Lane Departure Warning System – PRELIMINARY PATENT INFORMATION

HTTPS://WWW.LANEDEPARTUREWARNING.ORG/

System title

A road scene image processing system which approximates likely lane boundaries as a result of a vehicle's positioning with respect to the lane (delineated by visually detectable longitudinal lane markers) and a camera's positioning within the vehicle.

Background of the invention

The ability of an individual vehicle operator to extract and interpret lane marker information is of paramount importance to the vehicle operator’s efficient and safe usage of the roadway. However, situations (driver distraction, driver physical impairment, etc.) may arise which might potentially prevent the operator of a vehicle from using all of the available traffic control device resources (including lane markers). Under these circumstances, having a road scene image processing system in place as part of an overall vehicular safety system being used to minimize the potential consequences of ‘missed lane markings’ could potentially assist in reducing the frequency of crash occurrences, reducing crash severity, and thus helping to save lives. Additionally, a road scene image processing system might potentially provide travel lane guidance and roadway delineation resulting from the absence or obscurity of a formal longitudinal lane marker. Consider the three following scenarios from the vast range of potentially dangerous driving situations which might derive safety benefits from the presence of a road scene image processing system:

1) A vehicle operator traveling down a two-way two lane roadway momentarily turns their head to investigate a disturbance with their children in the back seat. The driver inadvertently slightly turns the steering wheel during the shift in position of their body and causes a gradual transition toward the centerline of the roadway. The system which is monitoring likely lane boundaries alerts the vehicle operator to the vehicle's positioning.

2) A vehicle operator is traveling down a straight two-way two lane roadway and momentarily turns their head to observe the scenery on the side of the roadway. However, before the vehicle operator returns their attention to the direction the road is heading in, a slight curve in the roadway is encountered and the vehicle (which is still heading approximately straight) begins to drift out of the lane. The system which is monitoring likely lane boundaries alerts the vehicle operator to the vehicle's positioning.

3) A vehicle operator on a one-way two lane roadway becomes distracted due to some physical discomfort they are experiencing. The vehicle (unbeknown to the operator) begins to transition towards the adjacent lane but the system which is monitoring the vehicle's positioning alerts the operator.

Potential field(s) of endeavor

Potential U.S. patent class: Class 701, Data Processing: Vehicles, navigation, and relative location.

- Potential U.S. patent subclass: 300, Relative location.
- Potential related U.S. patent subclass: 301, Collision avoidance.
- Alternative potential U.S. patent subclass: 1, Vehicle control, guidance, operation, or indication.
  - Alternative potential U.S. patent subclass: 23, Automatic route guidance vehicle.
  - Alternative potential related U.S. patent subclass: 28, Having image processing.

Alternative potential U.S. patent class: Class 382, Image analysis.

Brief summary

1) The system may potentially be used to calculate the position of a vehicle with respect to a likely lane boundary.

2) The system may potentially be used to calculate the rate of change of position of a vehicle with respect to a likely lane boundary.

3) The system may potentially be used to calculate prioritized warning lines with respect to a likely lane boundary.

4) Generally, the further into the field of view that the detectable longitudinal lane marker is located, the less reliable the system's likely lane marker boundary approximation becomes.

5) The system's calculation of a likely lane boundary with a visually detectable longitudinal lane marker present will be more reliable than it's calculation of a likely lane or road boundary without one present.

6) The system may potentially be used to calculate lane direction resulting from the detection of both positive and negative sloped longitudinal lane markers.

7) The system does not possess real-time processing functionality.

8) The system may potentially be used as part of an integrated vehicular safety system.

9) The system is not meant for use as part of a vehicular safety system which may affect vehicle control.

10) The system is not meant for use in construction zones with impermanent or irregular longitudinal lane markers.

11) The system has not been applied to road scene images acquired during rain, snow, fog, or extremely dusty conditions.

12) The system has not been applied to road scene images acquired at night.

13) The system has not been applied to road scene images containing raised pavement markers substituting for longitudinal lane markers.

14) The system needs development in a number of areas including (but not limited to):
- i) The software which performs the hybrid structural and statistical pattern classification.
- ii) The software which selects which likely borders are coupled.
- iii) The software that selects which of two likely parallel yellow longitudinal lane markers is adjacent to the vehicle.
- iv) The software for yellow marker extraction as it relates to yellow reversible lane markings.
- v) The method which can't discriminate road maintenance materials producing visual characteristics which are very similar to those of white longitudinal lane markers.

Description of information potentially related to invention

[*] Canon PowerShot A85 digital camera, Canon U.S.A. Inc., Lake Success, NY.

[*] Matlab student version with Simulink, version 6.5, release 13, The Mathworks Inc., Natick, MA.
Use of the Matlab language, the development environment, the function libraries, the handle graphics system, and GUIDE, for software development of the road scene image processing.

[*] Haralick, Robert M., and Shapiro, Linda G., *Computer and Robot Vision*, volume II, Addison-Wesley Publishing Company, 1993.
Modification to the **referenced** transform for transforming from Red-Green-Blue (RGB) coordinates to Luminance-Hue-Saturation (YIQ) coordinates.

[*] Fu, K.S., *Syntactic Pattern Recognition and Applications*, Prentice-Hall, 1982.
Improvement to the flow designated in the block diagram describing structural (syntactic) pattern classification as well as creation of a hybrid classification by combining the improved structural (syntactic) method with statistical methods.

[*] "Manual on Uniform Traffic Control Devices for Streets and Highways", 2003 Edition, U.S. Department of Transportation – Federal Highway Administration.
Use of patterns designated in manual for creation of pattern primitives, attributes, and statistical analysis.

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[*] Gose, E., Johnsonbaugh, R., and Jost, S., *Pattern Recognition and Image Analysis*, Prentice Hall, 1996.
Improvement to [5x5] diagonal edge detector specific to road scene image analysis.

[*] Cheok, K. C., Smid, G. E., Overholt, J. L., Pan, Z., and Warner, C., “Multi-Sensor based Collision Warning System”, submitted to the International Symposium on Automotive Technology and Automation, Department of Electrical and Systems Engineering, Oakland University, Rochester, MI, June 1999.

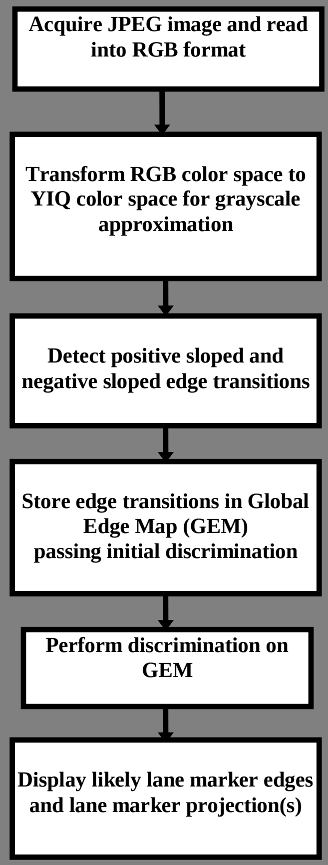
[*] Warner, Christopher A., “A New Systems Engineering Approach to Multi-Sensor based Collision Warning and Avoidance Systems”, Department of Electrical and Systems Engineering, Oakland University, Rochester, MI, unpublished paper, 2004.

Figures and descriptions

The road scene images serving as input to the system were acquired by attaching a Canon PowerShot A85 digital camera to the rear view mirror of different automobiles and acquiring images while traveling along various roadways in the state of Michigan. The images were then stored on the hard drive of a Gateway desktop computer running the Windows XP operating system and processed using a student version of Matlab by the Mathworks.

Figure 1: General block diagram of the image processing system

Figure one shows a generalized block diagram of the monocular camera road scene image processing system.



<u>Figure 2: General flow to preliminary road scene image processing software written in Matlab</u>

Once an image has been acquired and converted from Red-Green-Blue (RGB) to Luminance-Hue-Saturation (YIQ) coordinates to enable grayscale image processing techniques, the positive and negative sloped dark to light and light to dark edge transitions are detected. The edge detection essentially performs a form of correlation to quantitatively assess how well the local image portion corresponds to a particular mask (edge detector). These edge transitions undergo multiple levels of discrimination on their way to being stored in the resulting undiscriminated global edge map. Significant points are then extracted, slope approximations are generated, and the positive and negative sloped projections (if present) are then displayed. The generalized flow is shown in figure two.

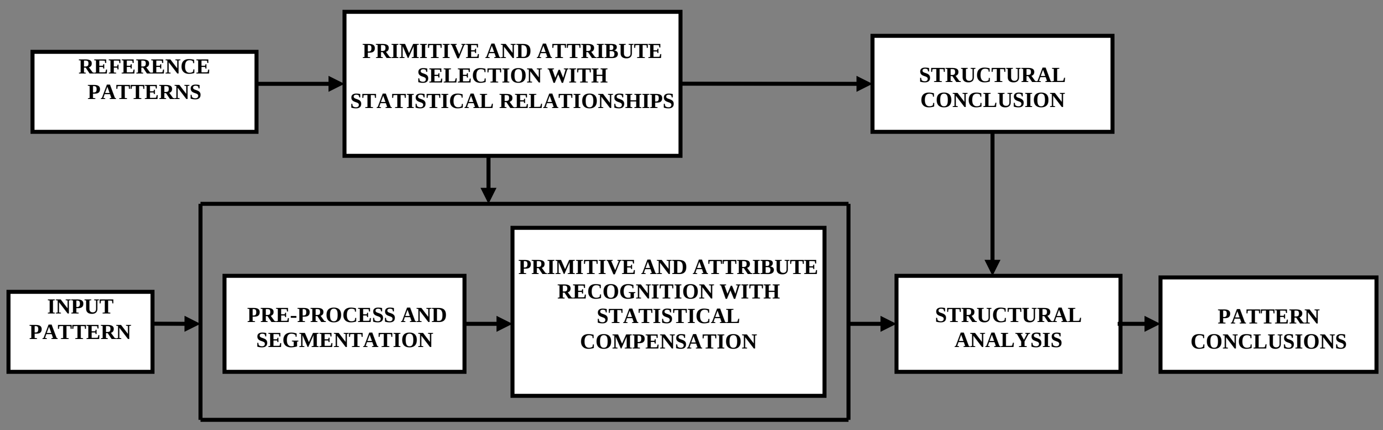


Figure 3: Potential generalized block diagram for performing hybrid structural (syntactic) and statistical pattern classification

Figure three illustrates a potential generalized block diagram for performing hybrid structural (syntactic) and statistical pattern classification. In this method, a series of reference patterns are evaluated for primitives, attributes and statistical relationships leading to a set of initial conclusions regarding the structure of the pattern. The actual input pattern is first preprocessed (if necessary) to improve the image quality or facilitate subsequent processing before the segmentation and recognition processes are performed. The input pattern may be broken down with sought after pattern primitives and attributes originating from the prespecified structural conclusions derived from the lane marker reference patterns. A preliminary stage in establishing a pattern representation may then occur during the construction of the prospective primitive (edge) map where thresholded statistical correlation is performed. Next, the individual prospective primitive components may be combined to form ‘primitive segments’. Reference numerical attributes and statistical relationships may be exploited during the segmentation, recognition, and structural analysis stages to help compensate for various sources of pattern variation. Finally, from the degree of correlation between the input and reference patterns, a conclusion may be formulated.

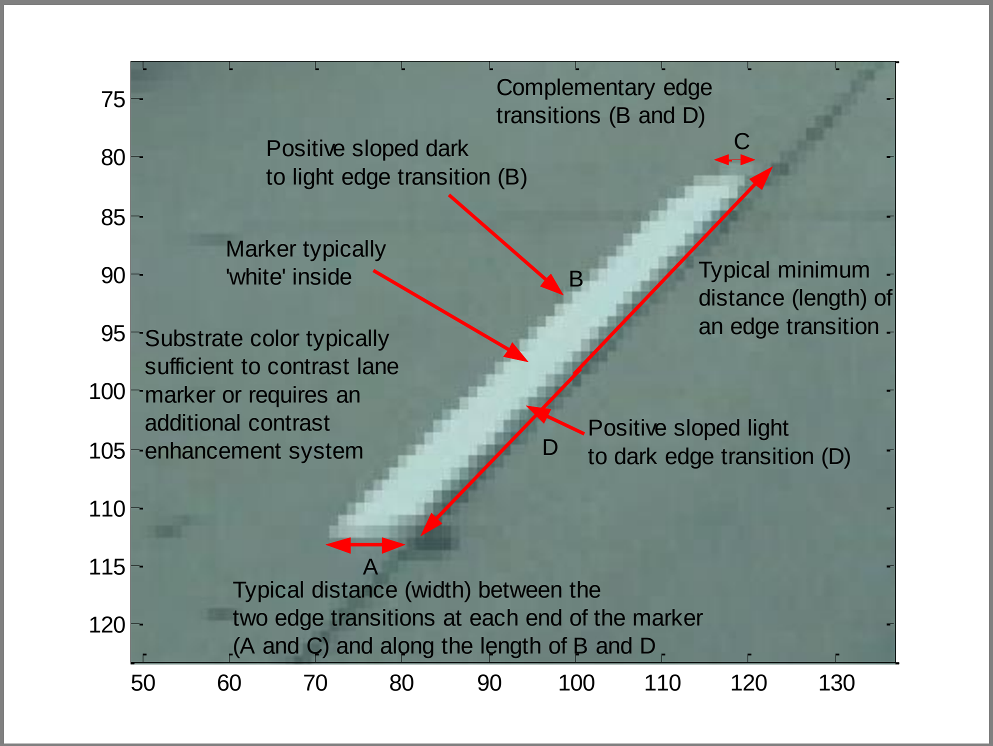


Figure 4: Some characteristics of the structure of a broken white lane marker

The structure of a lane marker may be formulated via organizing rules composed of primitives, attributes, and other statistically relevant relationships. The primitives and attributes are generated by carefully considering what the constituent components are that make up that pattern and how these components are related. Figure four looks at some of the characteristics of the structure of a broken white lane marker.

The 2003 edition of the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) lists the general functions of longitudinal lines as [1]:

1. A double line indicates maximum or special restrictions.
2. A solid line discourages or prohibits crossing (depending on the specific application).
3. A broken line indicates a permissive condition.
4. A dotted line provides guidance.

A fifth pattern which may be encountered is termed 'wide'. These five main patterns and some of their typical associated characteristics are shown in table one.

Table 1: Five commonly found patterns with associated characteristics from the 2003 MUTCD

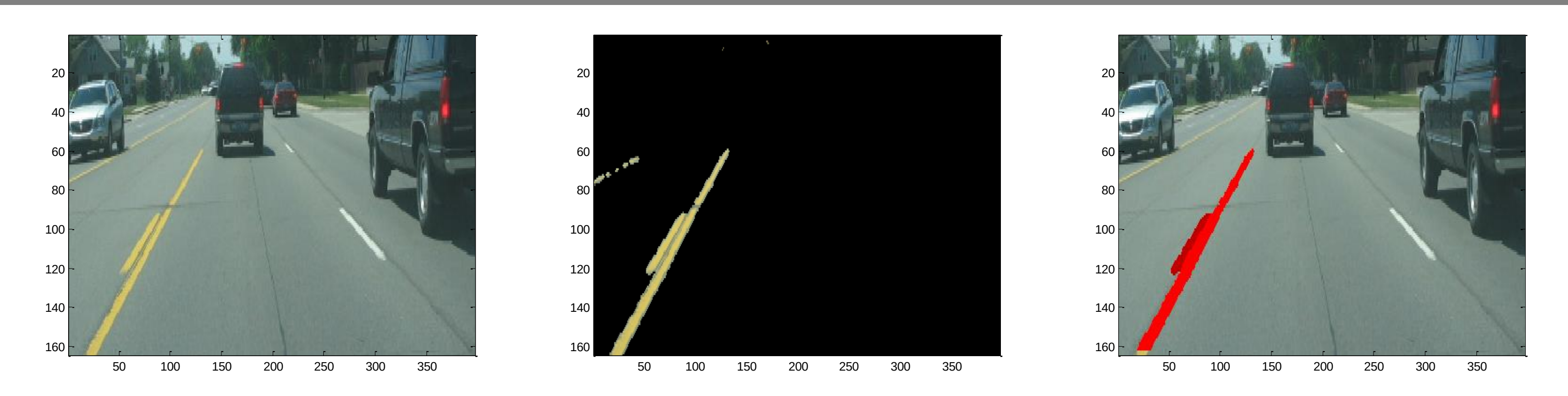
	Pattern	**Typical Width**	**Typical Gap**	**Typical Segment**
1.	Normal	100 mm to 150 mm	None	Location specific
2.	Wide	At least 200 mm to 300 mm (at least twice the width of a normal line).	None	Location specific
3.	Double	2 parallel normal lines separated by a discernible space.	None	Location specific
4.	Broken	100 mm to 150 mm	9 m or varies depending on need.	3 m or varies
5.	Dotted	At least 100 mm	(Line extension) 0.6 m to 1.8 m (Lane add/drop) 2.7 m	0.6 m 0.9 m

[1] "Manual on Uniform Traffic Control Devices for Streets and Highways", 2003 Edition, U.S. Department of Transportation – Federal Highway Administration.

The 2003 version of the Manual for Uniform Traffic Control Devices for streets and highways has listed colors which may be used to convey traffic control information. The color white generally indicates regulation while the color yellow generally indicates warning. The colors white and yellow are used for longitudinal line pavement markings with table two listing some of the types of delineation provided.

Table 2: Some lane marking delineation based on marker color from the 2003 MUTCD

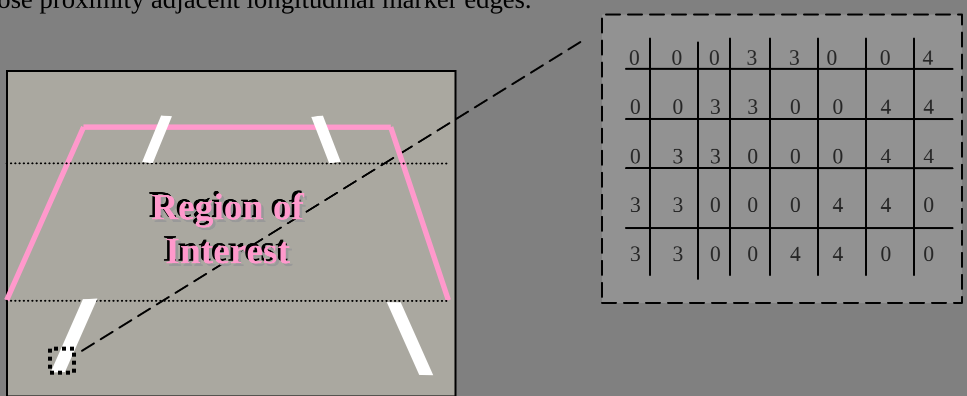
White Marking	**Yellow Marking**
1. Separation of traffic traveling in a uniform direction.	**1.** Separation of traffic flows in opposing directions.
2. Right edge of a roadway.	**2.** Left edge of roadways of divided and one-way highways.
	3. Left edge of the roadway of exit and entrance ramps.
	4. Separation of two-way left turn lanes from other lanes.
	5. Separation of reversible lanes from other lanes.



(a) (b) (c)

<u>Figure 5: (a) Cropped road scene image; (b) image with 'yellow longitudinal marker shades' color characteristic isolated; (c) distinct yellow longitudinal lane markers from analysis exploiting primitive relationships, color characteristics, and dimensional relationships</u>

The use of the RGB color space (or other chrominance information) to supplement edge detection of longitudinal markers may be necessary when the color characteristics of a yellow longitudinal lane marker have become degraded to the point that they are indistinguishable from the local substrate using only grayscale approximated values. Isolating certain color characteristics may be pursued by looking at the individual RGB values and ranges of values for ratios between the red to blue, blue to green, and green to red (row, column) image coordinate values. However, using *only* the color information may not allow sufficient differentiation between yellow pixel values corresponding to lane markers and those unrelated to lane markers. Similarly, using only the color characteristics may not provide sufficient discriminating capability between yellow longitudinal lane markers in very close proximity to one another. However, exploiting primitive relationships along with dimensional characteristics and those locations representing pixels with a high degree of color correspondence to yellow longitudinal lane markers may contribute to producing the distinct yellow marker segments shown in figure five (c). Thus, this color information may be combined with global edge map (GEM) values and dimensional relationships towards a color segmented image which allows further boundary and region based feature determination and enables the potential differentiation between normal and normal, normal and broken, and broken and broken yellow pairs of close proximity adjacent longitudinal marker edges.



(a) (b)

<u>Figure 6: (a) Artificial road scene image with sample longitudinal lane makers in FOV; (b) sample portion of potential global edge map</u>

The GEM was required because the edge detection process would be generating many different light to dark and dark to light edge transitions for longitudinal markers of different slopes. The use of the word global is intended to convey that it is an edge map which will be constituted of (potentially) many different types of edges and would be 'comprehensive'. Thus, this single edge map could be used to represent the contributions from the positive sloped light to dark transitions, the positive sloped dark to light transitions, the negative sloped dark to light transitions, the negative sloped light to dark transitions, and potentially others. A portion of a hypothetical global edge map for the artificial image of figure six (a) might be represented as that shown in figure six (b). The positive sloped dark to light transition might be represented by 3's in the GEM while the positive sloped light to dark transition might be represented by 4's in the GEM.

M	N	O	P
I	J	K	L
E	F	G	H
A	B	C	D

(a)

1) Look to diagonal and if found, look to next diagonal (If A then F and if F then K and if K then P).
2) If not found on diagonal, look sideward and also look upward (If not F then look at B and also look at E).
2a) If found both upward and sideward, look to specific elements within the next subsequent block for possible continuation points.
2b) If found only upward or only sideward, start looking at next diagonal from where it has been found (if found at E then look at J elseif found at B then look at G).

(b)

Figure 7: (a) Sample search arrangement; (b) preliminary generalized method for connecting joining components

A potential method may be preliminarily instituted with the knowledge that the prospective positive sloped edges being connected within the GEM should typically have a slope in the vicinity of one (or typically in the vicinity of negative one for negative sloped edges). This method should also be able to connect the prospective edges resulting from the analysis of a road scene image with a vehicle positioned approximately centered between adjacent lanes as well as prospective edges which may be encountered during lane maneuvers. The connection method should be able to compensate for movement to an inadvertent GEM neighbor as well as being able to skip to likely GEM locations in the case where no significant adjoining GEM values are found. Similarly, the method should be able to analyze local clusters of GEM values to assist with less certain traversal through highly dispersed relevant GEM regions. As an initial example of how one may traverse an edge map containing varying degrees of GEM value dispersion, figure seven (a) illustrates a sample arrangement created to assist in explaining the preliminary generalized method shown in figure seven (b) for a positive sloped prospective border sequence contained within the GEM.

During GEM discrimination, the segment designating a single prospective transition must be evaluated for its relationships to the structural conclusions derived from the reference longitudinal lane marker(s). This system attempts to establish a structural representation through the discrimination of unlikely pattern candidates from the set of those occurring within a road scene image. From the set of undiscriminated structural features remaining in the GEM along with flags set or cleared during the intermediate structural recognition stages, certain structural conclusions may be inferred. Thus, depending on factors including (but not limited to) the degree of correspondence to the reference primitives and attributes, a pattern conclusion may be formulated.

At this point, the GEM contains the border transitions which have exhibited a high level of correspondence to those occurring between longitudinal lane markers and the road substrate. However, a formalized representation which facilitates deduction of further content based context is still needed to both establish a relationship between a border and the rest of a road scene image and establish relationships between the individual borders within a road scene image.

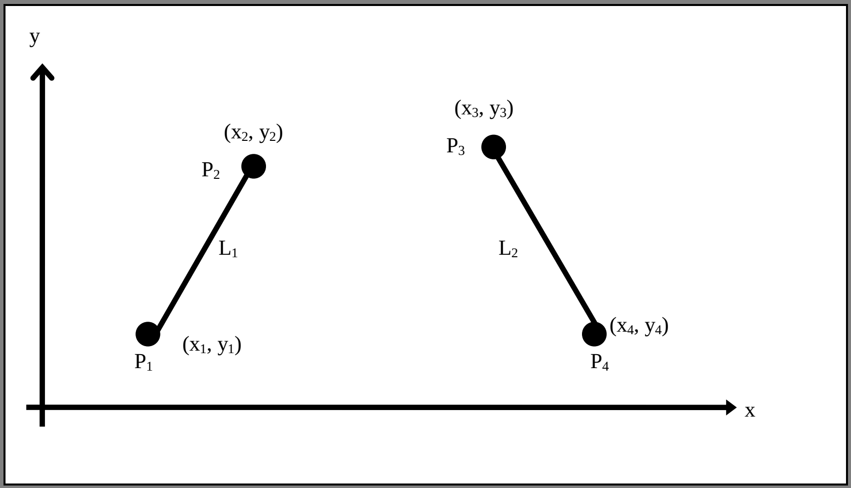


Figure 8: Cartesian coordinate representation of lines L_1 and L_2 with points (x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4)

The slope of a line containing two distinct points P_1 and P_2 on that line may be expressed as

$$y_1 - y_2 = m_1(x_1 - x_2), \quad \textbf{(1)}$$

where m_1 represents the slope of the line segment L_1 and the points (x_1, y_1) and (x_2, y_2) represent the starting and ending points of the line segment L_1. Similarly, a relationship for a second line segment L_2 may be expressed as

$$y_4 - y_3 = m_2(x_4 - x_3). \quad \textbf{(2)}$$

The slopes of these two lines may be calculated as

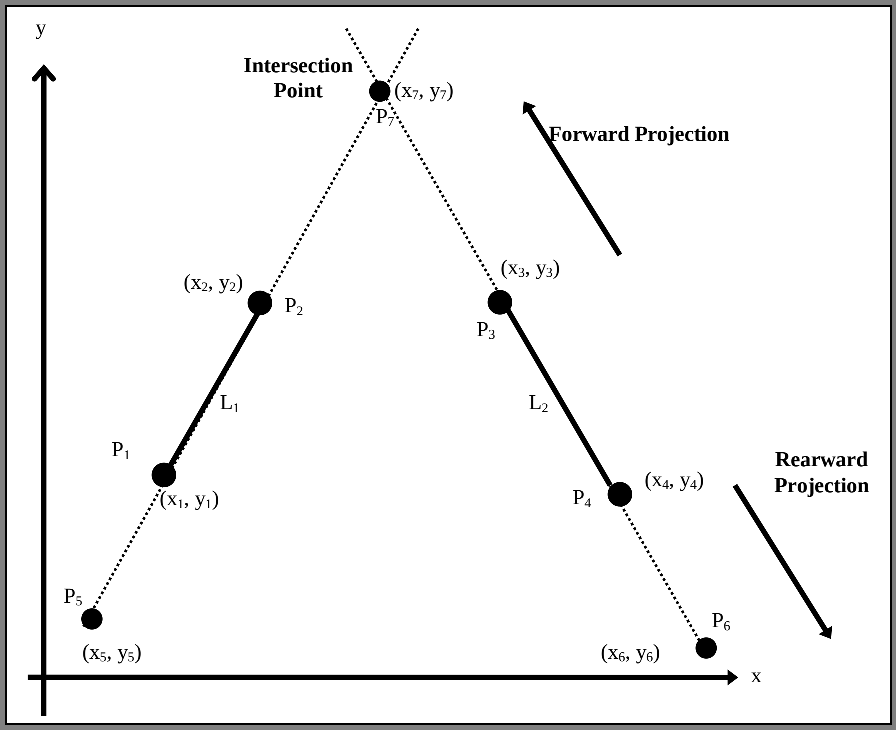
$$m_1 = (y_1 - y_2) / (x_1 - x_2) \quad \textbf{(3)}$$

and

$$m_2 = (y_4 - y_3) / (x_4 - x_3). \quad \textbf{(4)}$$

If L_1 and L_2 are not vertical and m_1 equals m_2, then the two line segments are parallel and ‘forward projections’ from the two would never intersect. Due to the perspective (and other important characteristics) of the road scene image processing system, there should never be a pair of parallel borders detected within the image for coupling. Similarly, there should never be a pair of vertical borders detected within the image for coupling. Finally, there should never be positive and negative sloped border transitions detected where the relative positions of L_1 and L_2 as indicated in figure eight are exchanged.

Clearly, figure nine indicates that forward projections from L_1 and L_2 will intersect and thus equations one and two may be coupled and solved through the techniques of linear algebra yielding precisely one solution. Figure nine also better illustrates how the forward and rearward projections for the line segments L_1 and L_2 may be represented and shows additional points used in the analysis. If one point on L_1 is known and one point on L_2 is known, and the slopes of the lines L_1 and L_2 are known or may be approximated, then the point (x_7, y_7) may be determined by solving a system of equations.



<u>Figure 9: Projections of lines L_1 and L_2 with labeling of additional points</u>

Now assume the point (x_1, y_1) is known and that the point (x_4, y_4) is also known. Also assume that the slope values m_1 and m_2 may be calculated or somehow otherwise approximated. The intersection point (x_7, y_7) couples the two linear equations for the forward projections via

$$y_1 - y_7 = m_1(x_1 - x_7) \tag{5}$$

and

$$y_4 - y_7 = m_2(x_4 - x_7). \tag{6}$$

Expanding equations five and six yields

$$y_1 - y_7 = m_1x_1 - m_1x_7 \tag{7}$$

and

$$y_4 - y_7 = m_2x_4 - m_2x_7. \tag{8}$$

Converting the system of equations into matrix form then yields

$$\begin{bmatrix} m_1 & -1 \\ m_2 & -1 \end{bmatrix}\begin{bmatrix} x_7 \\ y_7 \end{bmatrix} = \begin{bmatrix} m_1x_1 - y_1 \\ m_2x_4 - y_4 \end{bmatrix}. \tag{9}$$

From there, x_7 and y_7 may be solved for as

$$\begin{bmatrix} x_7 \\ y_7 \end{bmatrix} = \begin{bmatrix} m_1 & -1 \\ m_2 & -1 \end{bmatrix}^{-1}\begin{bmatrix} m_1x_1 - y_1 \\ m_2x_4 - y_4 \end{bmatrix}. \tag{10}$$

The rearward projections are also possible and may be determined using similar information to that which is used to formulate the forward projections. The rearward projection points are represented in figure nine by the coordinate pair (x_5, y_5) for the positive sloped transition and the coordinate pair (x_6, y_6) for the negative sloped transition. Since a relationship between distinct points on a line and the slope of that line has already been formulated to produce the forward projections, it is simply a matter of substituting the row value for the intended rearward projection point into a comparable equation to obtain the desired column value.

There are many complex issues related to what being ‘within a lane’ constitutes and when not being ‘within the lane’ constitutes a ‘lane departure’. To assist in preventing unintended lane departures, warning indicators may be used to alert the vehicle operator of a pending lane transition. Various standards have been initiated to provide further information related to lane departure warning systems (LDWS).

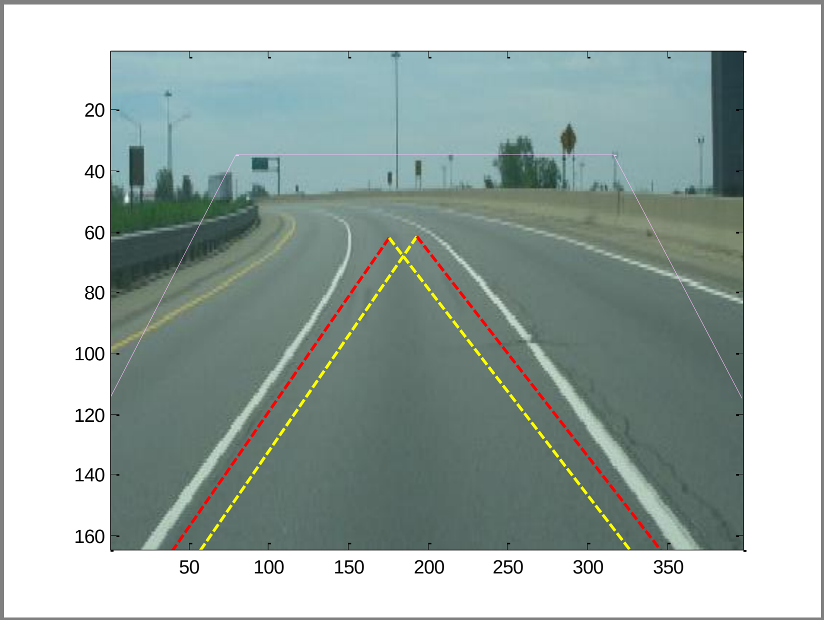


Figure 10: Sample road scene image with significant resulting projection lines

The first international standard covering Lane Departure Warning Systems is ISO 17361:2007 entitled “Intelligent transport systems - Lane departure warning systems - Performance requirements and test procedures”. It covers subjects including (but not limited to) terms and definitions, specifications and requirements, and test methods. Some of the potentially relevant topics introduced in this document include (but are not limited to) curvature and velocity based classification, lateral position and lane departure velocity, time to line crossing, earliest and latest warning lines, and three test procedures including warning generation, repeatability, and false alarm. Figure ten shows a road scene image containing left and right white normal longitudinal markers where the innermost and outermost projection lines generated by the road scene image processing system have been shown in different colors (yellow and red, respectively) indicating a difference in proximity to the white lane marker. Figure eleven gives a conceptual overview of the scope of analysis performed by the road scene image processing system.

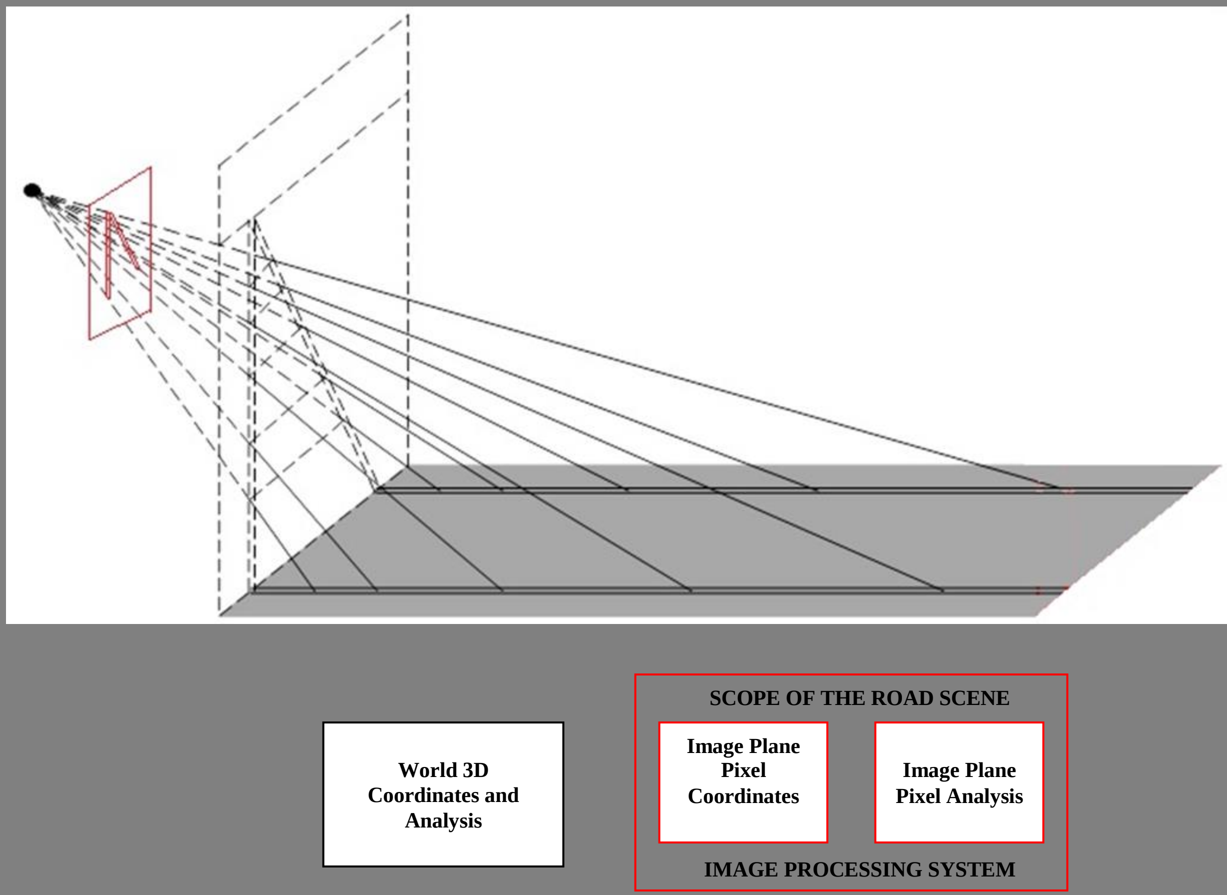


Figure 11: Artificial road scene image showing current analysis scope of the road scene image processing system

Over six hundred digital road scene images were acquired under various conditions on a wide variety of roads and thoroughfares found within the state of Michigan. The names for many of these roads are listed in table three.

Table 3: Roadways traveled during road scene image acquisition

NAMES OF SOME ROADWAYS TRAVELED FOR ROAD SCENE IMAGE COLLECTION	
1.	**Interstate 75**
2.	**Interstate 696**
3.	**Michigan 59**
4.	**Interstate 96**
5.	**Interstate 275**
6.	**Michigan 53**
7.	**Michigan 10**
8.	**Interstate 94**
9.	**Michigan 39**
10.	**Various local roads**

An example of a potential graphical user interface for the Preliminary Road Scene Image Processing software is shown in figure twelve.

Figure 12: A potential graphical user interface for the Preliminary Road Scene Image Processing Software

Claim(s)
(TBD)

Abstract of the disclosure

The road scene image processing system includes many aspects of image analysis including image pre-processing, image segmentation, and contextual analysis for road scene images acquired using a digital camera mounted to the rear-view mirror of different automobiles. In particular, road marker characteristics will be extracted including those for various white and yellow longitudinal lane markers. This lane marker information may be used to approximate a likely lane boundary as a result of a vehicle's positioning with respect to the lane (delineated by visually detectable longitudinal lane markers) and a camera's positioning within the vehicle. The system may then use the position of the vehicle with respect to prioritized warning lines to indicate potentially hazardous driving situations. This road scene image processing system should be relatively invariant to illumination conditions and should be able to perform during a wide range of environmental and operating conditions.

Drawings
(TBD)

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