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

Bihao WANG$^{1,2}$,
Vincent Frémont$^{1,2}$,
Sergio Alberto Rodríguez Florez$^{3,4}$

$^1$ Université de Technologie de Compiègne (UTC)  $^2$ CNRS Heudiasyc UMR 7253
$^3$ Université Paris-Sud  $^4$ CNRS Institut d’Électronique Fondamentale UMR 8622
Outline

- Introduction

- Road detection system
  - System overview
  - Binary map method
  - Confidence map method

- Evaluation

- Perspective
Outline

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- **Perspective**
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 Unmarked road
  Urban Marked two way road,
  Urban Marked Multiple lane road

- **Result presentation**
  
  Perspective View, Bird-Eye View

- **Evaluation**
  
  F1-measure, Accuracy, Average Precision, etc.

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Road Detection System

Overview [Wang2013]¹

Original color images

Pre-processing: Intrinsic image

Primary Detection: Confidence interval classification

Plane Extraction: V-disparity map

Integration Processing

Drivable road detection

Road Detection System

Pre-processing

Original color images

Off-line: Axis-Calibration

Pre-processing: Intrinsic image

Primary Detection: Confidence interval classification

Plane Extraction: V-disparity map

Integration Processing

Drivable road detection
Road Detection System

Pre-processing

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

\[ U = \begin{bmatrix} 1 / \sqrt{2}, -1 / \sqrt{2}, 0; -1 / \sqrt{6}, -1 / \sqrt{6}, 2 / \sqrt{6} \end{bmatrix} \]

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

Intrinsic image [Finlayson2009]\(^3\)

\[ I_\theta = \chi_1 \cos \theta + \chi_2 \sin \theta \]

Road Detection System

Primary Detection

Original color images

Pre-processing: Intrinsic image

Primary Detection: Confidence interval classification

Plane Extraction: V-disparity map

Integration Processing

Drivable road detection
Selected samples from hypothetical road area [Alvarez2011]$^4$ follow a Gaussian distribution.

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

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

$p : \text{pixel}$

Primary detection result: $I_R$

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Road Detection System

Plane Extraction

Original color images

Pre-processing: Intrinsic image

Off-line: Axis-Calibration

Primary Detection: Confidence interval classification

Plane Extraction: V-disparity map

Integration Processing

Drivable road detection
Road Detection System

Plane Extraction

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 $\varepsilon_v$ 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

- Original color images
- Pre-processing: Intrinsic image
- Off-line: Axis-Calibration
- Primary Detection: Confidence interval classification
- Plane Extraction: V-disparity map
- Integration Processing
- Drivable road detection
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**

  \[ L_R(u,v) = \sum_{i=u-1}^{u+1} \sum_{j=v-1}^{v+1} I_R(i,j) / 9 \]

  \[ ex : L = 5 / 9 = 0.556 \]

  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:

  \[ \Delta_v = \text{median}(\Delta(p_v)) \quad \text{--- road profile} \]

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

  \[ L_G = \frac{1}{2} L_G \cdot (1 + \text{sgn}(L_G)) \quad \text{--- eliminate negative value} \]
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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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.

Evaluation

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*Perspective space evaluation is applied on training dataset

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.
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!

bihao.wang@hds.utc.fr

vincent.fremont@hds.utc.fr

sergio.rodriguez@u-psud.fr