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Optimizations in Dynamic Origin Technique for Efficient Lane Detection for Autonomous Vehicles

P.Maya, and C.Tharini

Abstract—**Driver assistance systems have started becoming a key differentiator in automotive space and all major automotive manufacturers have such systems with various capabilities and stages of implementation. The main building blocks of such systems are similar in nature and one of the major building blocks is road lane detection. Even though lane detection technology has been around for decades, it is still an ongoing area of research and there are still several improvements and optimizations that are possible. This paper offers an Optimized Dynamic Origin Technique (Optimized DOT) for lane detection. The proposed optimization algorithm of optimized DOT gives better results in performance and accuracy compared to other methods of lane detection. Analysis of proposed optimized DOT with various edge detection techniques, various threshold levels, various sample dataset and various lane detection methods were done and the results are discussed in this paper. The proposed optimized DOT lane detection average processing time increases by 9.21 % when compared to previous Dynamic Origin Technique (DOT) and 59.09 % compared to traditional hough transform.**

Keywords—**lane detection; dynamic origin technique; partial hough transform; performance analysis; accuracy analysis; optimization; autonomous vehicles**

I. Introduction

AUTONOMOUS driving is a complex system made up of numerous sensors and control units. Recognizing and comprehending the surroundings is the first and most important step towards safe autonomous driving in real time. Real-time processing and robustness are the main requirements of lane detection. Lane line detection algorithms are mainly designed for structured road and noise such as shadows of trees or buildings, sky, guard walls and the vehicles ahead of the road are not considered.

Region of Interest (ROI) as the term suggests, it is the specific part of the picture that is of interest for lane detection. The necessary information lies in the lower part of input image [2],[10] and is considered for lane detection. Further the ROI is reduced by avoiding 4 pixels from the left and right and 8 pixels from bottom of the ROI[1] which is one third of input image. Dynamic-ROI [14] and A-ROI [4] are suggest for better performance.

The preprocessing methods used to manage the various unwanted noises by filtering, smoothing operations like Gaussian filter, mean and median, threshold method like FIR filter, The piecewise filtering [3], piecewise linear stretching method [3],[1] have been applied for contrast enhancement.

Authors are with B S Abdur Rahman Crescent Institute of Science and Technology, Chennai, India (e-mail: {maya_ece_phd_2014, tharini} @crescent.education).

The reason for preferring grayscale over color is to amplify an algorithm and comply with linear time complexity, so that the computational requirements are drastically minimized. Hence, gray-level conversion is considered in [11] paper.

Lane detection estimations are mostly edge-based. Robust edge detection techniques are [5] Roberts, Prewitt [7][13], Sobel [1] and Canny techniques [12] [4]. Cross differential algorithm is another name for the Robert operator [6] and it is a cross difference-based gradient algorithm.

Many academics have worked on lane detection using the Hough transform. For better results variations of Hough transform are used by the authors: -fast Hough transform [3], improved Hough transform [9].

This author's own papers had proposed partial Hough transform [2] which gives better performance and an alternative to Hough transform, namely, Dynamic Origin Technique (DOT) method [1] which gives better accuracy and performance.

II. Methodology

An optimized Dynamic Origin technique (Optimized DOT) The lane detection is achieved by optimized DOT and compared with other 2 methods of author's pervious work viz., Partial Hough transform [2], Dynamic Origin technique (DOT) [1] and one other method which uses traditional Hough transform. To increase the efficiency of DOT an optimized DOT is proposed in this research. The results from all 4 lane detection techniques are analyzed and the results are discussed in the following section.

A. *Explanation of Proposed Technique – Optimized Dynamic Origin Technique (Optimized DOT)*

The default approach for Dynamic Origin technique (DOT) for lane detection would be to process all the frames in a video in a mutually exclusive manner as below. This approach can be considered as full frame processing. However, it is possible to use the output from the previous frame to optimize the processing of the next frame. Information.

- **Full Frame Processing:**

Step 1: If this is not first frame, then check if results from previous frame's processing are available and proceed to Partial Frame Processing

Step 2: Read edge detection nonzero coordinates.

Step 3: Start from the first point along x-axis as the initial origin.

Step 4: Find a slope for all the detected edge points from the current origin point.

Step 5: Find the slope for the current origin point which is passing through the maximum number of points (Slope with maximum frequency).
Step 6: Move origin incrementally until right edge of image and repeat steps 5 & 6 for each increment.
Step 7: Select the origin and slope that will qualify as lanes from the set of results obtained in step 5.

- **Part frame Processing**

Step 1: Set the limits for origin based on lanes detected in previous frame as ±50 pixels around the origins selected in Step 6 in full frame processing.
Step 3: Start from the first point defined within the above limits as the initial origin.
Step 4: Find a slope for all the detected edge points from the current origin point.
Step 5: Find the slope for the current origin point which is passing through the maximum number of points (Slope with maximum frequency).
Step 6: Move origin incrementally until right side limit as defined in step 1 is reached and repeat steps 4 and 5 for each increment.
Step 7: Select the origin and slope that will qualify as lanes from the set of results obtained from Step 5.

This approach can be termed as partial frame processing which is shown in Figure 1. This approach will significantly improve the processing time while maintaining the same level of accuracy. In addition, if desired results are not obtained from part frame processing, then the system can reprocess the frame using full frame processing approach and defer the part frame processing to the next frame.

B. Dynamic Origin Technique (DOT)

In the Dynamic Origin Technique (DOT)**,** a starting point is set and an attempt is made to discover lines on y which the most points detected during the edge detection step line. Then the starting point is moved incrementally, and line detection is repeated. Each starting place will return one or more lines as aggregate of (x1, y1, ϴ). By setting threshold for the number of points that lie on a line, unwanted lines can be disregarded. In addition, as soon as all origins have been traversed, the resulting lines can be further cleaned up using other factors, for example: lane markings need to be separated through a certain gap and must fall inside a certain range of slope.

The slope of a line is discovered from an origin, which passes through the detected edge points in an image. The co-ordinates P_i(xi, yj) in which i= 1...n is considered as the detected edge points and a set of origins O_j (x_j, y_j) in which j = 1...m . The shown Equation (12), is used to calculate the slope of line for given Origin O(xj, yj) of all lines through Pi, i = 1...n as

$$M(P_{i,}\ O_j) = \frac{y_i}{x_j - x_i} \quad (1)$$

The maximum frequency F_{max} of slope is shown in Equation (2), which is passing through the maximum number of points.

$$F_{max} = \max\big(freq(M_i)\big)\ ,where\ i = 1,2,\ldots.n \quad (2)$$

M_{fmax} is the maximum number of points that have identical slope, while all these points lie on a line with slope Mi passing through origin Oj is shown in Equation (3).

$$M_{fmax} = M\ corresponding\ \ to\ \ F_{max} \quad (3)$$

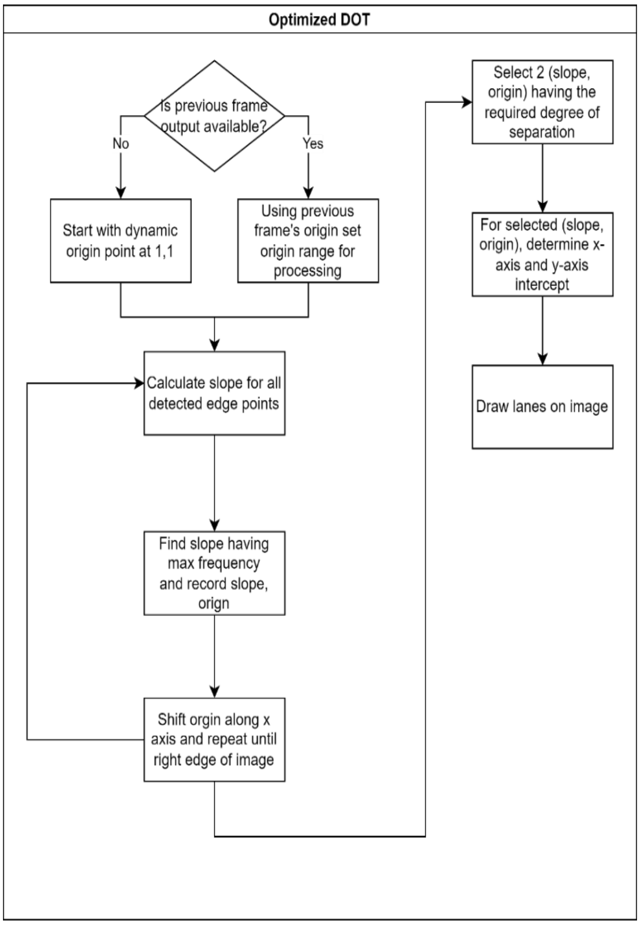

Fig. 1. Flow diagram of Optimized Dynamic origin Technique (Optimized DOT)

The final lane points L_k from passing through Origin O_j is shown in Equation (4).

$$L_k = T\big(M_{fmax}\ ,\ O(x_j, y_j)\big)\ ,\ \ where\ j = 1, \ldots \ldots .m \quad (4)$$

Repeat this process up to an origin O_n in horizontal direction. All lines which meet certain thresholds can be taken as detected lanes.

C. Partial Hough Transform

This is a partial version of Hough transform. In this, six different ϴ ranges are considered (-90 to -60), (-60 to -30), (-30 to 0) ,(0 to 30), (30 to 60) and (60 to 90).The Partial Hough transform can be applied without loss of detection even if the ϴ ranges are limited and used to reduce half of the processing time . Using Partial Hough Transform the range of left, right and center lane ϴ is concluded as 60 to 90, -60 to -30 and 0 to 30.

D. Hough Transform

The Hough transform is obtained by the given Equation (5).

$$\rho = x.cos\theta + y.sin\theta \quad (5)$$

The spatial polar coordinates of a point in an image plane are represented as (x,y) and (ϴ, ρ). The distance of straight line ρ is measured from the coordinate origin and minimum angle of straight line ϴ is in normal direction. Hough transform ϴ ranges over 360 degrees and provides more data than what is required in the limited environment of lane detection.

III. RESULTS AND ANALYSIS

This paper demonstrates the improvements of the proposed Optimized Dynamic Origin Technique in processing time and accuracy when compared with other 2 methods of author's pervious work viz., Partial Hough transform [2], Dynamic Origin technique (DOT)[1] and one other method which uses traditional Hough transform. The mentioned four lane detection methods are analyzed by

i. Varying edge detection techniques
ii. Varying threshold of edge detection
iii. Performance Analysis of challenged road
iv. Multiple dataset collection

The measuring parameters are

- Performance
- Accuracy

The MATLAB 2019a is the Software which is used for processing and measuring. The system configuration is AMD Ryzen 5 5500U Hexacore CPU, 2 Threads per CPU, 12 Logical Processors Radeon Graphics 2100 MHz.
The performance measured by MATLAB functions and accuracy is calculated by the Equation (6).

$$Accuracy = \left(\frac{(TLDR)+(1-FLDR)}{2}\right) \times 100 \qquad (6)$$

Where TLDR is True Lane Detection Rate and FLDR is False Lane Detection Rate.
The results are discussed in this section.

A. Varying Edge Detection Technique

Each of the lane detection approaches listed above are performed on the CALTECH dataset cordova1 video having 640x480 resolution, 250 frames with the following edge detection techniques such as Sobel, Canny, Prewitt, Log and ApproxCanny.The average processing time and average accuracy are computed and tabulated.

Table I result shows that average processing time of lane detection for proposed Dynamic Origin Technique (Optimized DOT), DOT, Partial Hough, Hough using different edge detection techniques. The Partial Hough Transform takes nearly 50% percent less processing time than Hough Transform. The proposed optimized DOT method takes lesser processing time than Partial Hough Transform as well as DOT method.

TABLE I.
PERFORMANCE ANALYSIS OF LANE DETECTION WITH VARIOUS EDGE DETECTION

Edge Detection Technique	Average Processing Time(s/frame)			
	Hough	Partial Hough	DOT	Proposed Optimized DOT
Sobel	0.007	0.0045	0.0032	0.0029
Canny	0.0043	0.0025	0.0021	0.0019
Prewitt	0.0041	0.0024	0.0019	0.0015
Log	0.0044	0.0031	0.0024	0.002
Approxcanny	0.0055	0.0048	0.0039	0.0035

TABLE II
ACCURACY ANALYSIS OF LANE DETECTION WITH VARIOUS EDGE DETECTION

Edge Detection Technique	Average Accuracy %			
	Hough	Partial Hough	DOT	Proposed Optimized DOT
Sobel	86.7	86.7	97	97
Canny	84.4	84.4	95	95
Prewitt	82.4	82.4	95	95
Log	80	80	94	94
Approxcanny	84.2	84.2	94	94

The following Figure 2 shows the Green line shows the proposed method which gives the best results.

Table II/Figure 3 result shows that Partial Hough Transform and Hough Transform have equal accuracy percentage and the proposed method has higher accuracy of 97% when Sobel edge detection is used.

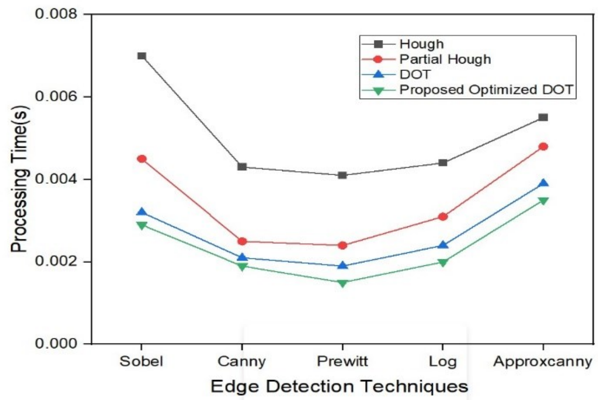

Fig. 2. Average Processing time of Lane detection with various Edge detection

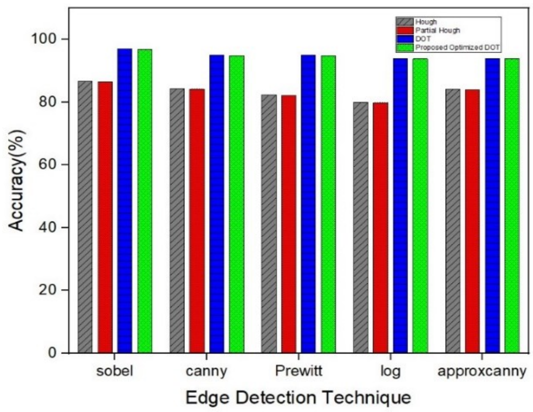

Fig. 3. Accuracy of lane detection with various Edge detection

Further analysis of data reveals that processing time is higher than when using Canny and Prewitt. Canny and Prewitt have multiple filtering stages so the processing time of these methods are higher. At the same time there also loss of information which reflects in lesser accuracy of detecting edges. Also it would be useful to separate out the processing time for the edge detection step of the overall lane detection process to validate that Sobel edge detection has the least processing time. This is shown in Table 3/Figure 4 and the time of 0.0011s confirms it. Thus, from this point, Sobel edge technique is chosen for the rest of analysis and measurements.

Table III
Processing time of various Edge Detection

S.No	Edge Detection Technique	Average Processing time (s)
1	Sobel	0.0011
2	Canny	0.004
3	Prewitt	0.008
4	Log	0.015
5	Approxcanny	0.0025

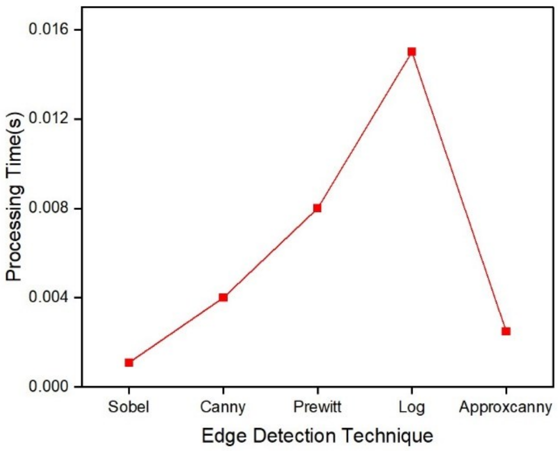

Fig. 4. Processing time of various various Edge detection

B. Varying Threshold of Edge Detection

Each of the lane detection approaches listed above are performed on the CALTECH dataset cordova1 video having 640x480 resolution, 250 frames with the Sobel edge detection techniques at various threshold levels, namely: -40, 50, 60, 70 percentage and Auto. Auto is a scenario where the threshold level is selected by Matlab. Processing time and accuracy of lane detection is measured and presented in table 4./Figure 5 The results show that Partial Hough transform takes nearly 50 percent of processing time than Hough Transform. The proposed Optimized DOT method takes lesser than Partial Hough Transform as well as DOT method.

TABLE IV
PERFORMANCE ANALYSIS OF LANE DETECTION WITH VARIOUS THRESHOLD LEVELS

Threshold Levels (%)	Average Processing time(s/frame)			
	Hough	Partial Hough	DOT	Proposed Optimized DOT
40	0.034	0.018	0.015	0.012
50	0.0074	0.0045	0.0032	0.0029
60	0.0049	0.0029	0.0025	0.0023
70	0.0036	0.0019	0.0014	0.0012
auto	0.0074	0.0045	0.0033	0.0029

TABLE V
ACCURACY ANALYSIS OF LANE DETECTION WITH VARIOUS THRESHOLD LEVELS

Threshold Levels (%)	Average Accuracy %			
	Hough	Partial Hough	DOT	Proposed Optimized DOT
40	87.9	87.9	97	97
50	86.7	86.7	97	97
60	85.5	85.5	95.2	95.2
70	82	82	89.2	89.2
auto	86.7	86.7	97	97

However as per Table 5/Figure 6 it can be observed that accuracy drops for threshold levels 60 & 70. Partial Hough Transform and Hough Transform have equal accuracy and the proposed optimized DOT method had better accuracy. Hence, for better accuracy as well as better processing time, a threshold level 50 % is recommended.

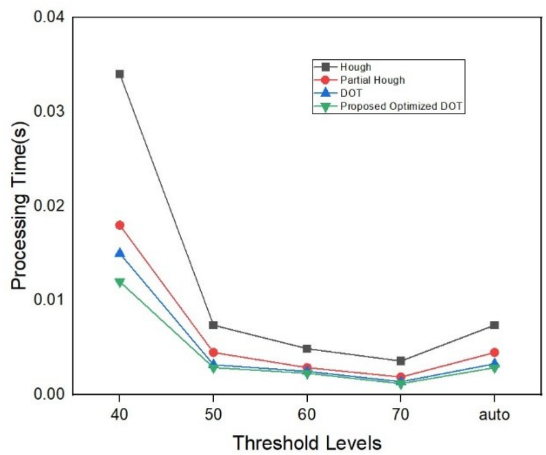

Fig. 5. Average Processing time of Lane Detection with various Threshold levels

The Figure 5, shows the Green line shows that the proposed Optimized DOT method gives the good results when threshold level of 60 or 70 percent is used.

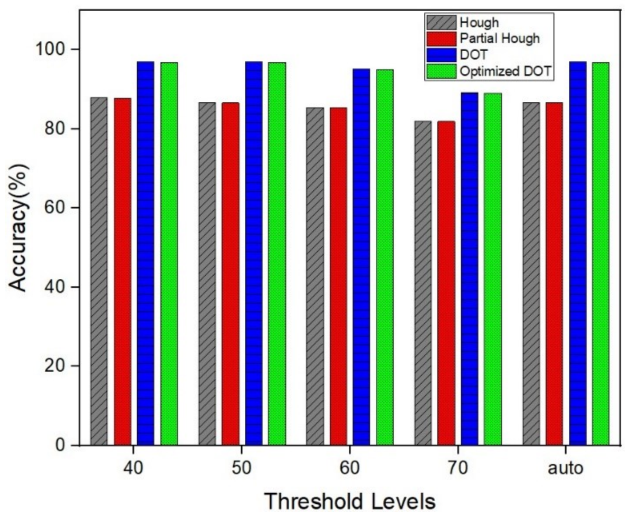

Fig. 6. Accuracy of lane detection with various Threshold levels

C. *Performance Analysis of challenged road (example: harder_challenge_video.mp4)*

The figure 7 shows for first 20 frames of harder_challenge_video.mp4. The processing time increases at frame number 4 to 6,9 to 11 and 18 to 20 where straight lane to curved lane switch occurs. The processing time is higher and accuracy is lower compared to other videos in the dataset as the harder_challenge_video.mp4 has continuously curved lanes and shadows.

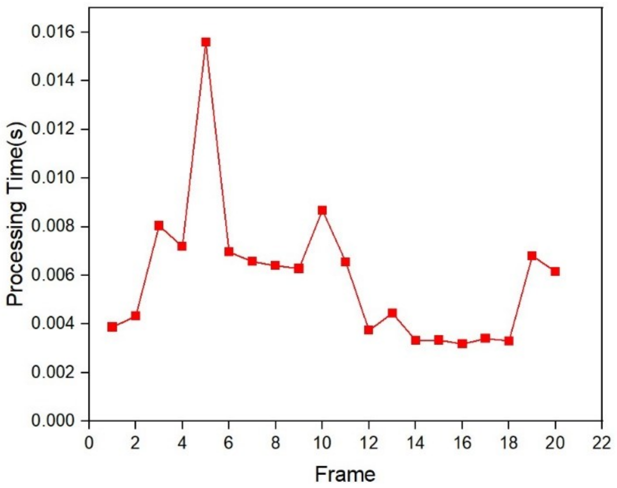

Fig. 7. Processing time of lane detection for curved lane

D. *Multiple Dataset Collection*

The results derived in the above sections were validated using a variety of datasets to confirm that the proposed hypotheses are correct.

The list of datasets is as below, which have a total of 5464 frames.

- Caltech dataset videos – cordova1, cordova2, washington1, washington2.
- 4 videos taken from internet.

Lane detection is performed on the above datasets using Hough Transform, Partial Hough Transform, DOT method and optimized DOT with Sobel as the edge detection and the threshold level as 50%. Table VI/Figure 7 shows the processing time of all 5464 frames. Table 7VII/Figure 8 shows the Average Accuracy time of all 5464 frames. The validity of the hypothesis can be confirmed by observing that Optimized DOT method has the best processing time and accuracy.

In all, Table I, IV, VI the processing time is highest when using Hough Transform which does processing for 360 degrees. When Partial Hough Transform is used, it has 50% improvement over Hough Transform because 30 degrees used for left lane and 30 degrees used for right lane detection. The data storage is reduced, and complexity reduced by using optimized DOT method gives the best result it uses a customized and heavily optimized approach which has a specialized use in lane detection. In Figure 8 & Figure 9 the labels in x-axis correspond to the S.No column in Table VI & Table VII which points to a video from the dataset used in this analysis.

TABLE VI
PERFORMANCE ANALYSIS OF LANE DETECTION WITH VARIOUS DATASET

S.No	Input Video	Number of frames	Size of frames	Average Processing time(s/frame)			
				Hough	Partial Hough	DOT	Proposed Optimized DOT
1	Caltech/cordova1.avi	250	640x480	0.007	0.0045	0.0032	0.0029
2	Caltech/cordova 2.avi	406	640x480	0.0064	0.0034	0.0026	0.0023
3	Caltech/washington1.avi	337	640x480	0.008	0.0041	0.003	0.0025
4	Caltech/ washington2.avi	232	640x480	0.007	0.0045	0.0032	0.0026
5	harder_challenge_video.mp4	1198	1280x720	0.033	0.021	0.018	0.0177
6	challenge_video.mp4	485	1280x720	0.023	0.015	0.01	0.0098
7	test2.mp4	1296	1280x720	0.015	0.011	0.008	0.0075
8	video sequence 1.mp4	1260	1280x720	0.021	0.012	0.008	0.0074

TABLE VII
ACCURACY OF LANE DETECTION WITH VARIOUS DATASET

S.No	Input Video	Number of frames	Size of frames	Average Accuracy %			
				Hough	Partial Hough	DOT	Proposed Optimized DOT
1	Caltech/cordova1.avi	250	640x480	86.7	86.7	97	97
2	Caltech/cordova 2.avi	406	640x480	86.5	86.5	96.6	96.6
3	Caltech/washington1.avi	337	640x480	84.6	84.6	96.3	96.3
4	Caltech/ washington2.avi	232	640x480	84.3	84.3	96.1	96.1
5	harder_challenge_video.mp4	1198	1280x720	82.1	82.1	95	95
6	challenge_video .mp4	485	1280x720	82.8	82.8	95.2	95.2
7	test2.mp4	1296	1280x720	87	87	98	98
8	Video.mp4	1260	1280x720	87.4	87.4	98.2	98.2

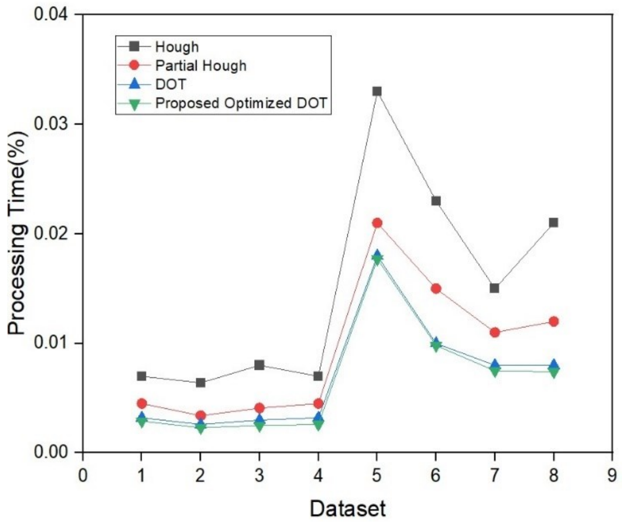

Figure 8. Average Processing time of lane detection with various Dataset.

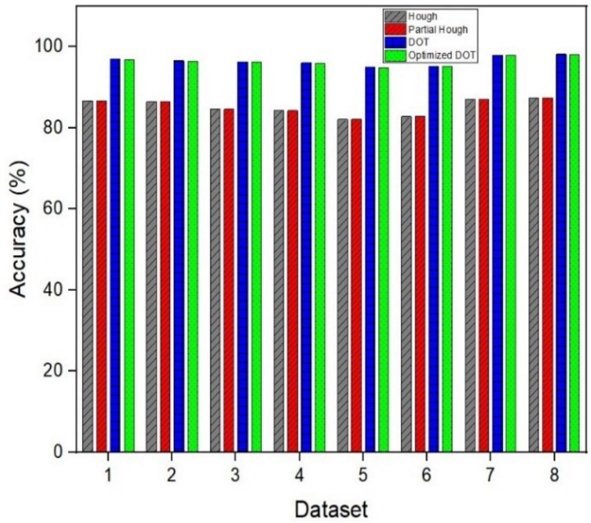

Figure 9. Accuracy of lane detection with various Dataset.

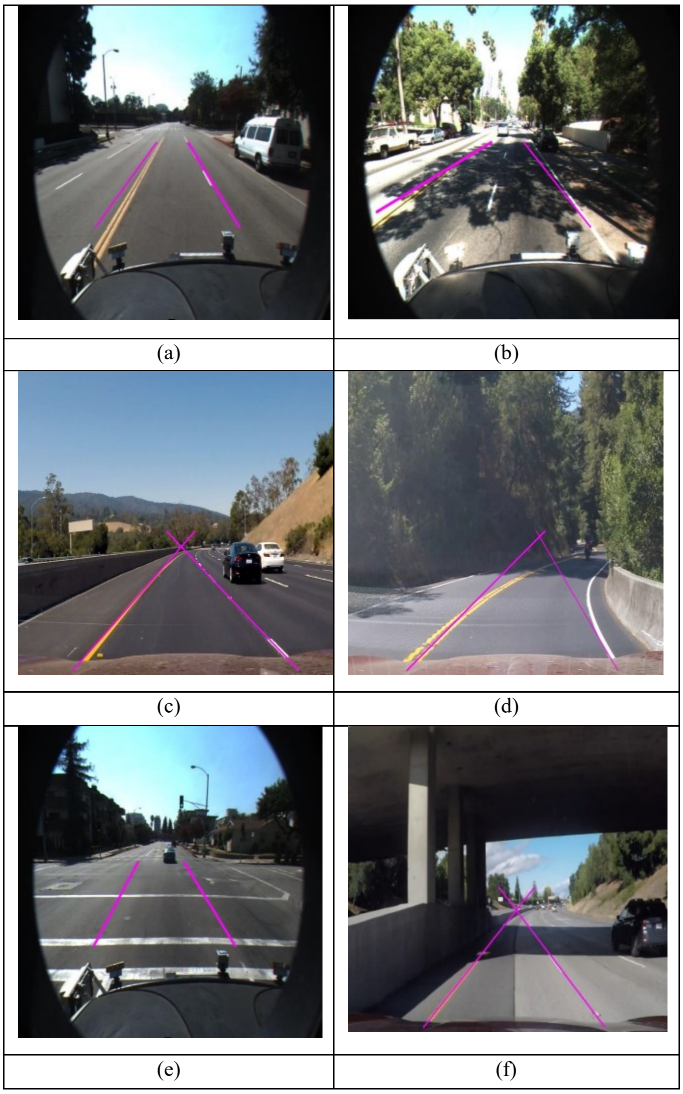

Fig. 10. Experimental results(a) output video frame at daylight. (b) output video frame at shadows. (c) output video frame at straight lane. (d) output video frame at curved lane.(e) output video frame at no lane.(f)output video frame at under pass

The Figure 10 shows the detected lanes with various road conditions.

The proposed Optimized Dynamic Origin Technique (Optimized DOT) was evaluated for various road conditions like daylight, night, shadows, straight lane, curved lane, under pass and no lane. The output images with the detected lanes are marked in magenta color which are shown in the above Figure 10.

IV. Conclusion

The original DOT was demonstrated as better than other approaches for lane detection namely – Hough Transform and Partial Hough Transform. Continuing the improvements to the original DOT approach, the proposed optimization DOT in this paper further improves the process time and can benefit real world applications in reducing CPU costs. The proposed optimized DOT lane detection average processing time increases by 9.21 % when compared to previous Dynamic Origin Technique (DOT) and 59.09 % compared to traditional hough transform. The average accuracy increases by 13.38% by proposed Optimized DOT Lane detection compared to traditional hough transform lane detection and maintains same accuracy of original DOT.

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