Drivable XOR Obstacle with Disparity AND Color

ir. Willem Sanberg
dr. Gijs Dubbelman
prof. dr. ir. Peter de With
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TU/e Technische Universiteit Eindhoven University of Technology

VCA Video Coding & Architectures research group

Where innovation starts
Introduction – Framework – Color Modeling – Results
Introduction – Previous work

Original critical path including disparity estimation

- Disparity Estimation
- Disparity Stixel World
Introduction – Previous work

**Original critical path** including disparity estimation

1. Disparity Estimation
2. Disparity Stixel World

**Previous critical path** including disparity estimation

1. Disparity Estimation
2. Extended Stixel World
Introduction – Previous work

Original critical path including disparity estimation

Proposed critical path without disparity estimation
Introduction – Previous work

Original critical path including disparity estimation

Proposed critical path without disparity estimation
Stixel World is Bayesian MAP:

We want to have

- Posterior \( p(\text{class} | \text{color}) \)

and measure

- Likelihood \( p(\text{color} | \text{class}) \)

and define

- prior \( p(\text{class}) \) for regularization
Proposed Framework: core

Proposed critical path
without disparity estimation

Current Frame $t_n$

Color-only Stixel World

Free-space result

Color Model

?
Proposed Framework: core

Proposed critical path
without disparity estimation

Color-only Stixel World

Current Frame $t_n$

Color Model

Free-space result
Proposed Framework: online learning

Proposed critical path without disparity estimation

Color-only Stixel World

Free-space result

Color Model

Learning Window
$t_{n-10}$ ... $t_{n-1}$

Current Frame
$t_n$

Color Modeling
Proposed Framework: supervision

**Proposed critical path**
without disparity estimation

**Color-only Stixel World**

**Free-space result**

**Background process** lagging in time or at a low frame rate
Color Modeling: representation

...which color?
Color Modeling: representation

...which color?

Disparity-based ground mask
Color Modeling: representation

...which color?

Hist. Eq.
RGB
HS
Illum.-Inv.
Grayscale

Disparity-based ground mask
Color Modeling: representation

...which color?

Fixed bins?

Disparity-based ground mask
Color Modeling: representation

...which color?

Fixed bins

Adaptive bins

Disparity-based ground mask
What about color variation?
What about color variation?

Exploit homogeneity of ground:

Model Color-pairs in 2D histograms
Color Modeling: geometric distortion

- Perspective imaging
  - \(\sim \text{cm}^2\) versus \(\sim \text{m}^2\)
  - Same number of pixels!
Color Modeling: distance-aware
Frames in the Learning Window

- Learning Window: \( t_{n-10} \) to \( t_{n-1} \)
- Color Model: \( \text{Color-only Stixel World} \)
- Proposed critical path: without disparity estimation

[ full ]
[ lagging ]
[ low FPS ]

Free-space result

Color Modeling
Color Modeling: summary

• Online learning:
  • Disparity estimation & segmentation of previous frames
  • Adaptive color space
  • Distance-aware likelihoods
Color Modeling: summary

• Online learning:
  • Disparity estimation & segmentation of previous frames
  • Adaptive color space
  • Distance-aware likelihoods

• Frame Analysis:
  • Adaptive color space
  • Stixel columns with local color pairs
  • Distance-aware posteriors
Results: previously
Results: proposed

<table>
<thead>
<tr>
<th>Further color settings: HEQ, 2D distance aware histograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>disparity only</td>
</tr>
<tr>
<td>RGB + full</td>
</tr>
<tr>
<td>IllumInv + full</td>
</tr>
<tr>
<td>Gray + low FPS</td>
</tr>
</tbody>
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Introduction – Framework – Color Modeling – Results

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Results: previously
Results: proposed

Further color settings: HEQ, 2D distance aware histograms
Results: Quantitatively

Histogram Equalization

Color Space

Learning Window
Results: Quantitatively

Free space per stixel column

- Correct
- False obstacle
- Missed obstacle
Results: Quantitatively

Free space per stixel column

Color-only not straightforward: many settings perform worse…
Results: Quantitatively

Free space per stixel column

Color-only not straightforward: many settings perform worse...

...but smart online adaptation could exploit them all.
For more information:

W.P. Sanberg, G. Dubbelman, P.H.N. de With,

“Free-space Detection using
Online Disparity-supervised Color Modeling”

Datasets available:

www.WillemSanberg.net
Stereo Disparity
Baseline: Disparity Stixel World

- **Stereo Camera**
- **Column-wise probabilistic analysis**
- **Segment ground or obstacle**
  - Rectangular patches
  - Expected disparity:
  - Ground: \( f(v) \approx \alpha \cdot (v_{\text{horizon}} - v) \)
  - Obstacle: \( f(v) \approx \mu_d \)
  - \( L^* = \arg \max_{L \in L} P(L|\mathcal{D}) \)

- **Solve efficiently with Dynamic Programming**

Baseline: Disparity Stixel World

Formulated as a MAP problem over the disparity input

• $L^* = \arg \max_{L \in \mathbb{L}} P(L | \mathbb{D})$

• $P(L | \mathbb{D}) \sim \prod_{u=0}^{w-1} P(D_u | L_u) \cdot P(L_u)$

• $P(D_u | L_u) \sim \prod_{n=1}^{N_u} \prod_{v=v_n}^{v_t} P(d_v | s_n, v)$

• $P(d_v | s_n, v) = \frac{p_{out}}{d_{max} - d_{min}} + \frac{1-p_{out}}{A_{norm}} e^{-\left(\frac{d_v-f_n(v)}{\sqrt{2} \cdot \sigma_{ln}(f_n,v)}\right)^2}$

• Uniform distribution for outliers (less strict modeling)

• Gaussian distribution for ground/obstacle modeling

Fuse Color data into core of the algorithm (assume independence)

- \( L^* = \arg \max_{L \in \mathbb{L}} P(L|D, C) \)
- \( P(L|D, C) \sim \prod_u P(D_u, C_u|L_u) \cdot P(L_u) \)
- \( P(D_u, C_u|L_u) \sim \prod_n \prod_v P(d_v|s_n, v) \cdot P(c_v|s_n, v) \)

- What about \( P(c_v|s_n, v) \)?
  - Learn \( P(c_v|s_n, v) \) online and self-supervised
    - Color representation?
    - Learning window?
    - Sample selection?
Results: consistent disp. errors (pitfall)
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