white image is shown in Figure 4. This image shows a clear perspective flow of image lines from the lower right corner toward the upper left vanishing point.



Figure 3: Image after median filtering.

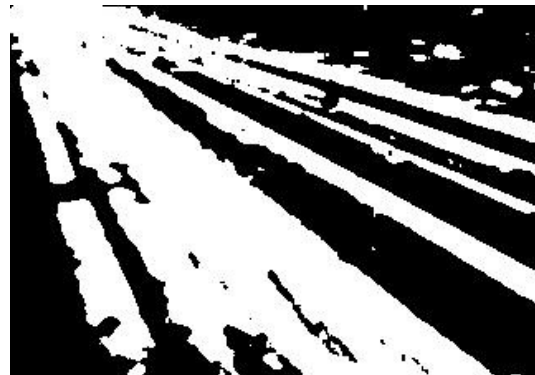


Figure 4: The thresholded black and white image.

Line Detection

Using the thresholded image, a Hough Transform (HT) is performed. The HT algorithm maps all points in the image space into sinusoids within an alternate polar coordinate

parameter space. The polar coordinates defined within this parameter space define the angle and magnitude or length of vector normals for probable lines in the image space (see Figures 5 and 6). Using these parameters, it is possible to map points in the HT parameter space to lines in the image space.

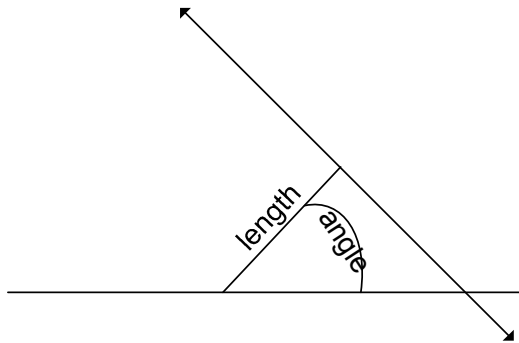


Figure 5: The polar representation of a line.

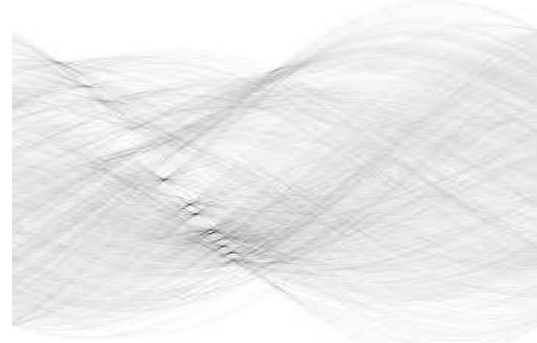


Figure 6: The Hough Transform parameter space.

Each point in parameter space is associated with a numerical value which relates to the likelihood of the line defined by the polar coordinates actually existing in the real scene from the image. The local maxima of this space define the most prominent lines within the image scene and provide the basis for use of HT parameter space to detect road paths.

Local maxima in the parameter space are reflected as bright spots in the resulting parameter space image (see Figure 6) and reflect the most well defined lines in the image.

Further analysis of this parameter space will reveal that the local maxima for the parallel lines within the image are themselves represented in a single parameter space line. This feature explains the appearance of a ridge in the parameter space image of Figure 6.

Perspective Line Detection

The revelation that collections of parallel image lines represent lines within the parameter space allows for the further reduction of our parameter space using another Hough Transform (see Figure 7). Within this secondary parameter space, a new set of sinusoids are plotted representing the likely ridges within the initial HT space. The maxima within this space reflect the ridges within the initial Hough space and the sets of parallel lines within the original image scene. This method is commonly known as a Cascaded Hough Transform or CHT (Tuytelaars et al. 1997). The appearance of multiple peaks reflects the existence of multiple sets of parallel lines within the initial image which is common in images. Figure 7, however, reflects only a single peak which directly relates to the parallel scene lines representing the edges and flow patterns of the road in Figure 1.

This single peak reflected in this secondary parameter space reflects a line in parameter space which passes through all image space perspective projection lines. Using the line represented by this peak, it is, therefore, possible to collect all parallel image lines into a single set for common analysis and trigonometric determination of the perspective projection vanishing point. One can imagine the ridge in the initial HT parameter space reflecting an arc in the image space which passes through all component lines of a single parallel line set.

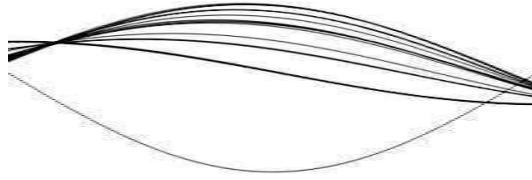


Figure 7: The secondary parameter space mapping of Figure 6.

Vanishing Point Determination

Using the secondary parameter space mapping, it is possible to use an inverse Hough Transform or trigonometric techniques to determine the perspective projection lines. Selection of any two parameter space points allows us to form the equations of two parallel image space lines. The intersection of these lines is the perspective vanishing point. In our example, the perspective vanishing point does not lie within the image space, but is easily determined using a planar space expanding beyond the image boundaries on an alternate coordinate system.

Angle of Rotation

Once the vanishing points of the current image and our training image have been determined, it is possible to calculate the distance between the two points and hence the road line relative to the stationary traffic camera to determine the heading direction or angle or rotation of the camera in two dimensional space. The relative rotation of the roadway in this image relative to a training or reference image roadway allows for the determination of the angular rotation of the camera. This angular rotation is easily mapped to real world directional coordinates based on the calibration information for our camera and reference image. This approach assumes a fixed camera location and the knowledge of certain camera calibration settings.

Results

The research presented within this paper reflects the use of computer vision techniques to extract important information from 2D images of roads. This work also detailed the use of a secondary Hough Transform to detect parameter space ridges within Hough Transform parameter space. These secondary HT parameter space maxima allowed the collection of multiple parameter space lines into sets for common analysis.

Using these techniques, it is possible to map the various images from single traffic locations and stationary cameras into true directional heading components. In addition, the methods detailed allow for use in detecting ribbons of curved road sections using methods detailed in other research (Laptev et al. 2000, Kim 2005).

Conclusion

This paper discusses the implementation of a vanishing point based camera heading detection system capable of analyzing the two dimensional heading from traffic camera images. Although this implementation performed well for the problem of detecting two dimensional vanishing points and camera rotational heading in a 2D image plane, it must be further adapted to detect 3D characteristics and account for the image acquisition distortion

common to video monitoring systems. In addition, the Hough Transform implementation discussed suffers from high computational complexity which may hinder use in a realtime video situation. Adaptation to realtime camera video would likely benefit from the implementation of optical flow methods (Shapiro and Stockman 2001) across multiple image frames in addition to the methods described in this paper.

The perspective projection vanishing point determination technique discussed within this paper allows for simple vanishing point detection and is easily adapted to the detection of multiple vanishing points. Additionally, the secondary Hough Transform method allows for clear distinction of multiple sets of parallel lines without the difficulties common to simple edge detection techniques.

Future study on this topic will analyze the 3D camera position and consider the calibration information for the individual traffic camera position. In addition, this research will be adapted to analyze images from curved road positions. It is expected that the multiple instances of parallel line segments present in curved road sections will be easily detectable within the two HT parameter spaces.

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