Steering Angle Estimation for Autonomous Vehicle Navigation Using Hough and Euclidean Transform

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***Abstract*— The recent trend of proliferation of road accidents and fatalities, calls for a methodology that can appease the burden on the drivers during certain crucial moments, requiring fast response and decision making. This paper expatiates a novel and effective procedure for determining the steering angle required to keep the vehicle in the middle of the lane. The procedure used is divided in multiple stages. The first stage includes determination of the road's midpoint using Robert edge detection and morphological operations. This midpoint is then used to determine the angle by which a vehicle must steer to maintain its position at the center of the road. It is done using Euclidean distance transform and trigonometric equations. The input data suffers non-linearity, irregular intensity, non-uniform contrast difference which makes edge extraction ineffective. To tackle such situations, Hough transform and virtual road edge was used to determine the road and lane edges. The algorithm was tested rigorously using video samples, acquired from camera mounted on hood of a car, characterizing various road conditions. The results underscored the robustness and effectiveness of the same.**

Keywords*— *Euclidean distance transform; Morphological operations; Robert edge detection; Hough transform; Virtual Edge

I. Introduction

The year 2012 saw an enormous 1.3 million deaths and a loss of USD $518 billion globally, making the development of driver assisting systems imperative [1]. Though, safety is a concern, intelligent transportation systems (ITS) can enhance the automobile user base by reducing the driver's attribute requirements and moreover lead to an economical utilization of fuel as proposed by Daniel Zeng [2]. Autonomous guided vehicles, till date have been using laser and radar based range measuring devices for lane and edge feature extraction and have considered CCD image acquisition trivial [3]. But, the heavy dependence of RADAR and LIDAR systems on the difference in the altitude of the road lanes with respect to the pavements and high cost considerations would diminish the practical usability of the devices in low and middle income countries which contribute to 90% of the fatalities [1].

II. PREVIOUS WORKS

A. The traditional lane detection algorithms, which worked solely with the marked roads, based their procedures on gradient-information of an image to extract the edges. Most of them apply threshold to the gradients, which hampers the detection process if the image contrast is diminished by weather conditions or reduced lighting [3].

B. Further problems involve obscurity of one side of the edge, as observed by the eclectic night time samples taken in unmarked roads sparsely illuminated by streetlight.

C. Detection of the curves in the roads and detection of sharp turns and U-turns had been carried out earlier using ant colony optimization or by utilizing a laser based lane detection system [3][5]. The above methods entail a high computation complexity and hence, lead to increased time delay in processing, which is a liability when the video is being captured real time in high speed cars.

D. Most of the previous works on vehicle assistance focused enormously on road feature detection but, failed to gather characteristics essential for vehicular navigation. Several other ways proposed by Tian Shu et al, either use cameras near the vicinity of wheel base or a wheel base sensor system to detect movement [7].

III. PROPOSED WORK

The proposed procedure impregnates the void of economic viability and efficiency in extracting the navigational features from the roads that can assist the vehicle automation. The following issues have been taken into consideration by the algorithm.

To tackle situations created by gradient technique as discussed earlier, the algorithm uses Hough transform following a reduced correlation in the steer angle values. Moreover, the problem of invisibility of edges was solved by predicting the position of the second edge from the inclination angle and position parameters of the Standard Hough Transform (SHT) [4]. The derived 'virtual edge' (VE) provides a near to accurate estimation of the lane and has been made robust by training on several road conditions. The vehicle can be guided along the desired path even with partially visible lanes by the application of Euclidean distance transform [6]. This paper proposes a novel methodology to calculate the steering angle using a single car-hood mounted camera and hence, assists in ensuring vehicle stability at the mid-line of the road.

IV. SYSTEM ARCHITECTURE

The design flow graph to calculate the steer angle is depicted in Fig.1. First, the video is captured using a conventional CCD digital camera mounted on the hood of the vehicle. The real time dynamic image is then processed in the computer placed in the vehicle, storing the direction parameters in a variable and indicating the deviation from midpoint via two LED indicators which resemble left and right.

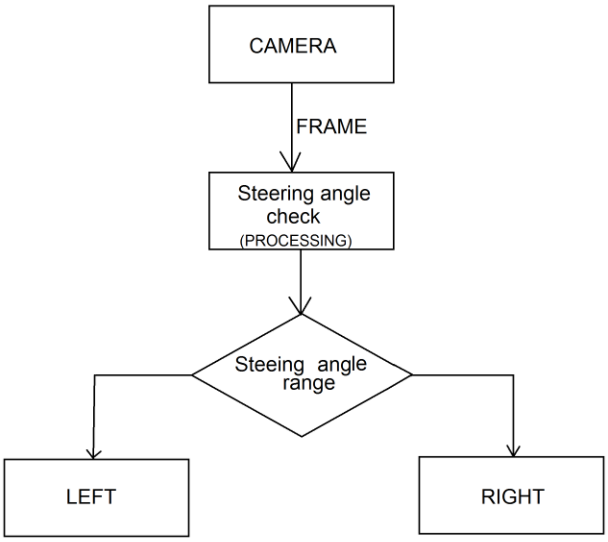


Fig.1 System Architecture

V. VIDEO DATABASE

The camera captures images at an angle of view of 40^o with the horizontal with a resolution of 480*640 pixels and at the rate of 30 frames per second. The image is a three channel RGB image with pixel values in the form of 8 bit unsigned integers. The database constitutes of videos taken at several time intervals during both night and day, which encompasses the variation in noise sources such as shadows, low illumination, marked and unmarked roads, invisible edges and obstacles. Fig. 2 demonstrates the video characteristics taken at different times of a day.

Day Time Frames **Night time frames**

(a)

Time:1:00PM "Red line denotes reference line"

(b)

Time:8:00PM "Shadows on Road"

(c)

Time:3:00PM "Shadow on Road" "Unmarked Road"

(d)

Time:9:00PM "Right Edge Invisible"

(e)

Time:4:00 PM "Moderate illumination" "Object Blocking Edge"

(f)

Time:9:30 "Multiple Vehicles Visible"

Fig.2 Video Database

VI. ALGORITHM IMPLEMENTATION

The flow graph of the computer vision processing of videos is manifested in Fig.3. By default, the edge detection and Euclidean Distance Transform (EDT) are used to for steering angle estimation as the FPGA implementation of the algorithm renders a low time delay than Hough Transform. The angle variable that stores the steering angle data is monitored in a loop. Any discrepancies, with the variable that leads to a difference of more than 30^o (determined experimentally) in steering angle, which can be considered unviable, channels the algorithm to Hough transform and 'virtual edge' concept. The algorithm being robust to low lighting and degraded weather conditions, provides a near to accurate prediction of the steering angle.

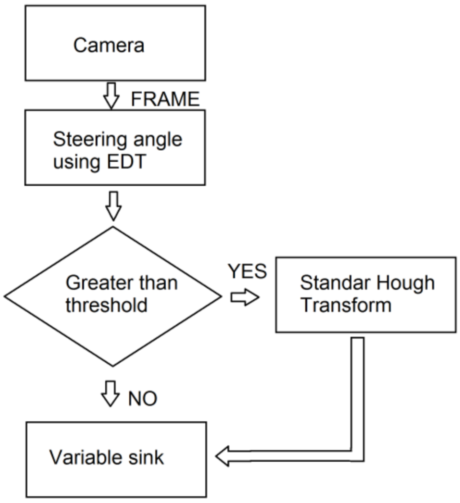


Fig.3 Processing Flow Graph

Both the components of the algorithm are delineated in details:

A. *Robert cross edge detection and Eucledian Distance Transform*

The dynamic image (Fig. 4a) is first converted into grayscale image by the standard luminosity formula:

$$Y=0.2126R + 0.7152G + 0.0722B \tag{1}$$

Conversion to grayscale ensures lower processing time and complexity which is one of the constraints of real time image processing.

The intensity image shown in Fig.4b is cropped to 250*640 in order to reduce the unnecessary skyline portion from the image. It reduces the amount of pixels to be processed and reduces the probability of noise in the edge detection process.

(a) The input image frame (b) The grayscale image

Fig.3 Grayscale Conversion

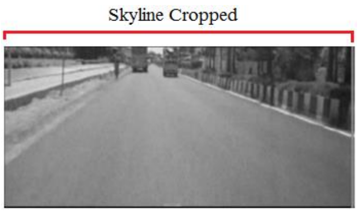
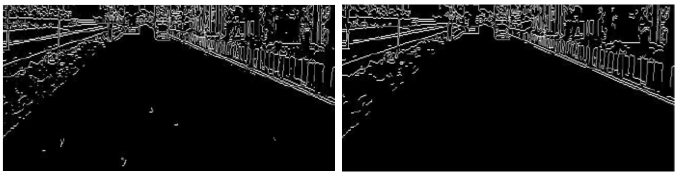


Fig.4 cropping for efficient edge visualization

For edge detection, Robert Cross operator is used, since it is proven to be the most efficient in road lane detection process with 83.33% of true edge detection and is robust to noise also [8]. The image is convoluted with the Robert kernels in order to obtain the gradient of the image.

$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \text{ and } \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \quad (2)$$



(a) Output of Robert Edge detection (b) Output after Area opening

Fig.5 Edge detection and noise filtering

In order to obtain a uniform lane marked with pixel values of ‘0’, morphological area opening is performed on the resultant binary image.(Fig.5b) The opening operation constitutes subsequent dilation and erosion of the image with the structuring element. Area open, performed in the image removes connected components with fewer than 20 pixels with a connectivity of 8-connected neighborhood. This clears the noise and any anomalies due to Robert cross Edge detection. Area opening undergoes the following operation:

$$A \odot B = (A \ominus B) \oplus B \quad (3)$$

Where A is the image and B is the structuring element. Next step involves, extracting the region of focus from the edges to be used in further algorithms. A patch of pixels from the leftmost and rightmost contour of the road edges are partitioned from the original image. The image shows the connected points at a minimum distance of 10 pixels from the left and right boundary. This removes all undesired information and extracts the region of interest (ROI) from the image as shown in Fig.6.

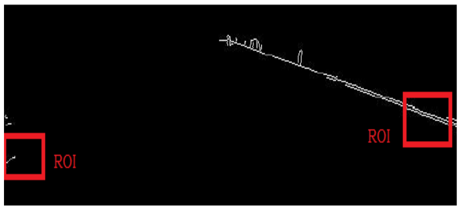
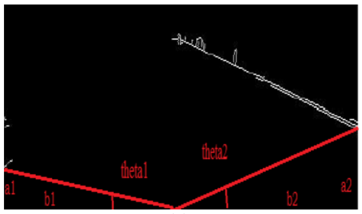


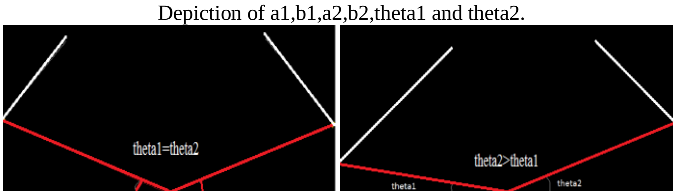
Fig.6 Extraction of ROI

Deviation from the mid-line of the image, which is the required steering angle is then obtained by calculating the Euclidean distance from the centre of the image to the nearest ‘1’ valued pixel (Road’s Edge). The distance transform algorithm is formualted using Maurer’s linear time algorithm [6]. Then, the absolute values at (300,0) and (300,640) positions in the distance transform matrix is recorded. Trigonometric equations are used to determine the position of the vehicle with respect to the road and to estimate the angular movement parameters required to synchronize the vehicle with the centre of the lane.

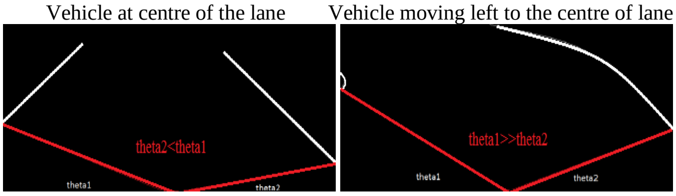


(a)

Depiction of a1,b1,a2,b2,theta1 and theta2.



(a) Vehicle at centre of the lane (b) Vehicle moving left to the centre of lane



(c) Vehicle moving right to the centre of lane (d) During sharp turnings

Fig: 7 Comparison of various cases of angular aberration from centre of the road.

$$\theta_1 = arctan(a1/b1) \quad (4)$$

$$\theta_2 = arctan(a2/b2) \quad (5)$$

$$\Phi = \theta_1 - \theta_2 \quad (6)$$

$$\mu = a1 - a2 \quad (7)$$

b1=b2=640/2=320 pixel distance

a1= distance of (250, 0) value from edge.

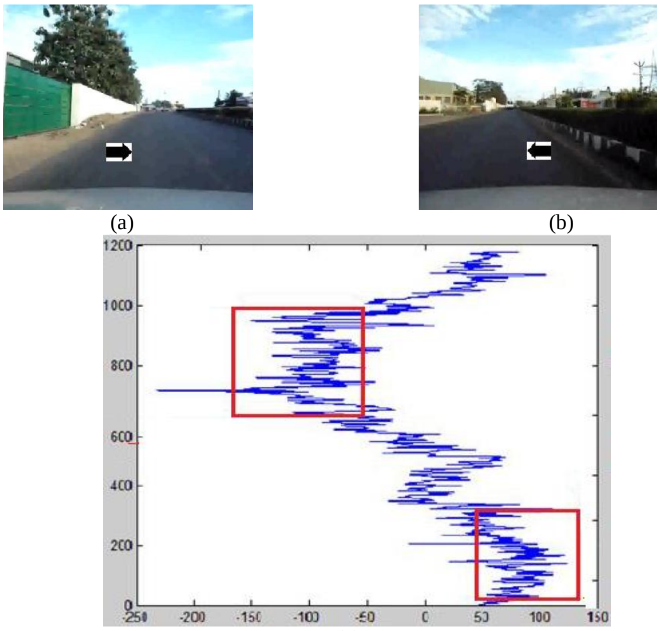
a2= distance of (250, 640) value from edge.

Φ is the minimum steering angle required to align the vehicle at the mid-line of the lane. The other essential parameter is the perpendicular steering distance μ. The value of μ fluctuates from -150 to 100 based on the samples taken from the database as described in Fig.8. A negative μ indicates rightward drag of the vehicle and Φ denotes the steering angle to align it along the mid-line of lane. Similarly, a positive μ and Φ indicate leftward drag. Table 1 and Fig.7 show the four scenarios that the algorithm can face and their implications.

TABLE 1.
CONDITIONS FOR DIFFERENT ROAD SCENARIOS

Scenario	**Steer Straight**	**Steer Right**	**Steer Left**
μ	$-30<\mu<30$	a2>a1 $\mu<-30$	a2<a1 $\mu>30$
Φ	$\theta_1-\theta_2=0$	$\theta_2>\theta_1$ Φ=negative	$\theta_2<\theta_1$ Φ=positive

A threshold value of 30 for μ is assigned, in order to tackle sudden fluctuations in steering due to noise.



(a) (b)
(c)
Fig.8 Fluctuations in the values of steering distance plotted against frame.

In Fig.8, the x axis depicts the value of μ and y axis indicates the frame number in a video sequence. A negative μ value indicates a right arrow i.e vehicle has to move right to maintain the mid-lane trajectory as shown in Fig.8a whereas a positive μ value indicates a left arrow i.e vehicle has to move left to be in mid-lane position shown in Fig.8b.

B. Standard Hough Transform and Virtual Edge

Hough transform and virtual edge concept is used in the face of rapid fluctuations in the steering angle variable. This procedure employs an algorithm that is robust to noise and gives valid results in more than 80% of cases. The steering angle is obtained by giving way to increased complexity and strain on the processors in cases of low illumination and anomalous results.

The Canny edge detection kernels are used for edge detection as it uses a two dimensional threshold, low threshold and high threshold. The high threshold detects the strong edges whereas low detects the weak edges and considers them only if connected to strong edges. Hence, canny is more likely to obtain the lane edges even with an increased noise. The threshold values are obtained by calculating the mean of the grayscale image and by applying thumb rule [9].

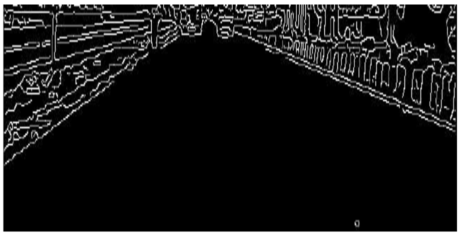


Fig.9 Output of Canny Edge Detection

The next step involves obtaining the straight lines using Standard Hough Transform.The Standard Hough Transform (SHT) is a parameter space matrix whose rows and columns correspond to ‘ρ’ and ‘θ’ values respectively [4]. The elements in the SHT represent accumulator cells. Initially, each cell is set to zero. Then, for every non background point in the image, ρ is calculated for every θ. ρ is then rounded off to the nearest allowed row in SHT. That accumulator cell is then incremented. The value ‘Q’ in SHT(r,c) means that there are Q points in the XY plane lie on the line specified by the θ(c) and ρ(r). Peak values in the SHT represent potential lines in the input image.

$$\rho = x\cos(\theta) + y\sin(\theta) \tag{8}$$

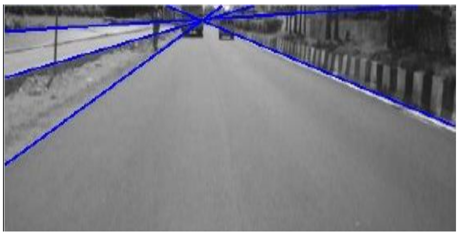


Fig.10 Result after SHT

In Fig.10, the blue colored lines mark the number of lines detected by Hough Transform accumulator space. But, the choice of the lines demarcating the edges of the road has to be done. To achieve this, the image is block processed, dividing it into two parts of equal area with a vertical line running through the center. Processing involves, searching for the co-ordinates of the first line from the bottom of the image. Fig.11 shows the lane edges obtained.

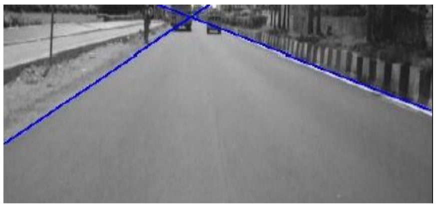


Fig.11 Road lane extracted

In case of low average luminosity of the image, one of the lane edges may not be discerned by basic SHT implementation. In such cases, the invisible road edge is approximated. To determine the edge parameters of angle of inclination and position, a linear relationship between θ values of left and right edges is formulated. Graphs of variation of the θ values in y axis and the frame number in the x axis are generated. A linear portion from both is extrapolated and the following equations are derived:

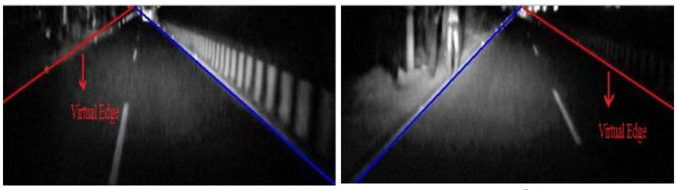
For left virtual edge-

$$\theta = -(1/3)*(\psi+45) + 10 \tag{9}$$

For right virtual edge-

$$\theta = -(1/3)*(\psi-45) - 10 \tag{10}$$

Where θ is the virtual edge inclination and ψ is the inclination of the detected opposite edge. Fig.12a and Fig.12b demonstrate the virtual edge implementation results in low illumination frames, where the red line indicates the virtual edge.



(a) (b)

Fig.12 Red line indicating the formation of Virtual Edge

The edge with the lowest row value in a frame is obtained and a line connecting both the edges from the point is drawn. The mid-point of that line indicates the mid-point of the road. Finally, steering angle (Φ) is calculated by joining the center pixel of the image with the midpoint pixel and subtracting the inclination (ω) from 90º as shown in Fig.13

$$\Phi = 90 - \omega \tag{11}$$

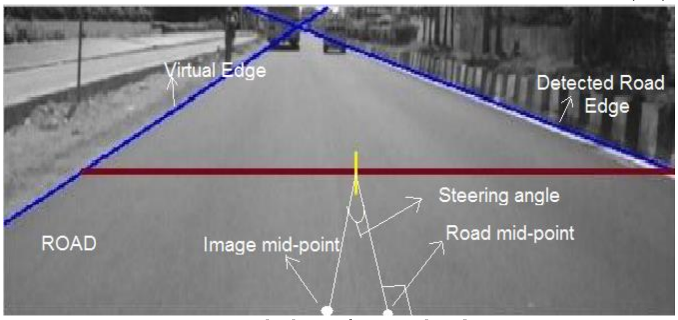


Fig.13 Steer calculation from road mid-point

VII. CONCLUSION

This paper illustrates a novel hybrid methodology for the calculation of the steering angle required to keep a vehicle at center of the lane. The algorithm has been tested rigorously and thus concluded effective in real time video samples taken both at day and night times. It responded as desired in case of noise introducing cases such as shadows and irregular contrast. The method proposed by this paper is considered successful in the case of the camera and the vehicle which were used for database generation as well as testing. The steering angle calculated by the proposed method was a good approximation of actual physical steering angle required.

However, the scope of the project can be increased to cases of rain, fog and mist to make it more robust. The proposed technique can be essential in development of Intelligent Vehicle Systems that are capable of self-maneuvering and navigation in harsh Indian road scenario. Further research into development of the algorithm and hardware implementation is required for practical use on roads.

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