Color-Based Road Detection and its Evaluation on the KITTI Road Benchmark

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Outline

- Introduction
- Road detection system
  - System overview
  - Binary map method
  - Confidence map method
- Evaluation
- Perspective

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Introduction

Objective:

- Environment Understanding
- Traffic Safety – Collision avoidance
- Traffic Efficiency – Path planning

Method:

- Appearance character

  Primary detection from intrinsic image
- Geometric structure

  Plan extraction by stereo vision
- Likelihood distribution

Introduction

KITTI-Road Benchmark [Fritsch2013][2]

- Dataset:

  Urban **U**nmarked road
  Urban **M**arked two way road,
  Urban **M**arked **M**ultiple lane road

- Result presentation

  Perspective View, Bird-Eye View

- Evaluation

  F1-measure, Accuracy, Average Precision, etc.

[2] **Jannik Fritsch, Tobias Kuehnl, and Andreas Geiger**, "A new performance measure and evaluation benchmark for road detection algorithms", *International Conference on Intelligent Transportation Systems*, IEEE 2013.

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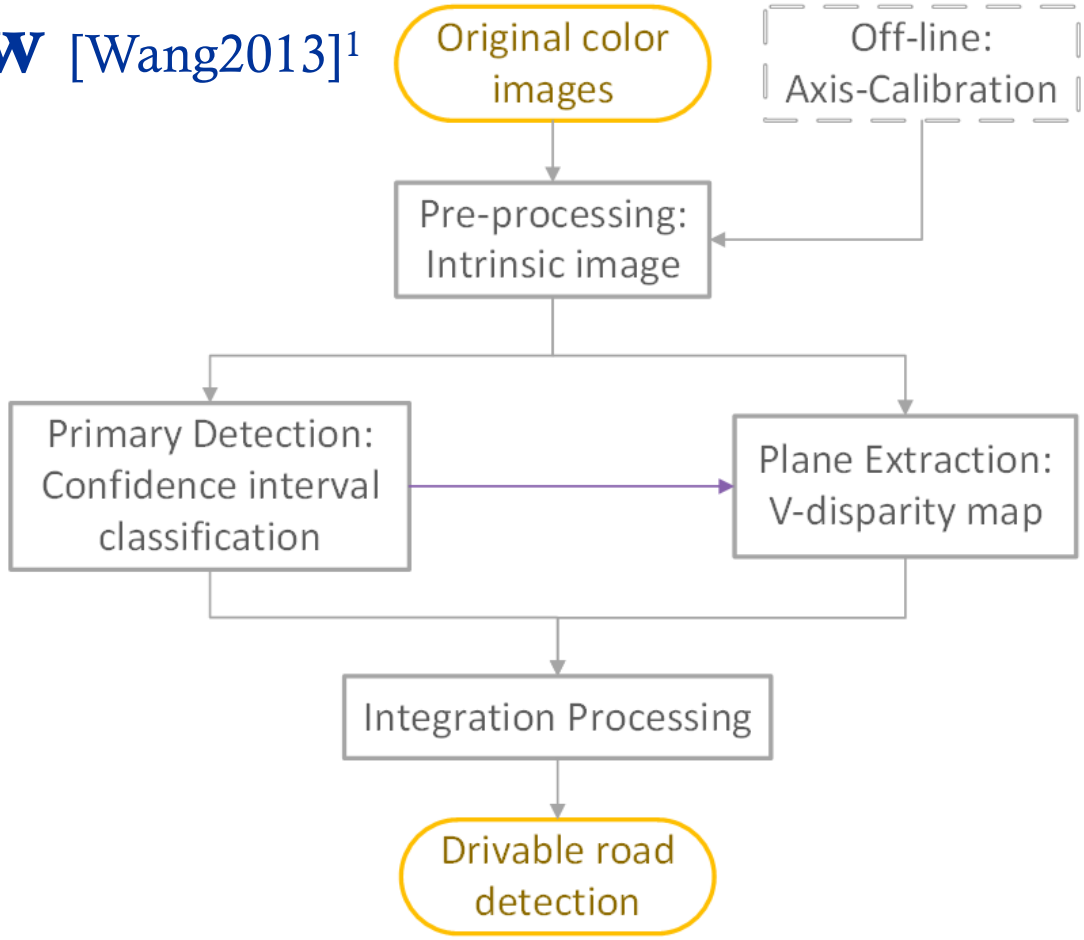
Road Detection System

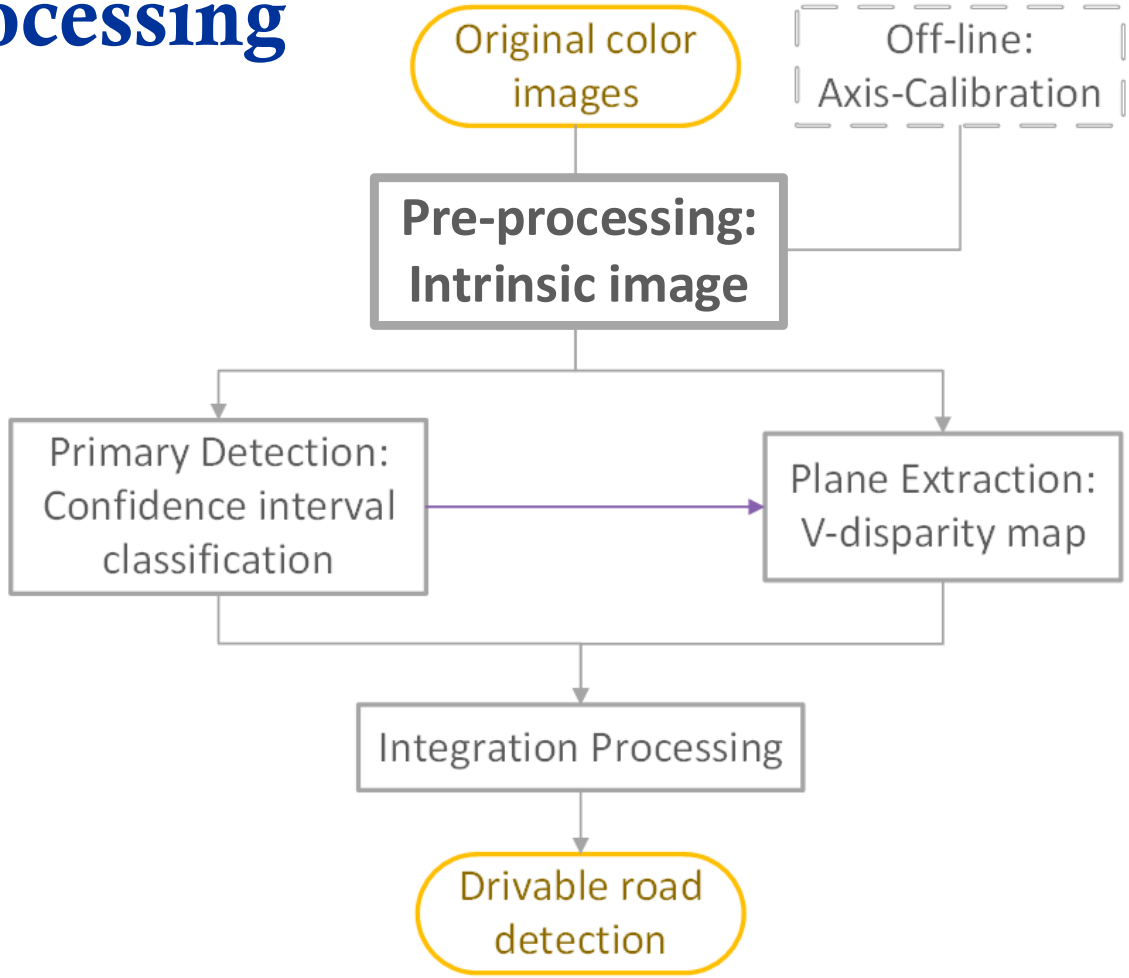
Overview [Wang2013][1]



[1] **Bihao Wang and Vincent Frémont**. "Fast road detection from color images" , *IEEE Intelligent Vehicles Symposium (IV)*,1209-1214, 2013.

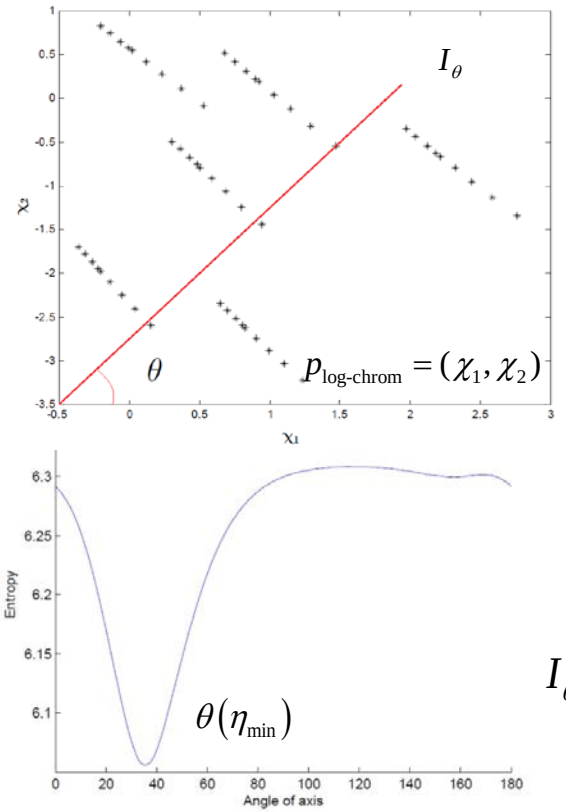
Road Detection System

Pre-processing



Road Detection System

Pre-processing



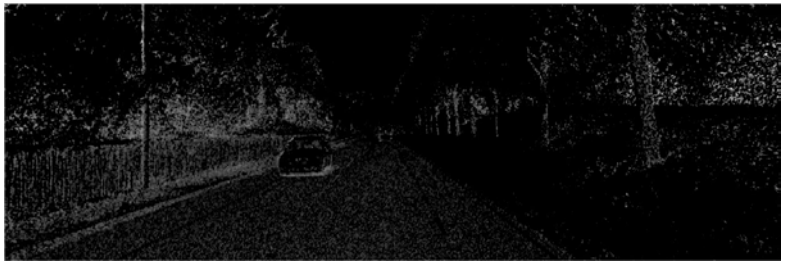
$$\rho_{1,2,3} = \log(R, G, B / \sqrt[3]{R \cdot B \cdot G})$$

$$U = \left[1/\sqrt{2}, -1/\sqrt{2}, 0; -1/\sqrt{6}, -1/\sqrt{6}, 2/\sqrt{6}\right]$$

$$\chi = U \cdot [\rho_1, \rho_2, \rho_3]^T$$

$$I_\theta = \chi_1 \cos\theta + \chi_2 \sin\theta$$

Intrinsic image [Finlayson2009][3]

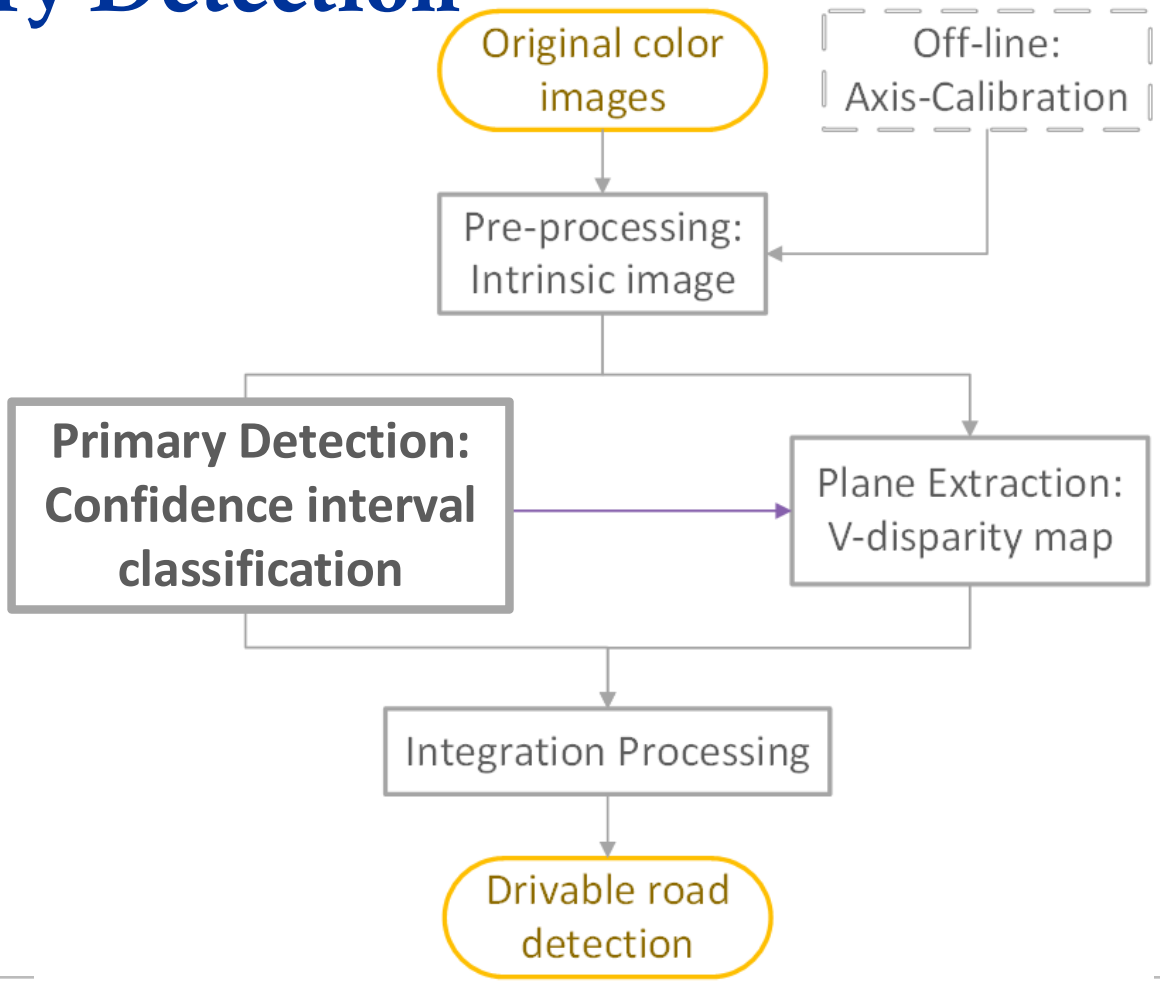


I_θ (grayscale× 10)

[3] **Finlayson, Graham D., Mark S. Drew, and Cheng Lu**. "Entropy minimization for shadow removal." *International Journal of Computer Vision* 85.1 (2009): 35-57.

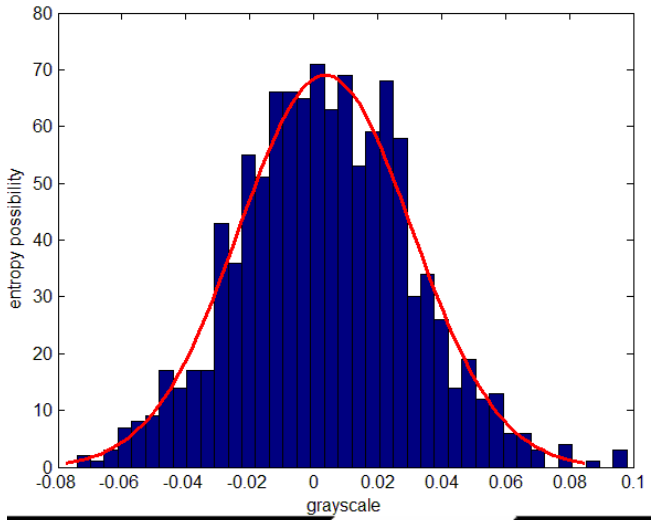
Road Detection System

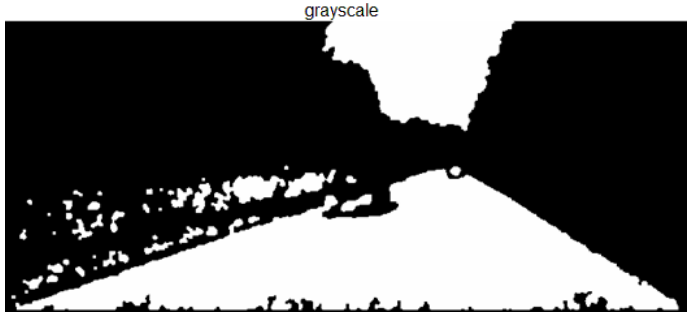
Primary Detection



Road Detection System

Primary Detection





Selected samples from hypothetic road area [Alvarez2011][4] follow a Gaussian distribution.

Confidence Level: $1-\alpha = 0.7, 0.8, 0.9, 0.95...$

Confidence Interval: $\begin{cases} I_R = 1, & \text{if } \lambda_1 \le I_\theta(p) \le \lambda_2 \\ I_R = 0, & \text{otherwise} \end{cases}$

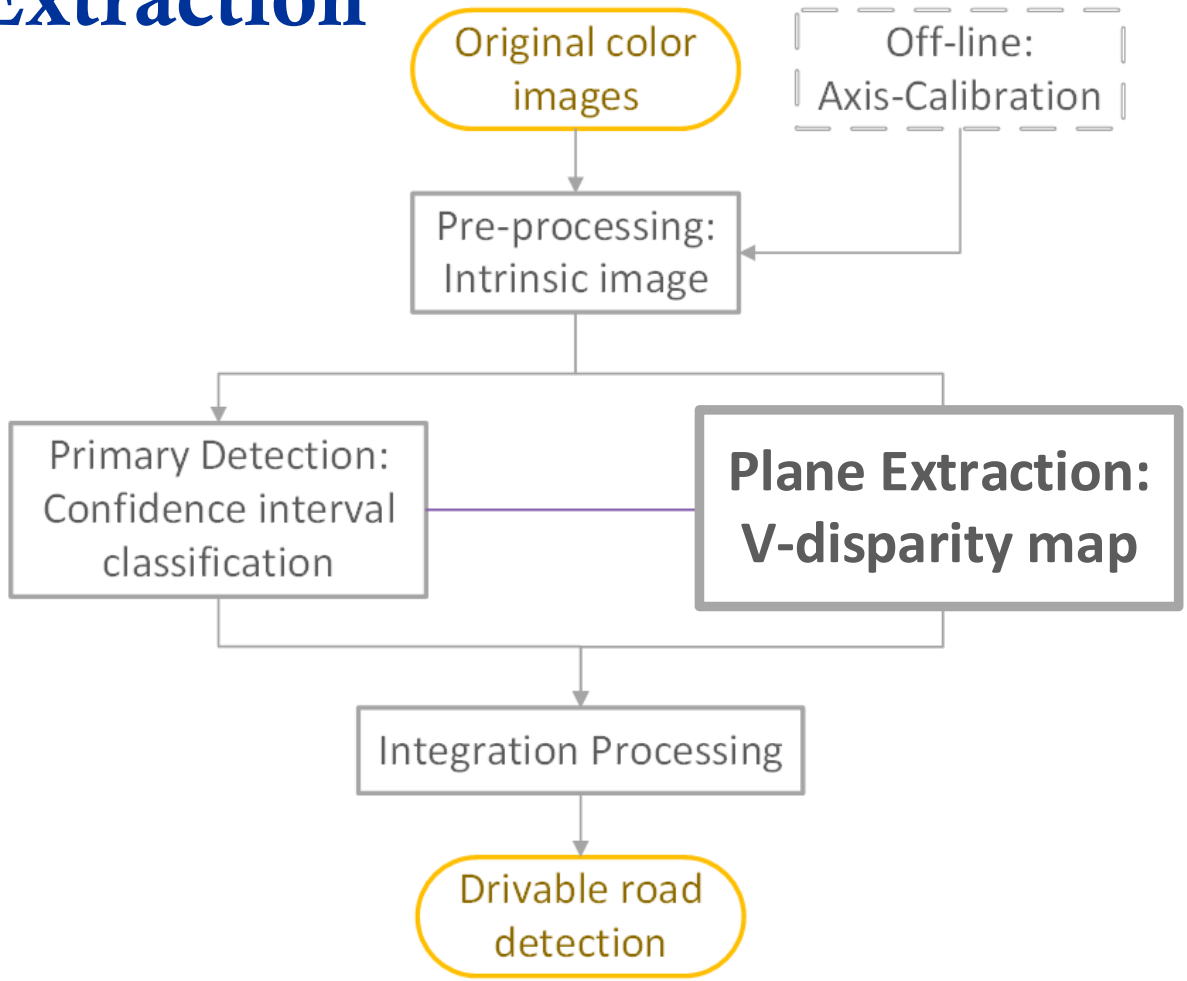
p : pixel

Primary detection result: I_R

[4] **Alvarez, J.M.A. and Lopez, A.M.,** "Road detection based on illuminant invariance", *Intelligent Transportation Systems, IEEE Transactions on*, 12(1), 184-193. 2011.

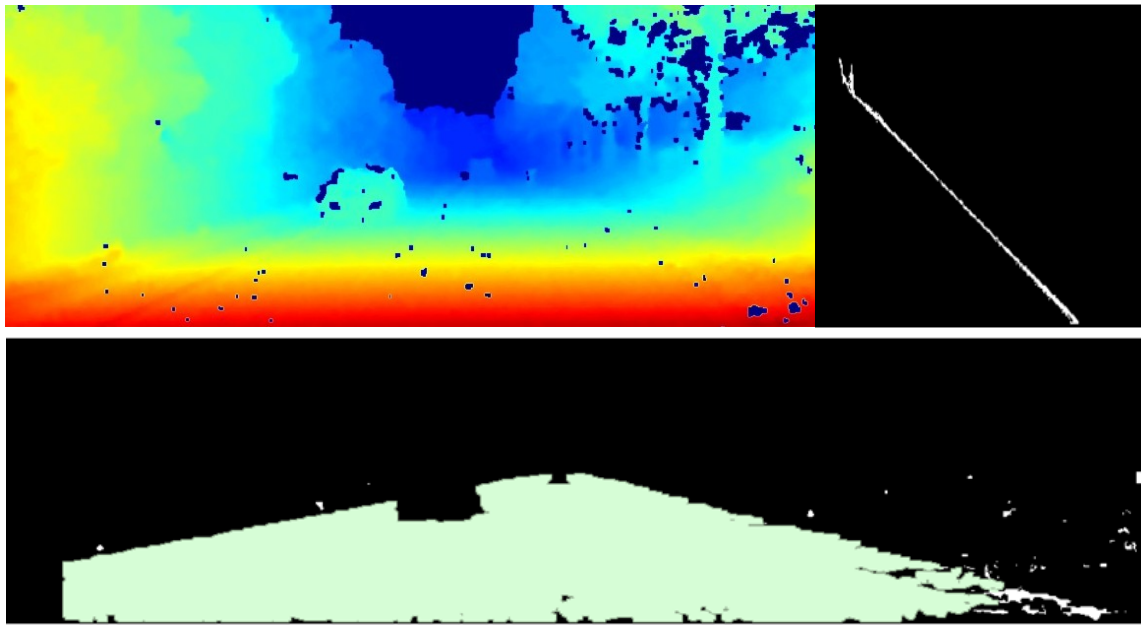
Road Detection System

Plane Extraction



Road Detection System

Plane Extraction



Ground plane extraction result I_G

In V-disparity map, road profile can be described as :

$$\Delta_v = a \cdot v + b$$

for each pixel p

if $\Delta_p \in [\Delta_v \pm \varepsilon_v]$

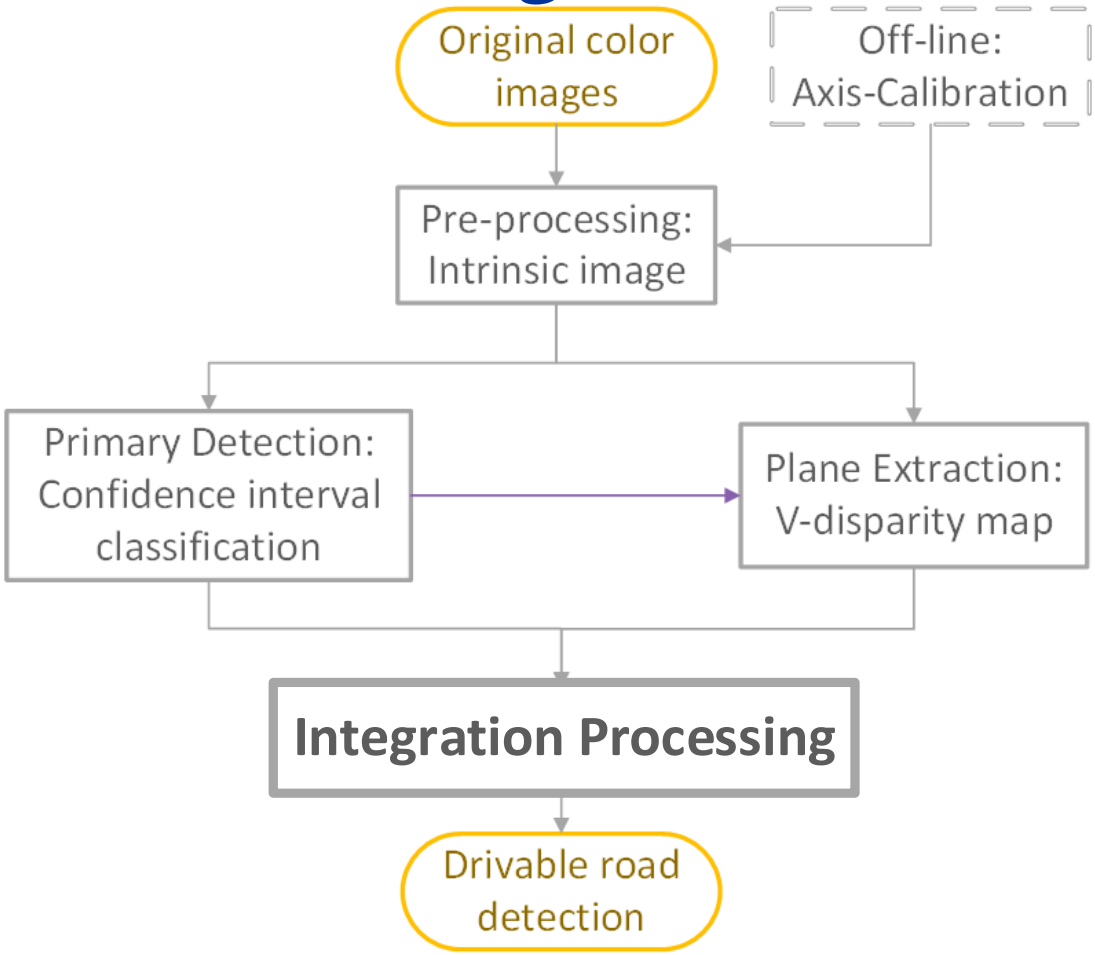
then, $I_G = 1$;

else, $I_G = 0$.

The range of variance ε_v for ground plane extraction of each row v in the image is positive related to its distance to the camera.

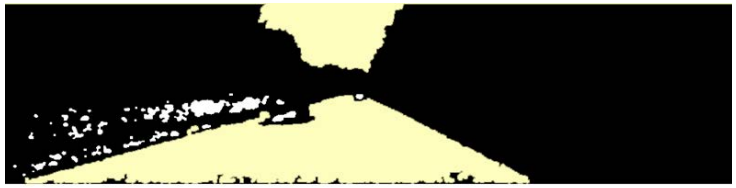
Road Detection System

Integration Processing

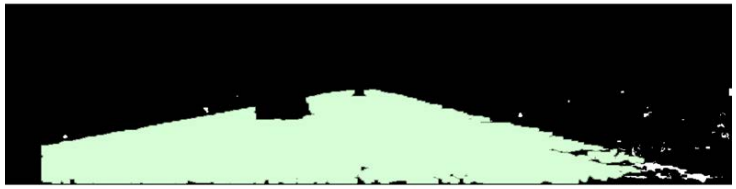


Road Detection System

Integration Processing



I_R Primary road detection result from intrinsic image



I_G Ground plane extraction result from stereo vision (V-disparity)

$I_{road} = I_R \cap I_G$ Intersection calculation

Free road surface detection result

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Binary Map

- **Improvements**
  - Narrowed confidence interval for primary detection
  - Set I_R as ROI to speed up V-disparity accumulation
  - Refinement of road profile in V-disparity map
  - Dynamic bound for Plane extraction: $\varepsilon_v = c \cdot v$
  - Compensation of the holes caused by disparity map.

Before After

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Confidence Map

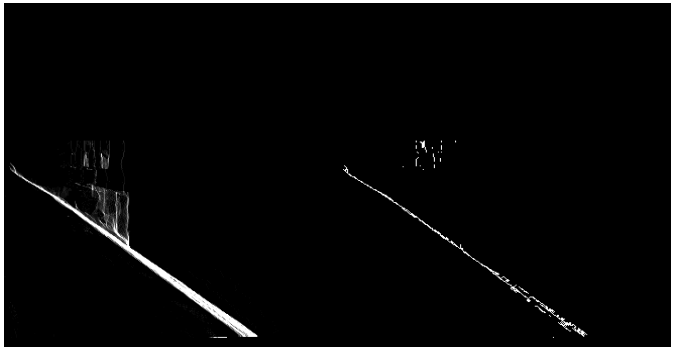
- **Pre-detection**

0	1	0
0	1	1
1	0	1

$$L_R(u,v) = \sum_{i=u-1}^{u+1} \sum_{j=v-1}^{v+1} I_R(i,j)/9 \qquad ex: L = 5/9 = 0.556$$

The pixels whose neighbors are mostly pre-detected as road area have a higher likelihood of being on the road surface.

- **Plane extraction**



For each row of the image:

$$\Delta_v = \text{median}(\Delta(p_v))$$ --- road profile

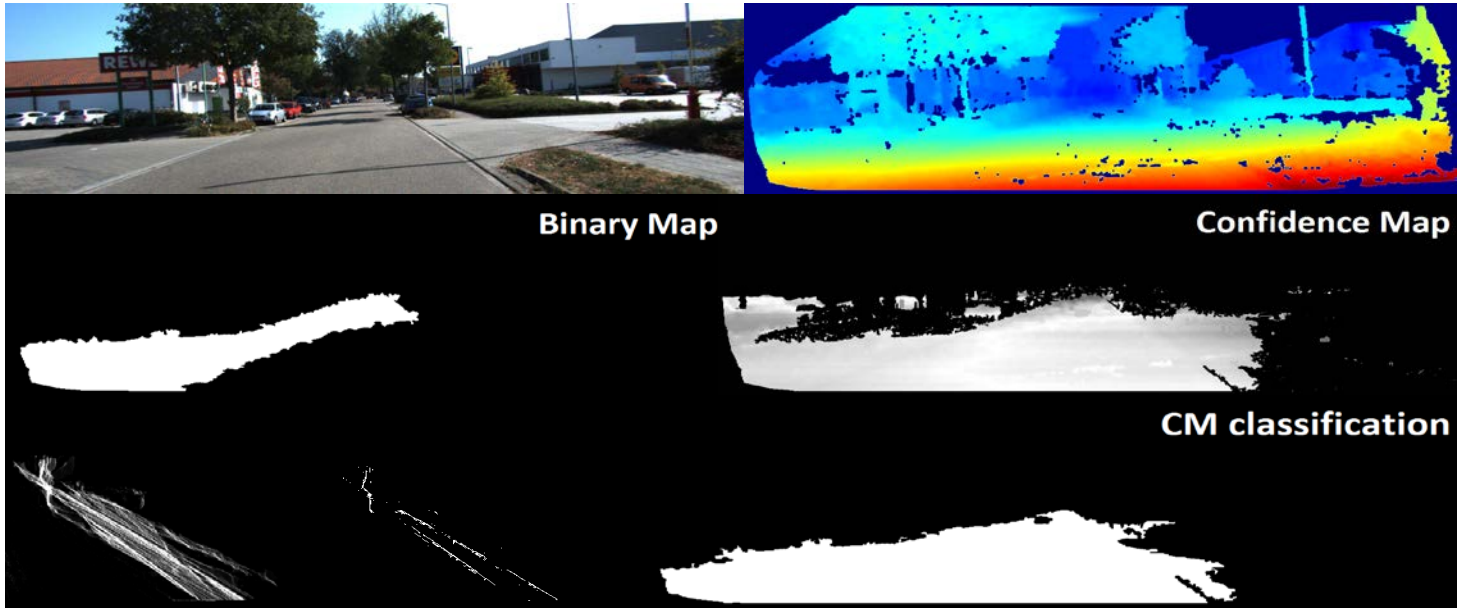
$$L_G(u,v) = 1 - \left|\Delta_{I_R}(u,v) - \Delta_v\right| / \Delta_v$$ --- deviation

$$L_G = \frac{1}{2} L_G \cdot (1 + \text{sgn}(L_G))$$ --- eliminate negative value

Confidence Map

- **Likelihood combination**

$$L_c(u,v) = L_R(u,v) \cdot L_G(u,v)$$



Confidence map outperforms binary map in non flat ground scene. It avoids the ambiguity of road profile in V-disparity map .

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Evaluation

URBAN - BEV Space					
	F_{max}	Prec.	Rec.	FPR	FNR
SPRAY[5]	86.33	86.75	85.91	7.55	14.09
BM	82.32	76.15	89.56	16.15	10.44
CNN[6]	78.92	76.25	81.79	14.67	18.21
BL[2]	75.61	68.93	83.73	21.73	16.27

In the comparison, binary map detection (BM) performs the best in the measurement of **Recall** and **False Negative Rate**, and the Second in **F1-measure**.

[5] **T. Kuehnl, F. Kummert, and J. Fritsch.,** "Spatial ray features for real-time ego-lane extraction". *In Proc. IEEE Intelligent Transportation Systems*, 2012.

[6] **Jose M. Alvarez, Theo Gevers, Yann LeCun, and Antonio M. Lopez.,** "Road scene segmentation from a single image". *In ECCV 2012, volume 7578 of Lecture Notes in Computer Science*, pages 376–389. Springer Berlin Heidelberg, 2012.

Evaluation

UM Perspective space*

	F_{max}	AP	Acc.	Prec.	Rec.	FPR	FNR
BL	89.27	92.18	96.53	88.93	90.17	2.26	9.83
BM	85.67	72.21	94.89	77.83	95.26	5.18	4.74
CM	81.69	80.46	94.09	81.06	82.33	6.67	17.67

UMM Perspective Space*

	F_{max}	AP	Acc.	Prec.	Rec.	FPR	FNR
BM	88.76	81.29	94.55	87.04	90.55	4.20	9.45
CM	85.28	82.08	92.99	85.09	85.46	4.67	14.54
BL	82.81	89.21	91.23	77.54	88.86	8.02	11.14

UU Perspective Space*

	F_{max}	AP	Acc.	Prec.	Rec.	FPR	FNR
BL	80.79	86.13	94.70	79.00	82.67	3.42	17.33
BM	80.50	62.53	94.19	73.44	89.07	5.02	10.93
CM	75.88	71.48	93.18	72.53	79.55	4.69	20.45

The confidence map method (CM) outperforms the improved binary map method (BM) on the measurement of **Precision**

Both BM method and CM method outperform the Baseline result on the **F1-Measure** and **Accuracy**

Current CM method still need to be improved to face more complex environment

*Perspective space evaluation is applied on training dataset

Evaluation

Binary Map

It provides a straightforward information of free road area without training*

Confidence Map

It can cope with more complex environment like non-flat road.

* Procedure of finding a proper threshold for confidence map through PR curve on training dataset.

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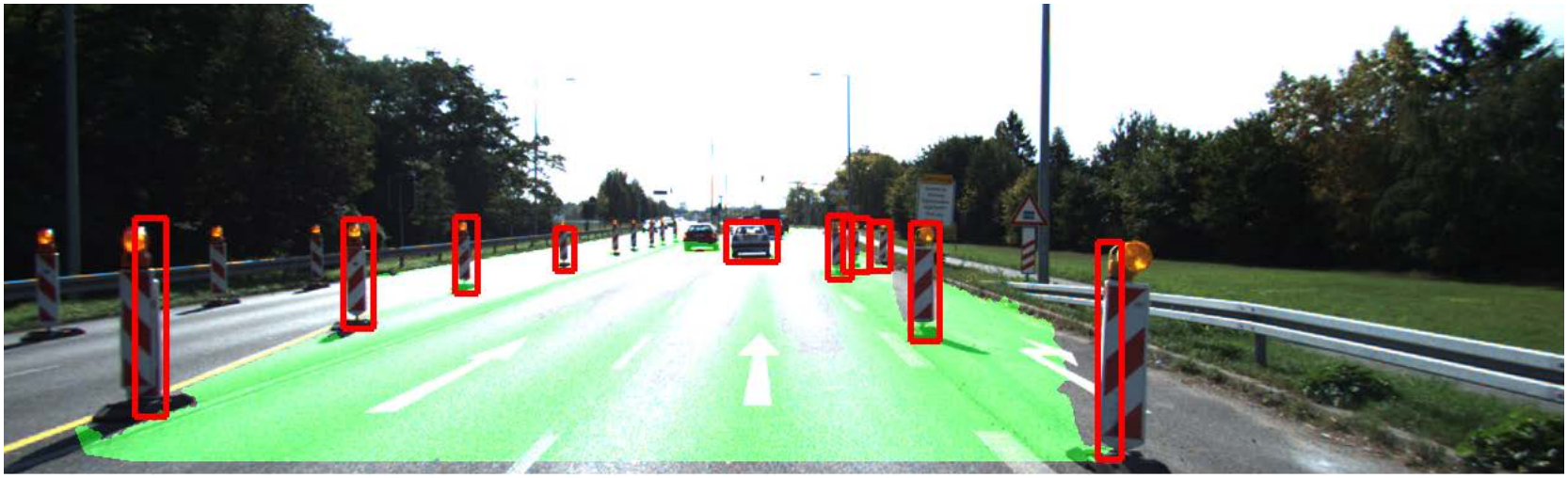
Perspective

- Automatic seeds selection
- New likelihood construction
- On-road obstacle detection
- Tracking of road structure



THANK YOU FOR YOUR ATTENTION!

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