iMorpheus.ai

自动驾驶论文讲坛

上采样深度图像及其应用

·本周分享

深度图 (Depth map) 是除点云 (Point Cloud) 以外另一种描述三维场景的数据格式，对它的处理也是自动驾驶领域重要的一环。本次 Journal Club 将会和大家一起学习一种将 Camera 和 Lidar 做数据融合，得到高精度高分辨率深度图像并将其应用于路沿检测 (Curb Detection) 的方法。

参考文献：

[1] J. Dolson, J. Baek, C. Plagemann, and S. Thrun. Upsampling range data in dynamic environments. In CVPR, 2010.

[2] Tan, J.; Li, J.; An, X.; He, H. Robust Curb Detection with Fusion of 3D-Lidar and Camera Data. Sensors 2014, 14, 9046–9073.

·主讲人

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中科院上海技术物理研究所在读博士

• 时间

星期五 03/11/2017

北京时间 12:00 PM

线上会议直播 - Zoom.us

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The Application of Upsampled Range Data

Xudong Zhang

2017-11-3

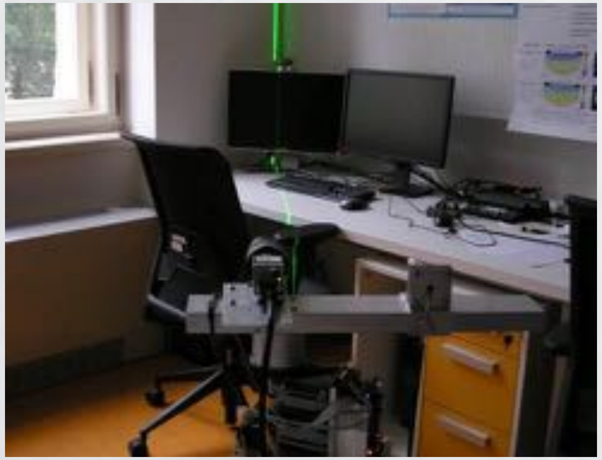
[1] J. Dolson, J. Baek, C. Plagemann, and S. Thrun. Upsampling range data in dynamic environments. In CVPR, 2010.
[2] Tan, J.; Li, J.; An, X.; He, H. Robust Curb Detection with Fusion of 3D-Lidar and Camera Data. Sensors 2014, 14, 9046–9073.

CONTENTS

Point Cloud V.S. Depth Map

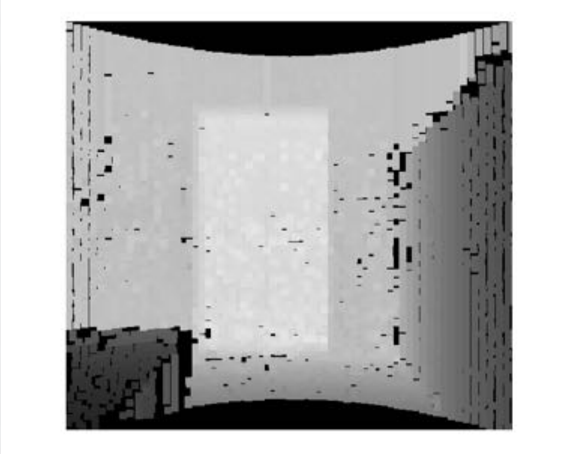
Depth Map

Point Cloud

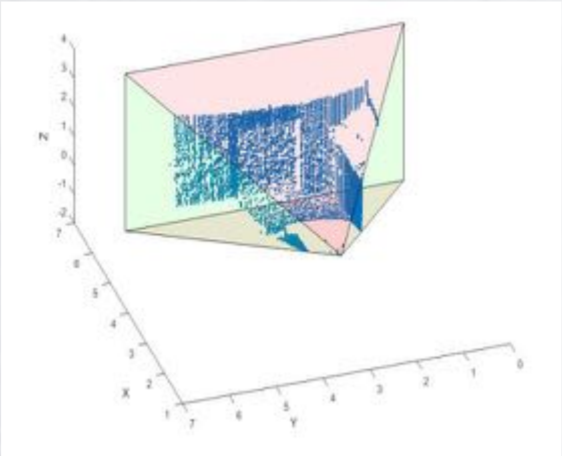


a

b



e



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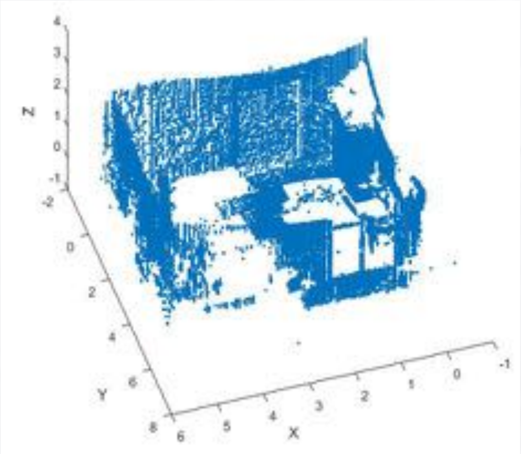
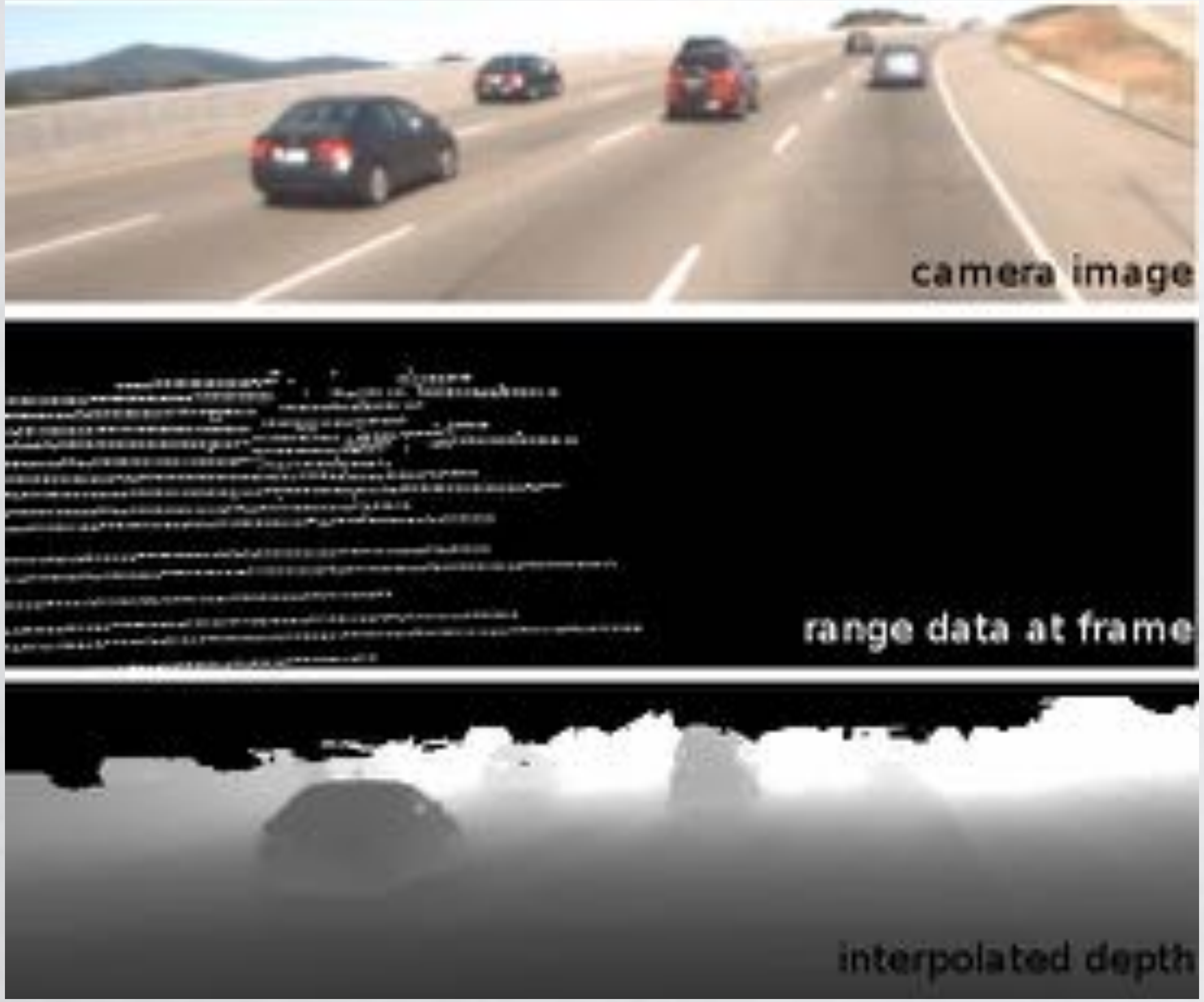


c

Lidar’s Point Cloud

1. Accurate & Long range
2. Sparse
3. Expensive
4. Low acquisition rate
5. Available under many situations



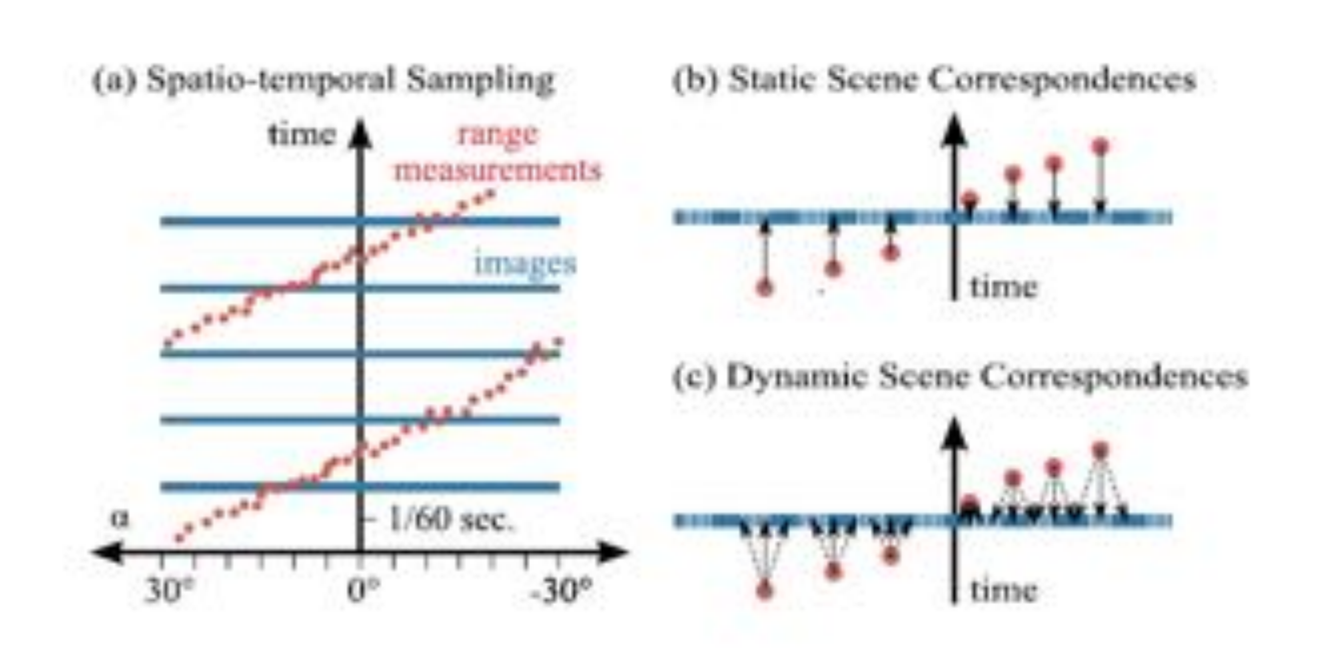
Target: To recover an accurate, dense depth map.

Keyword: Upsampling range data

Method: Corresponding to a single camera frame
or using depth data from neighboring frames

Problem: Different data acquisition rates

Problems



Interpolate depth information with a level of accuracy
Assign confidence value
Parallel Framework

1. Fusion with stereo camera：
   Stereo camera systems range error increases quadratically with depth.
   → Accuracy limited ×
2. Markov Random Fields (MRFs)
   Using color information from a camera image
   → Assumption: static within the sweeping time ×

2 *Upsampling range data*

d-dimensional filters: (u, v)

Interpolation: (ρ, u, v, t)

$(r, g, b, u, v) \rightarrow (\rho, u, v)$

Data Processing & Motion Priors

Confidence Weighting:

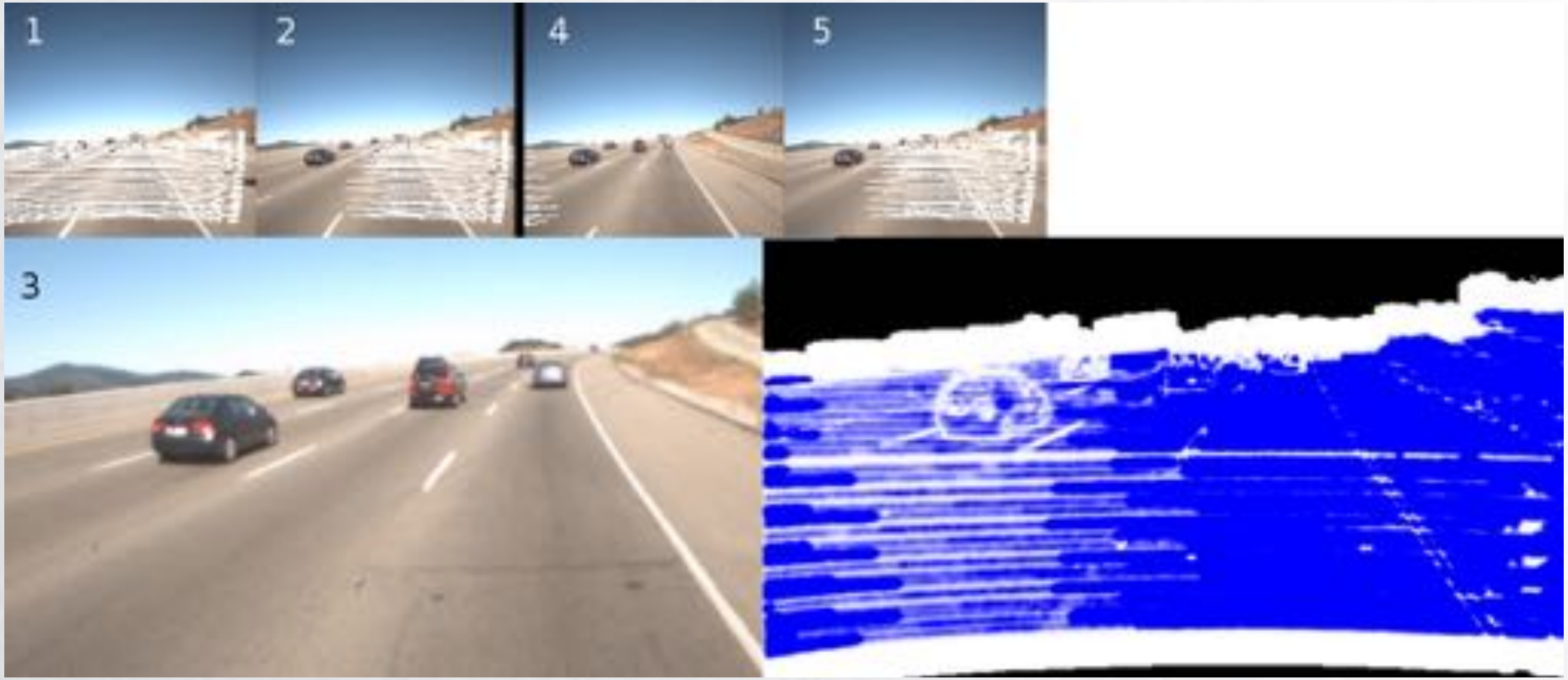
standard deviations

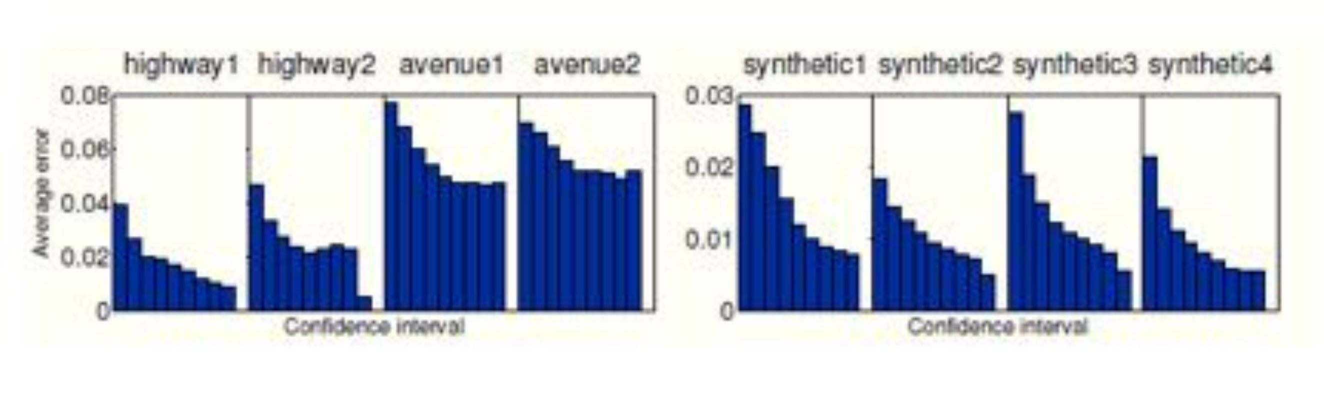
$$\hat{v}_i = \sum_{j=1}^{n} f(|p_i - p_j|) \cdot v_j \ . \quad (1)$$

$$f(x) = e^{-|x|^2/2\sigma^2} \quad (2)$$

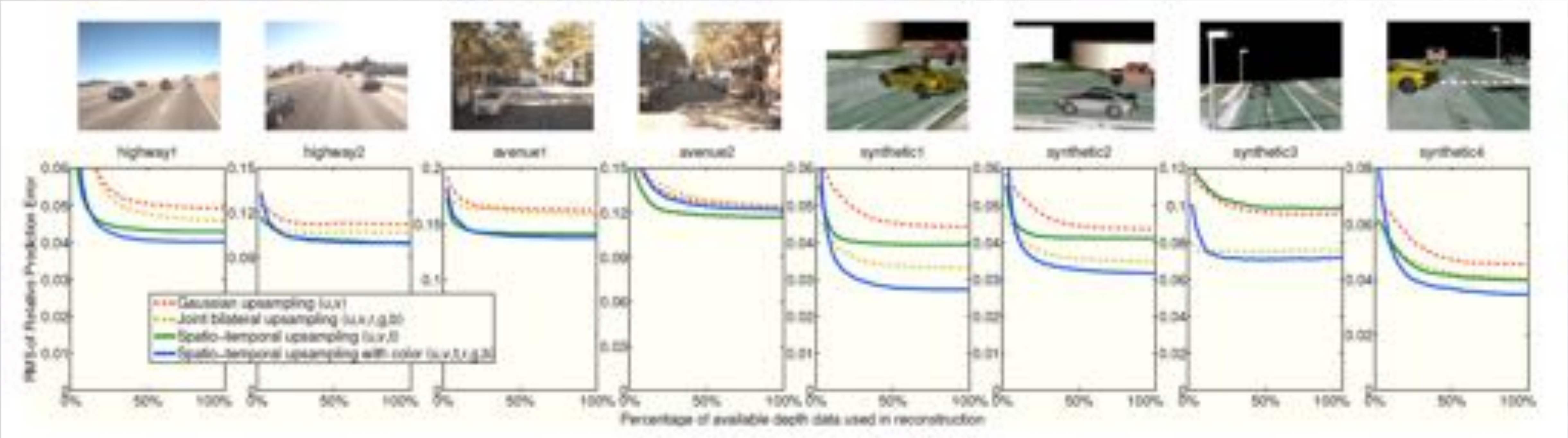
$$p^* = (s_u \cdot \Delta t) \cdot \frac{r_u}{(2d)\,\mathrm{atan}(\frac{\theta}{2})} \ , \quad (3)$$

Confidence Weighting



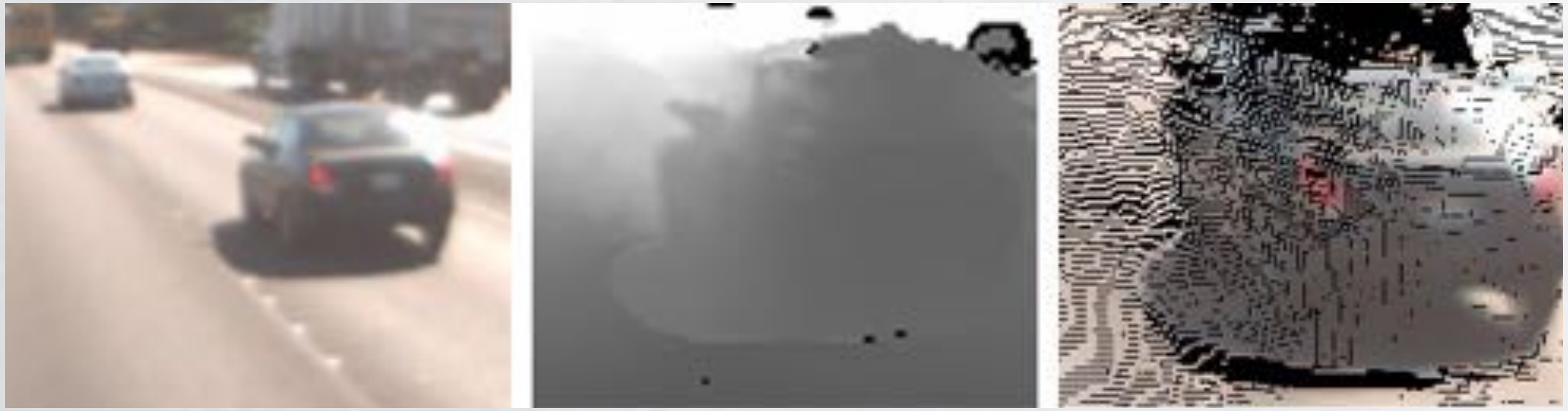



1
2
3
4
5
6
7
Time


highway1
highway2
avenue1
avenue2
synthetic1
synthetic2
synthetic3
synthetic4
RMS of Relative Prediction Error
Gaussian upsampling (u,v)
Joint bilateral upsampling (u,v,r,g,b)
Spatio-temporal upsampling (u,v,t)
Spatio-temporal upsampling with color (u,v,t,r,g,b)
Percentage of available depth data used in reconstruction

Evaluation

√



×

3

Application: Curb Detection

a

b

c

d

e

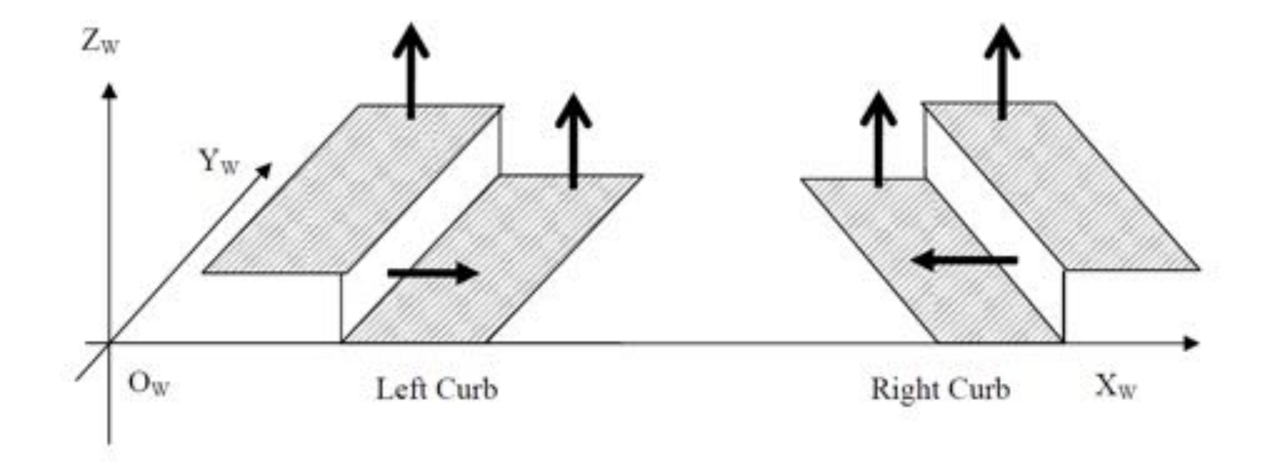
f

Limit the driving area

Map Building and Vehicle Localization

Curb detection & Lane Line Detection

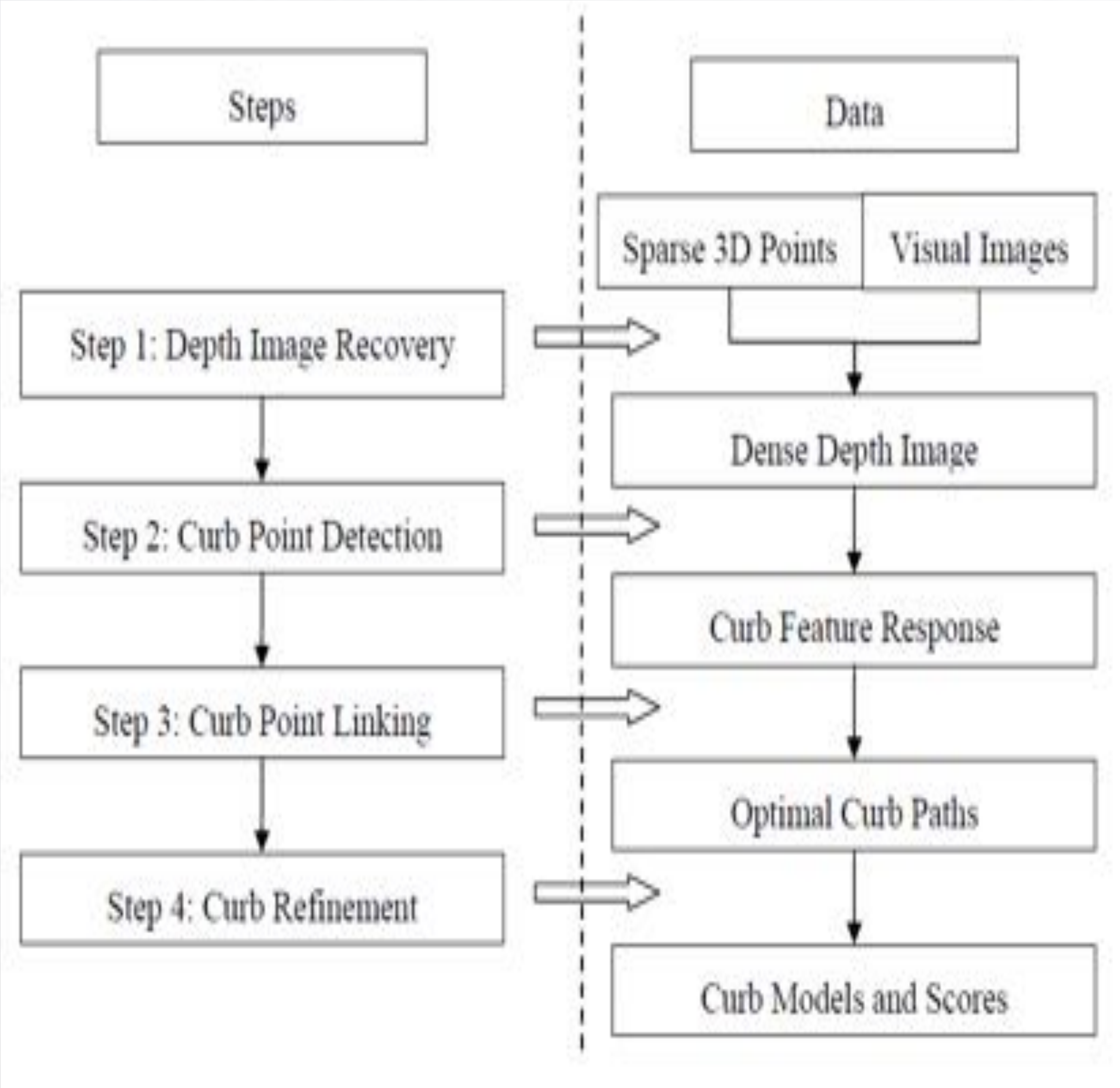
Lidar? Camera?



Geometric Properties:
Height
Normal
Consistency

Image property:
Edge
Variety

Detection Steps

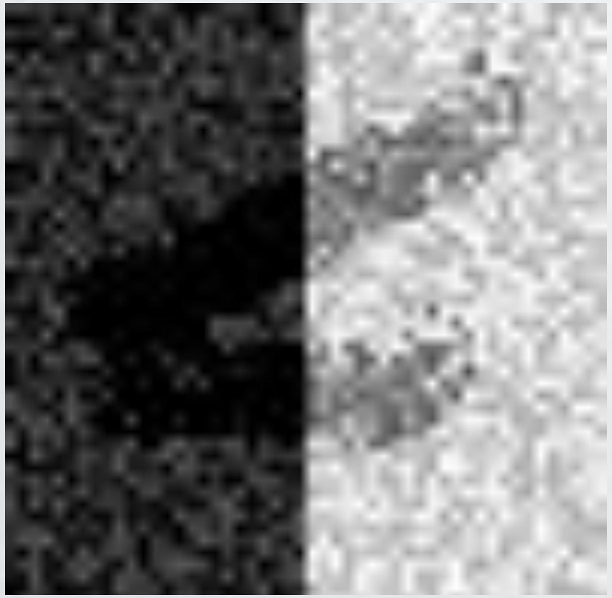


Contributions:

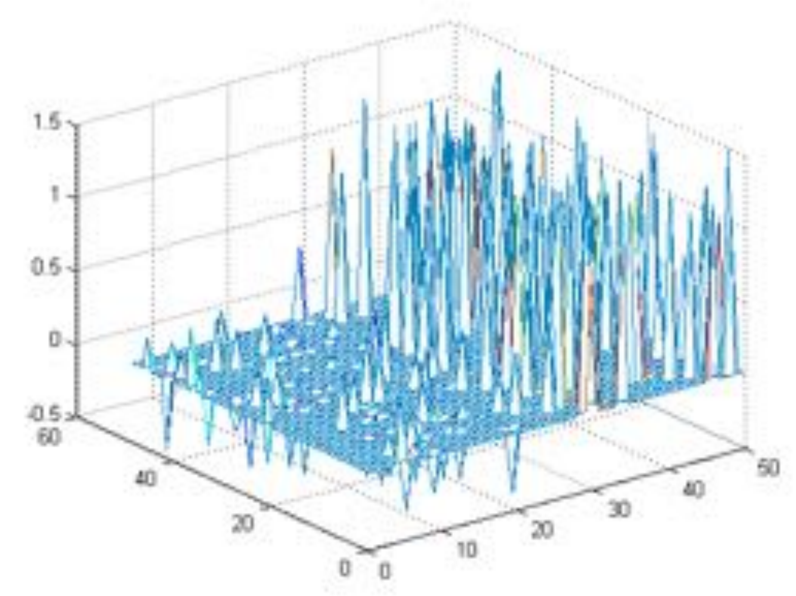
1. The “ first” to use the dense depth map
2. Novel filter-based method
3. Markov Chain model for curb point linking
4. Filtering out the outliers
5. The “ best” result

Example

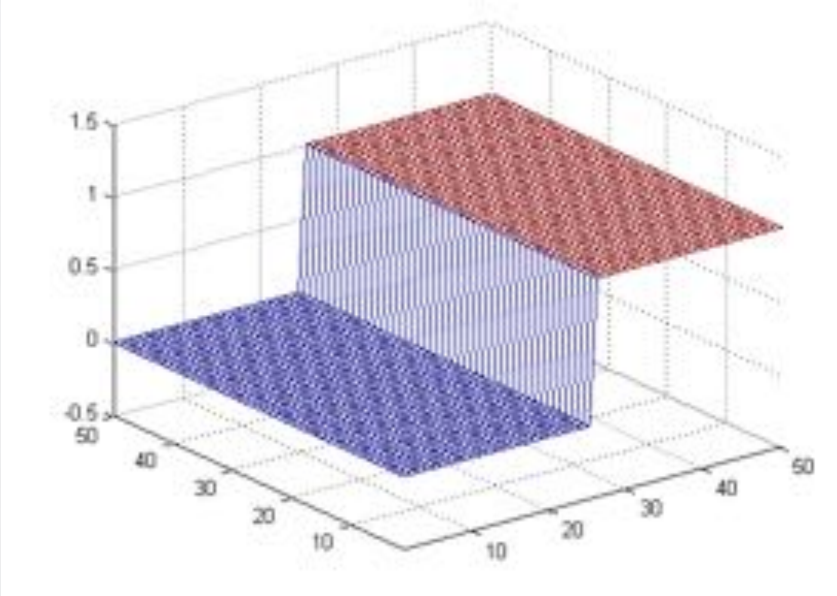
a



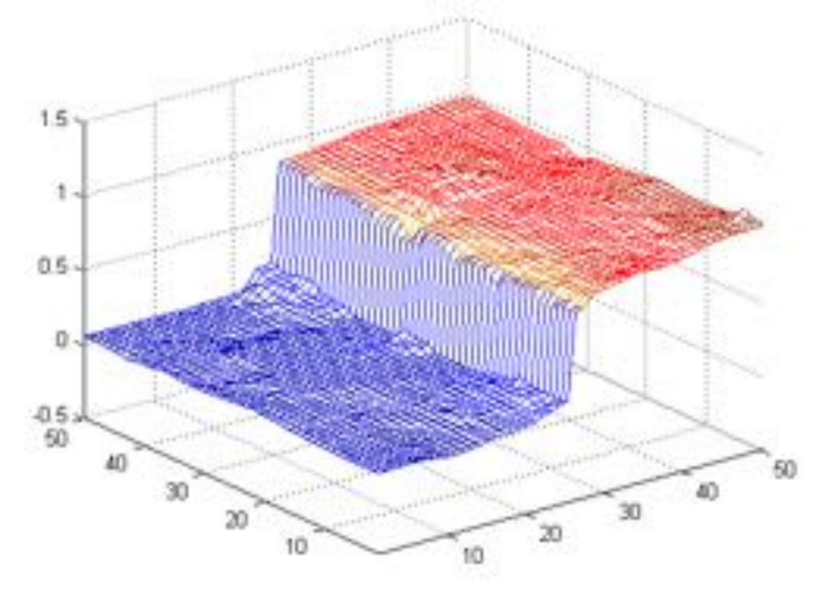
b



c



d

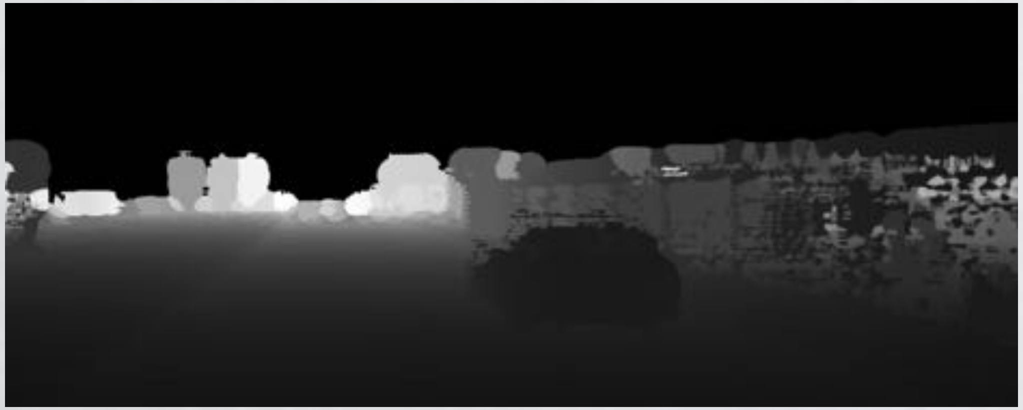


Example

a

b

c



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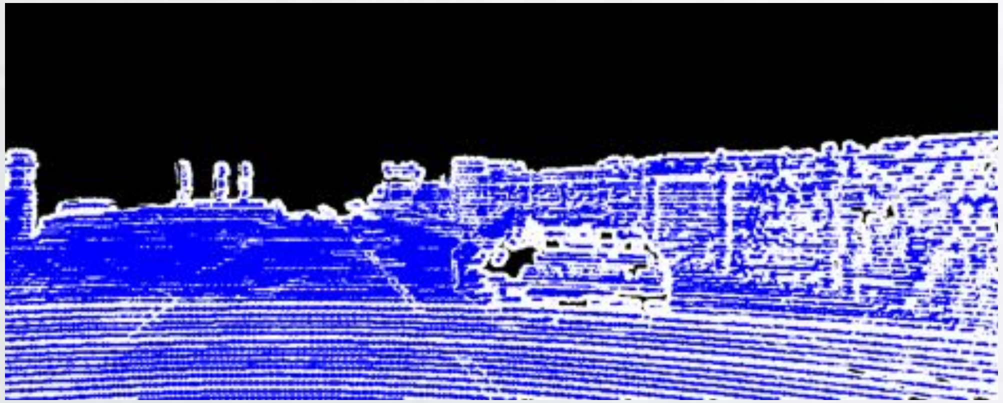
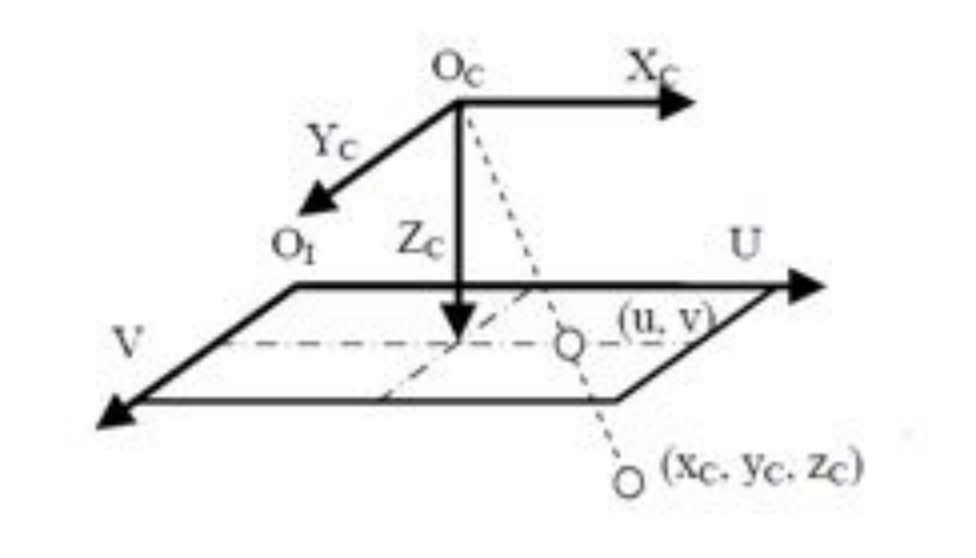




$$u = f_x \times \frac{x_C}{z_C} + c_x$$

$$v = f_y \times \frac{y_C}{z_C} + c_y$$

$$x_C(u,v) = \frac{u - c_x}{f_x} \times d(u,v)$$

$$y_C(u,v) = \frac{v - c_y}{f_y} \times d(u,v)$$

$$z_C(u,v) = d(u,v)$$

$$\begin{bmatrix} x_W \\ y_W \\ z_W \end{bmatrix} = R^{-1} \bullet \left(\begin{bmatrix} x_C \\ y_C \\ z_C \end{bmatrix} - T \right)$$

road region： $z_W < T_z$

$$u = \frac{x}{z} \times f_x + c_x$$

$$v = \frac{y}{z} \times f_y + c_y$$

$$d(u,v) = z$$

$$\nabla \equiv \hat{x}\frac{\partial}{\partial x} + \hat{y}\frac{\partial}{\partial y} + \hat{z}\frac{\partial}{\partial z}$$

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial u}\frac{\partial u}{\partial x} + \frac{\partial}{\partial v}\frac{\partial v}{\partial x} + \frac{\partial}{\partial d}\frac{\partial d}{\partial x}$$

$$\frac{\partial}{\partial y} = \frac{\partial}{\partial u}\frac{\partial u}{\partial y} + \frac{\partial}{\partial v}\frac{\partial v}{\partial y} + \frac{\partial}{\partial d}\frac{\partial d}{\partial y}$$

$$\frac{\partial}{\partial z} = \frac{\partial}{\partial u}\frac{\partial u}{\partial z} + \frac{\partial}{\partial v}\frac{\partial v}{\partial z} + \frac{\partial}{\partial d}\frac{\partial d}{\partial z}$$

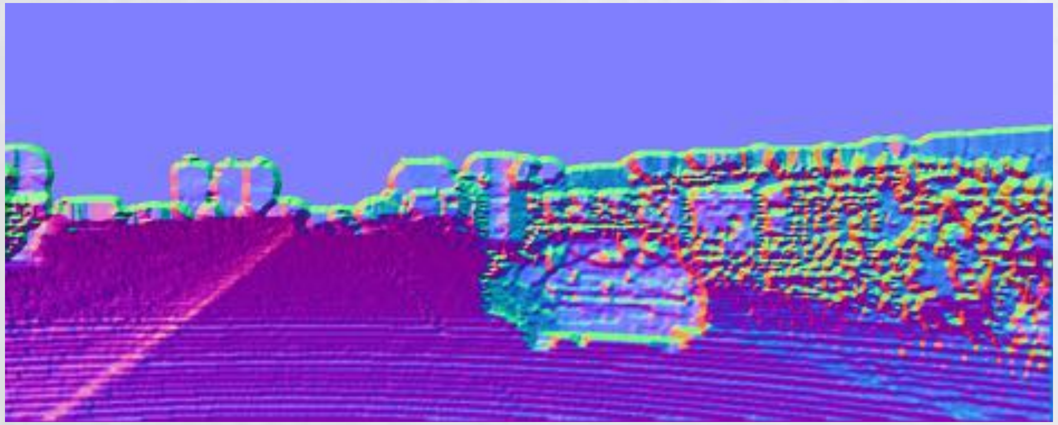
$$Sobel_u = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} / 8$$

$$Sobel_v = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} / 8$$

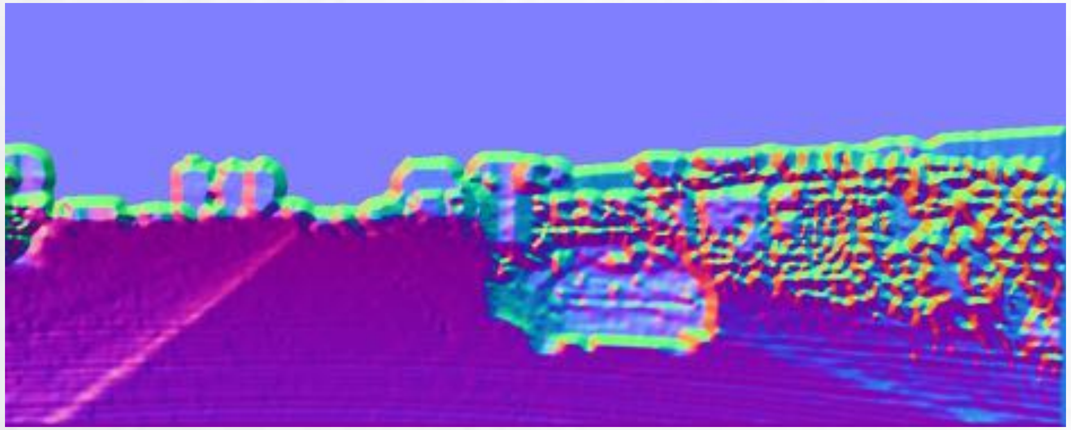
$$\nabla \equiv \begin{bmatrix} \hat{x} & \hat{y} & \hat{z} \end{bmatrix} \bullet \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -\frac{x}{z} & -\frac{y}{z} & 1 \end{bmatrix} \bullet \begin{bmatrix} \frac{\partial}{\partial u} \times \frac{f_x}{z} \\ \frac{\partial}{\partial v} \times \frac{f_y}{z} \\ \frac{\partial}{\partial d} \end{bmatrix}$$

X_w right side Y_w point ahead Z_w upside

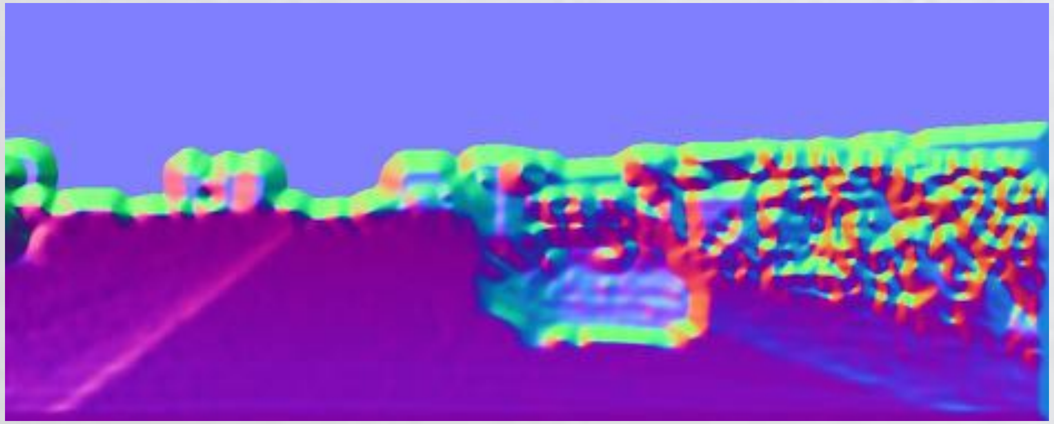
(N_x, N_y, N_z): r=$(N_x+1)/2$, g=$(N_y+1)/2$, b=$(N_z+1)/2$



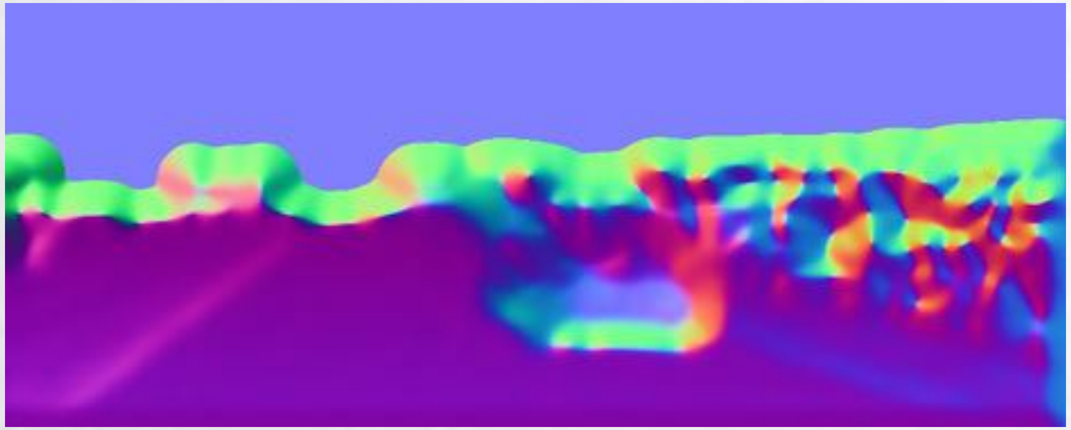
$\sigma_s = 1$



$\sigma_s = 2$

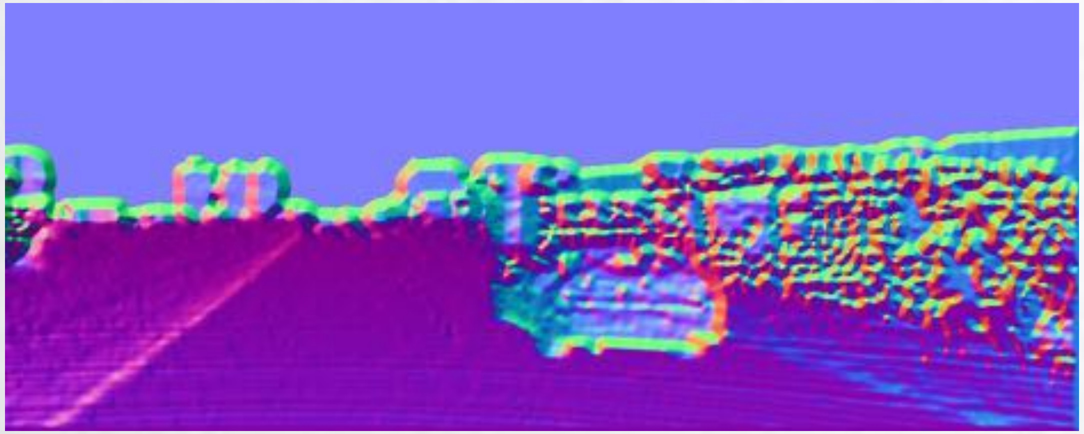


$\sigma_s = 4$

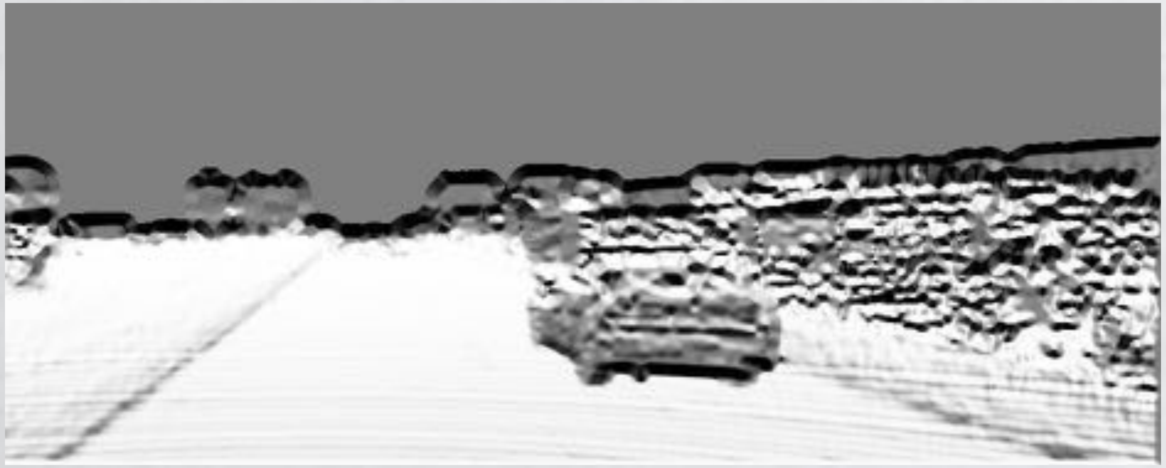


$\sigma_s = 8$

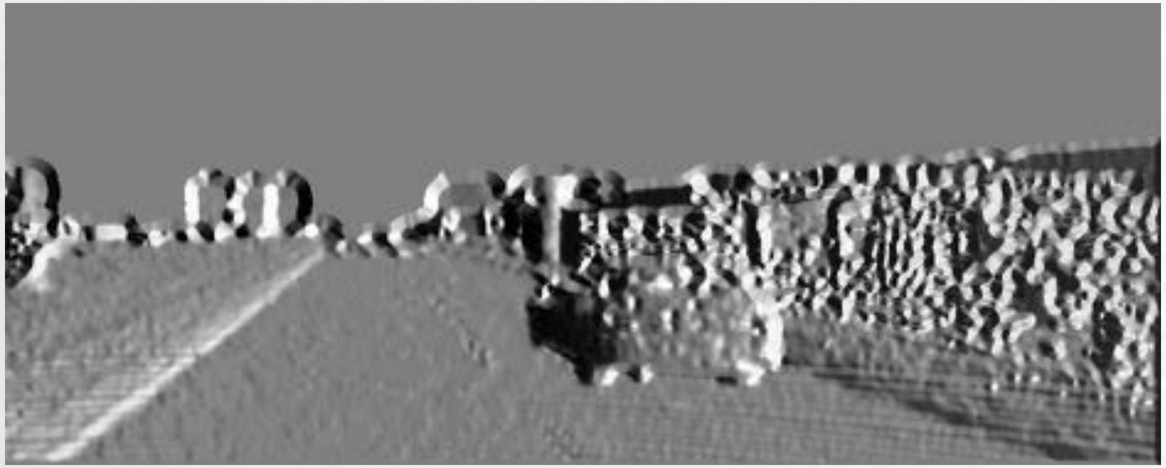
X_w right side
Y_w point ahead
Z_w upside



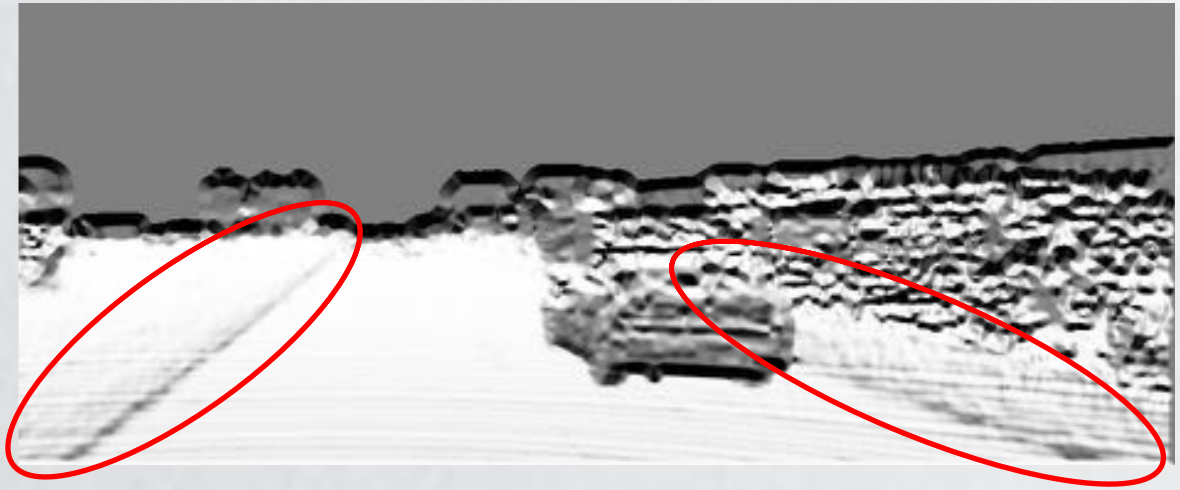
Normal image



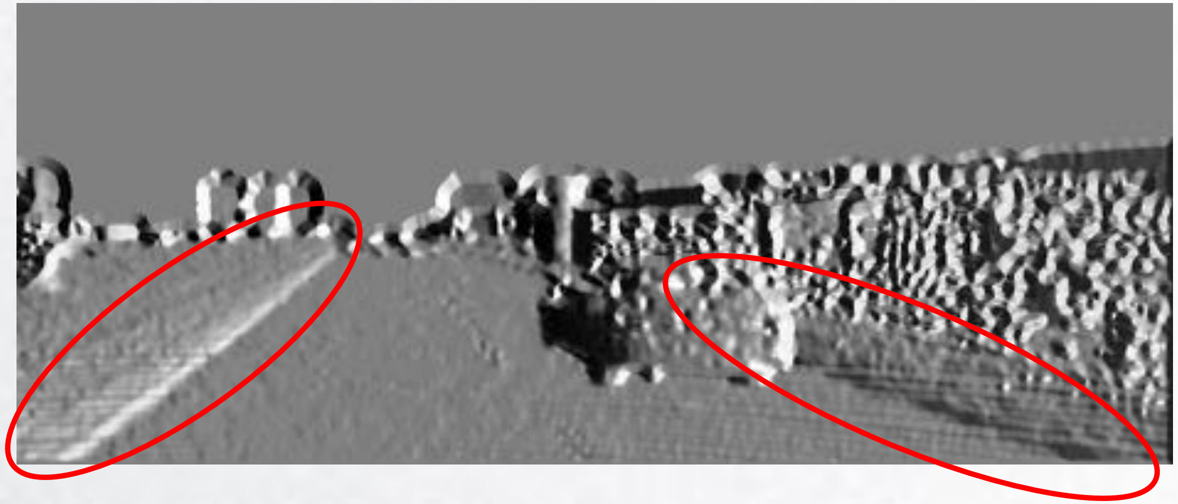
Normal projection in Z_w



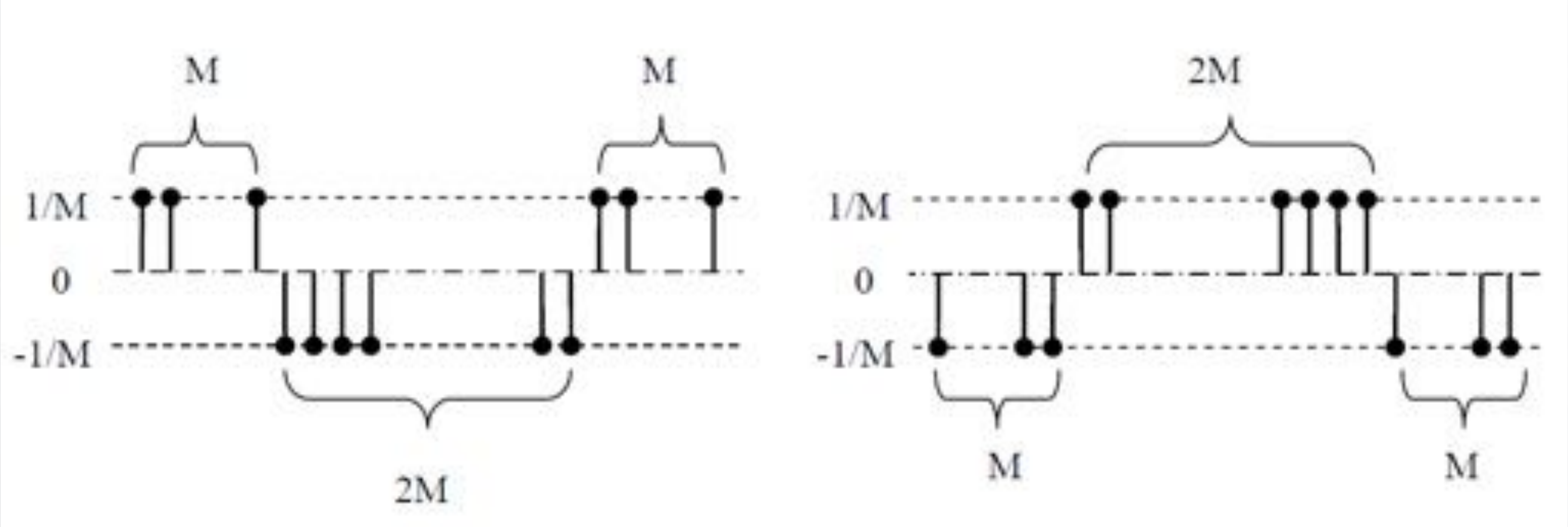
Normal projection in X_w



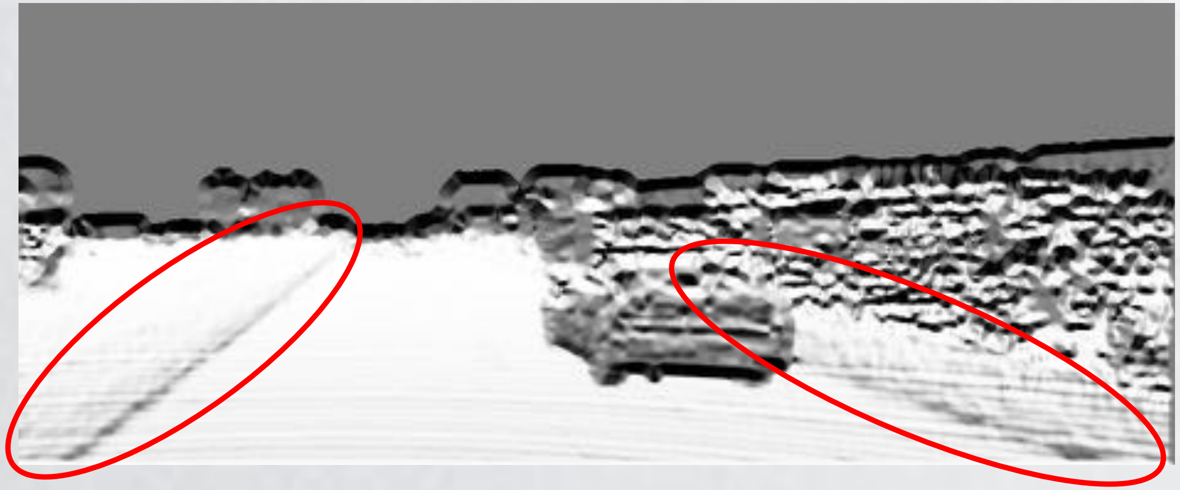
Normal projection in Z_w



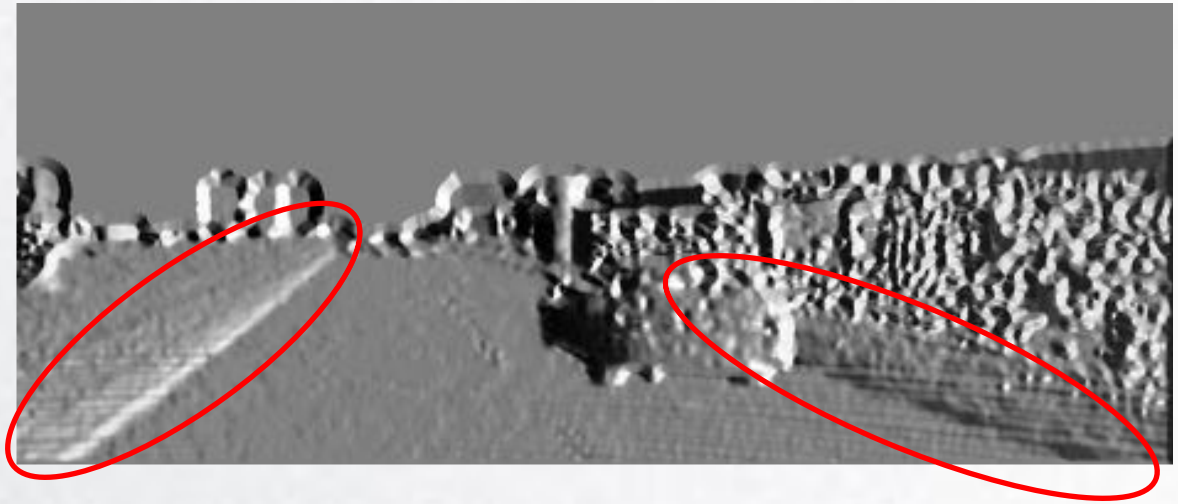
Normal projection in X_w



“bright-dark-bright” pattern & “dark-bright-dark” pattern



Normal projection in Z_w



Normal projection in X_w

Left side curb feature

Right side curb feature

Markov Chain

Economic Predicting, Management decision, Weather forecasting

$$P\{X_{n+1} = j | X_0 = i_0, \dots, X_{n-1} = i_{n-1}, X_n = i_n\} = P\{X_{n+1} = j | X_n = i\}$$

Linking & isolating noises

$$nodePot(X_i^k) = \frac{1}{Z_i} \times (1 - \exp(-(\frac{f_{(i,k)}}{\sigma_n})^2))$$

$$Z_i = \sum_k (1 - \exp(-(\frac{f_{(i,k)}}{\sigma_n})^2))$$

Left

Right

$$edgePot(X_{i+1}^{j}, X_i^k) = e_x(X_{i+1}^{j}, X_i^k) \times e_f(X_{i+1}^{j}, X_i^k)$$

$$e_x(X_{i+1}^{j}, X_i^k) = \exp(-\frac{(j-k)^2}{\sigma_x^2})$$

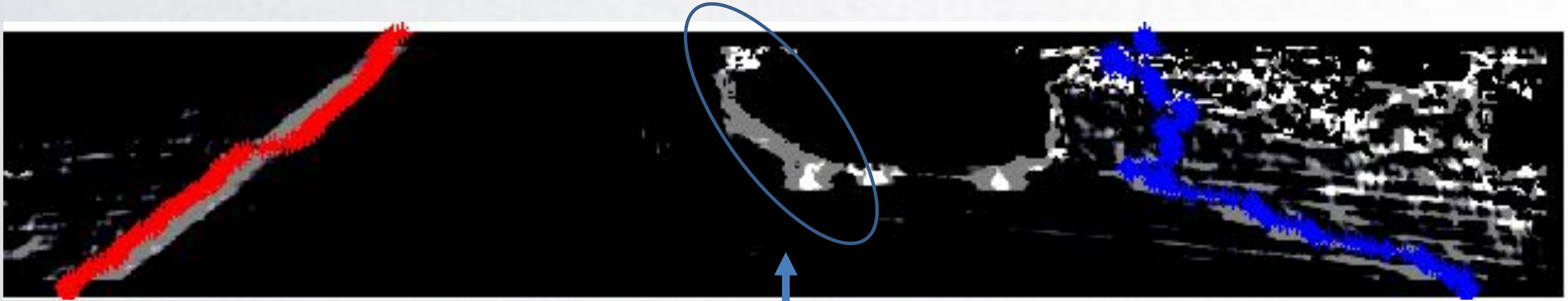
$$e_f(X_{i+1}^{j}, X_i^k) = \exp(-\frac{(f_{(i+1,j)} - f_{(i,k)})^2}{\sigma_f^2})$$

Position and Feature

$$p(X_{i+1}^{j}) = nodePot(X_{i+1}^{j}) \times \max_{k \in N(j)}(p(X_i^k) \times edgePot(X_i^k, X_{i+1}^{j}))$$

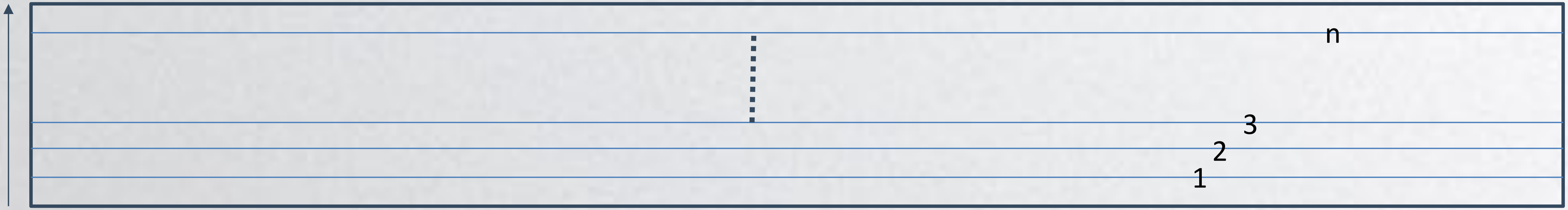
$$link(X_{i+1}^{j}) = \arg_k \max_{k \in N(j)}(p(X_i^k) \times edgePot(X_i^k, X_{i+1}^{j}))$$

Linking



Why not?

Because the program functions row by row.



Refinement

Curve-fitting

$$u = a \times v^2 + b \times v + c$$

Weighted Curve-fitting

$$\min_{a,b,c} \sum_i w_i \times (u_i - a \times v_i^2 - b \times v_i - c)^2$$

Weighted Least Square Method

$$\begin{bmatrix} \sum_i w_i \times u_i \times v_i^2 \\ \sum_i w_i \times u_i \times v_i^1 \\ \sum_i w_i \times u_i \times 1 \end{bmatrix} = \begin{bmatrix} \sum_i w_i \times v_i^4 & \sum_i w_i \times v_i^3 & \sum_i w_i \times v_i^2 \\ \sum_i w_i \times v_i^3 & \sum_i w_i \times v_i^2 & \sum_i w_i \times v_i^1 \\ \sum_i w_i \times v_i^2 & \sum_i w_i \times v_i^1 & \sum_i w_i \times 1 \end{bmatrix} \bullet \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

Results & Scores

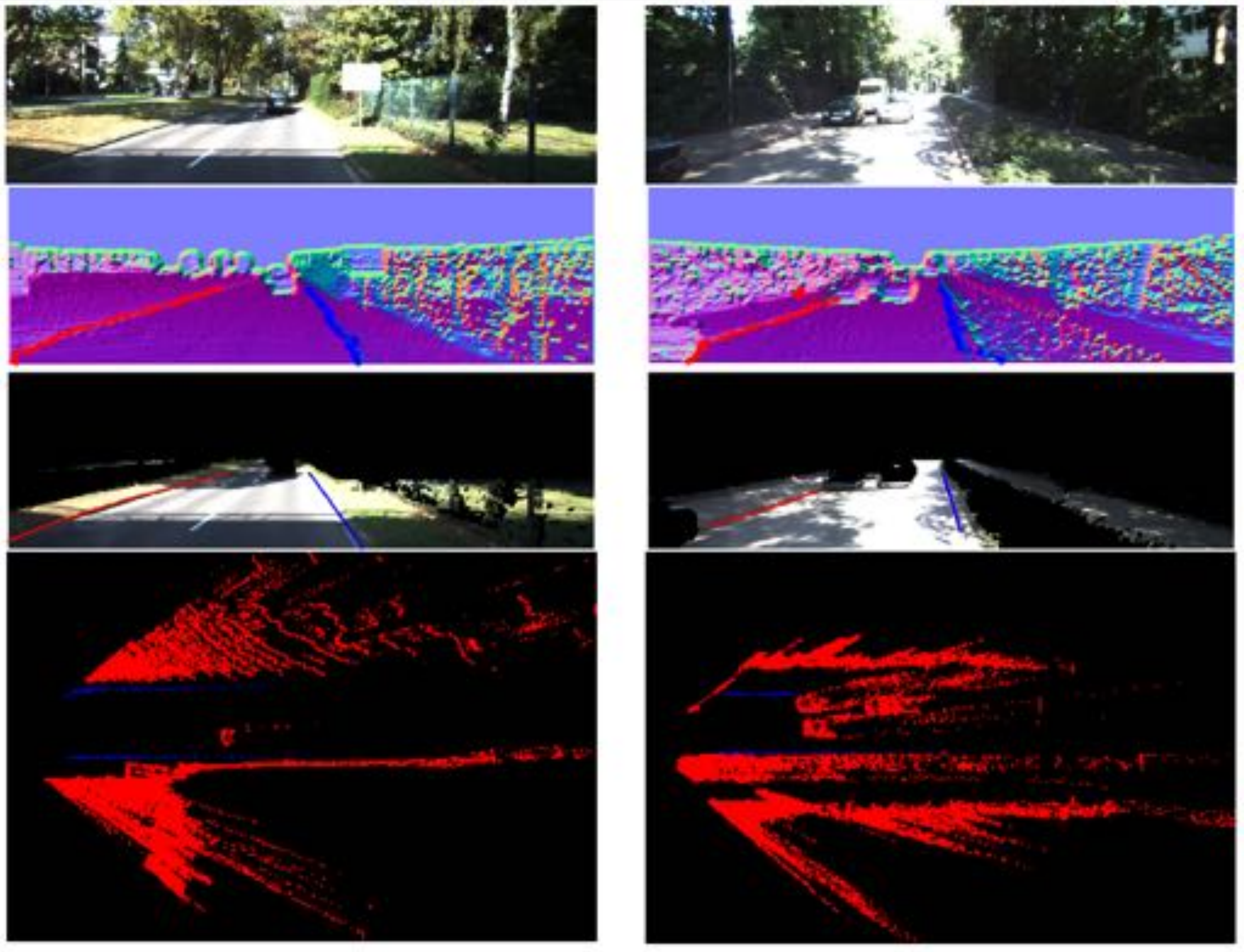
$$score = \sum_i w_i \times \exp\left(-\frac{(u_i - a \times v_i^2 - b \times v_i - c)^2}{\sigma_{sc}^2}\right)$$

Left score = 36.6604

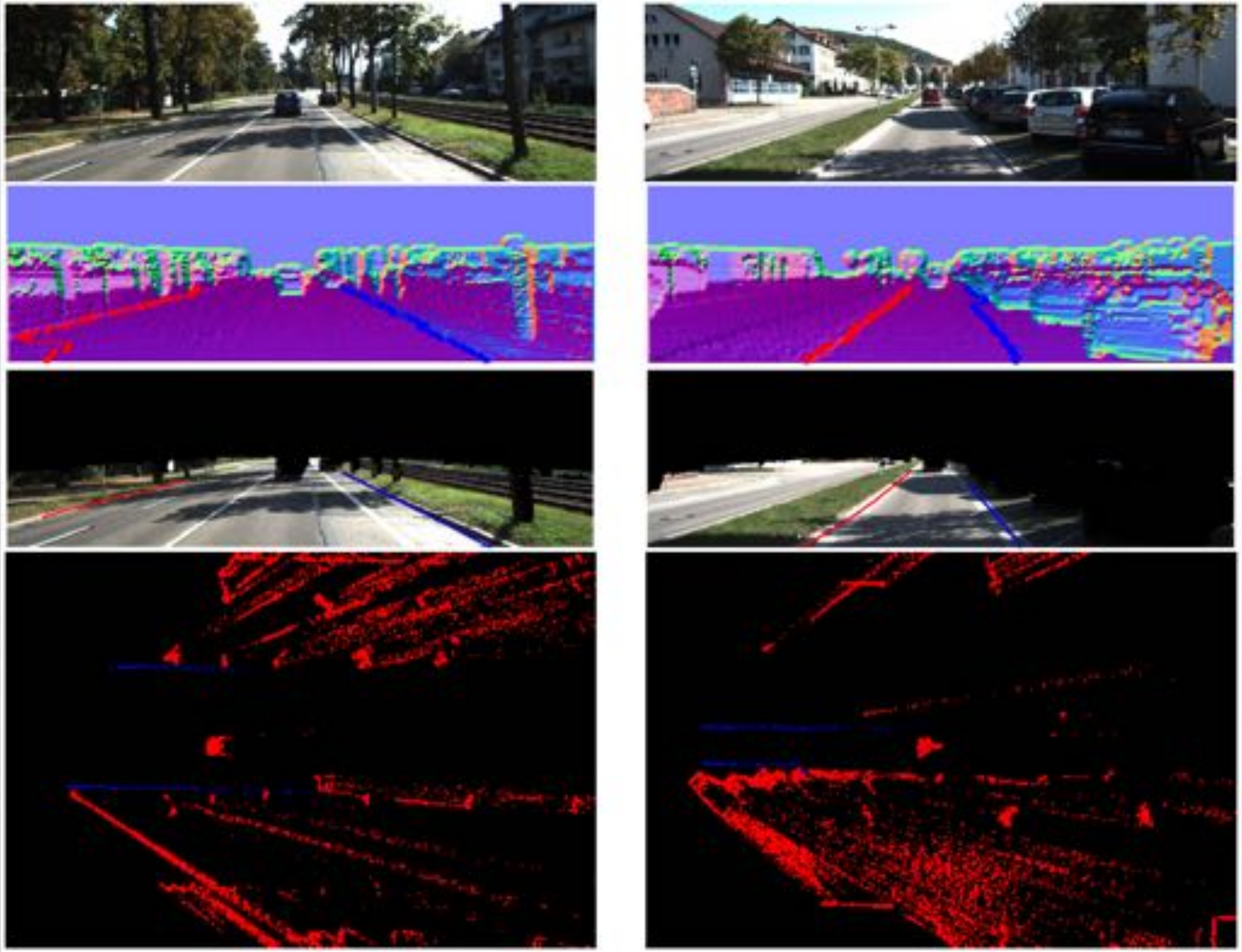
Right score = 12.7776

4 Discussion

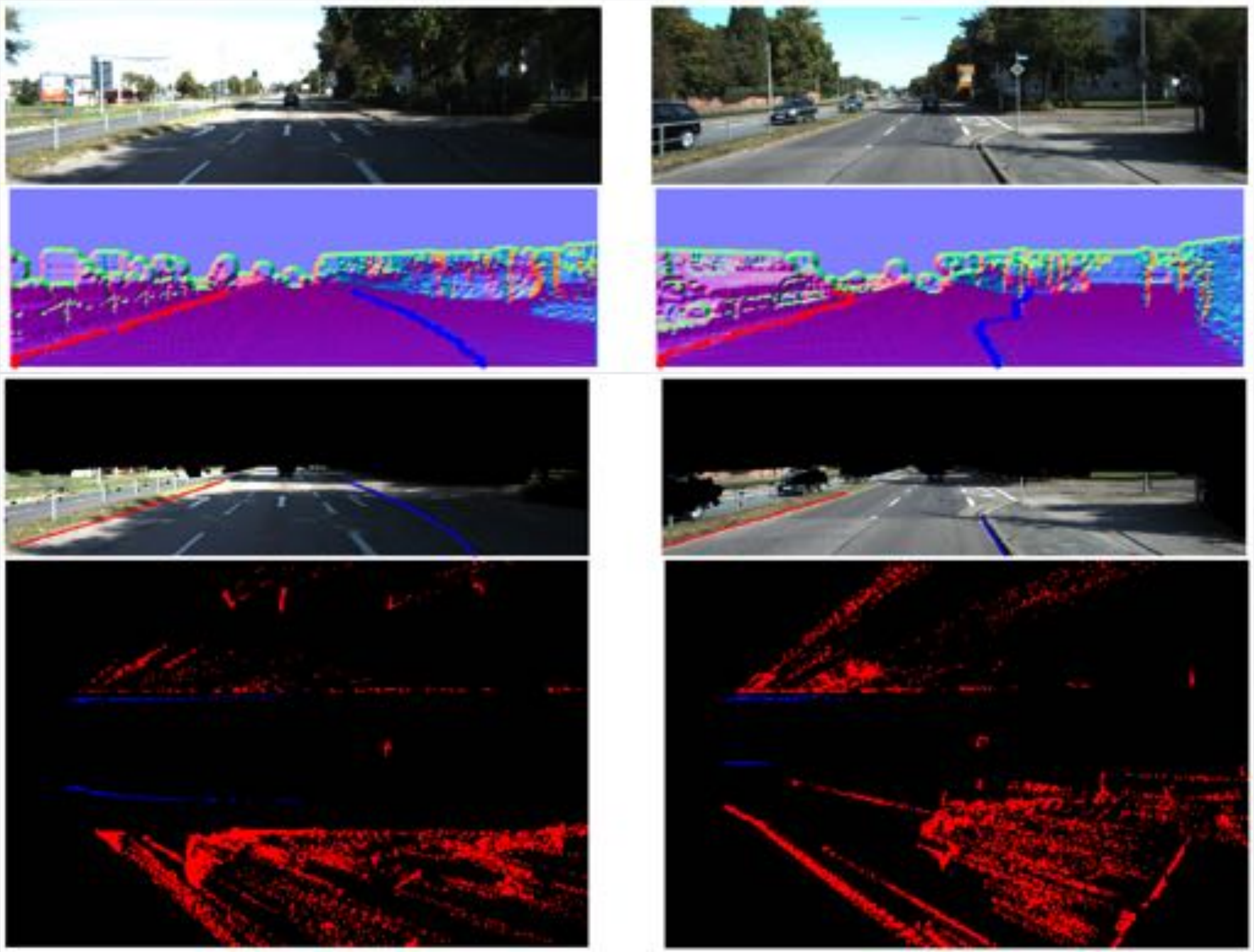
Illumination Change and Strong Shadow



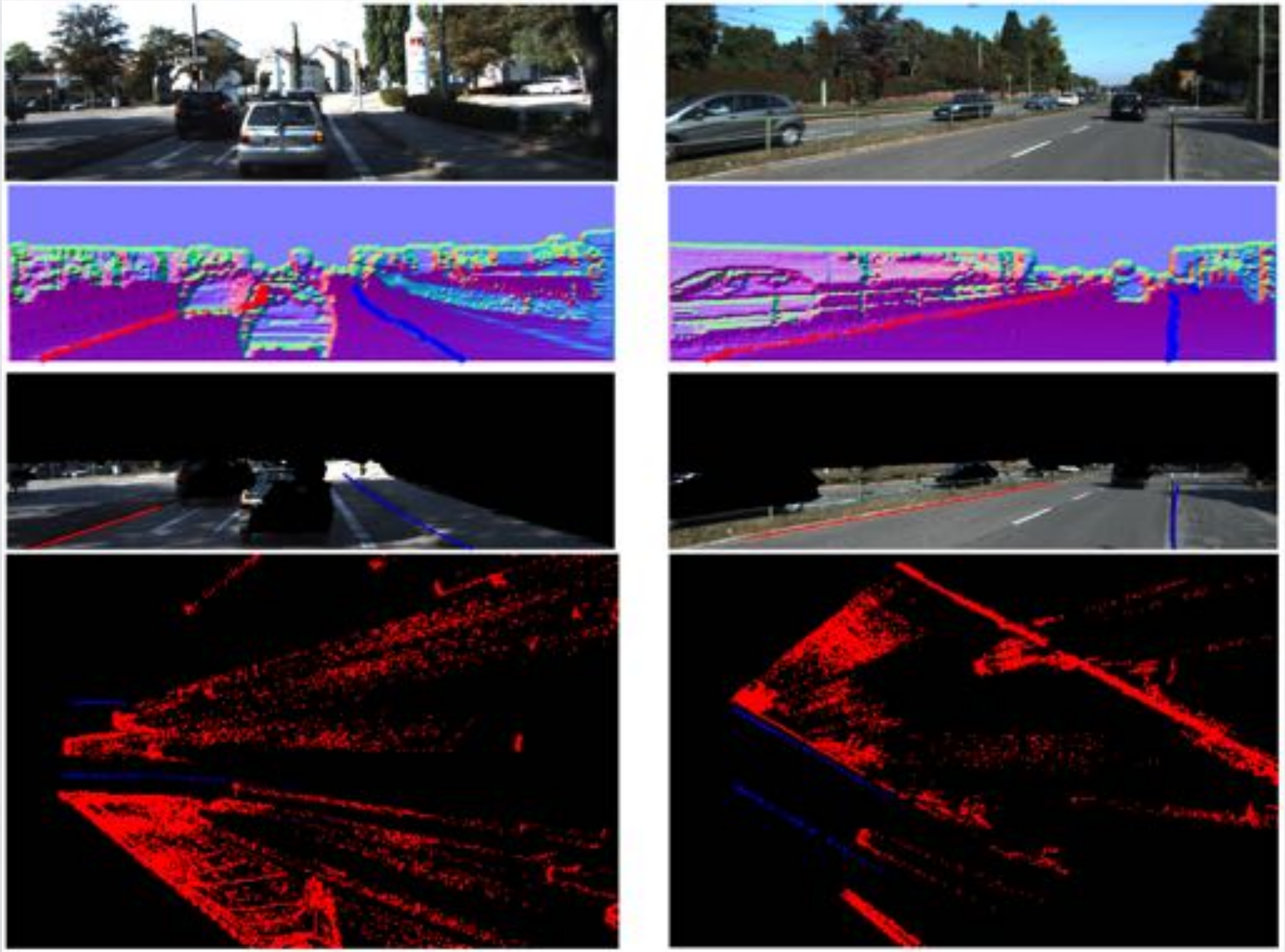
Different Road Widths



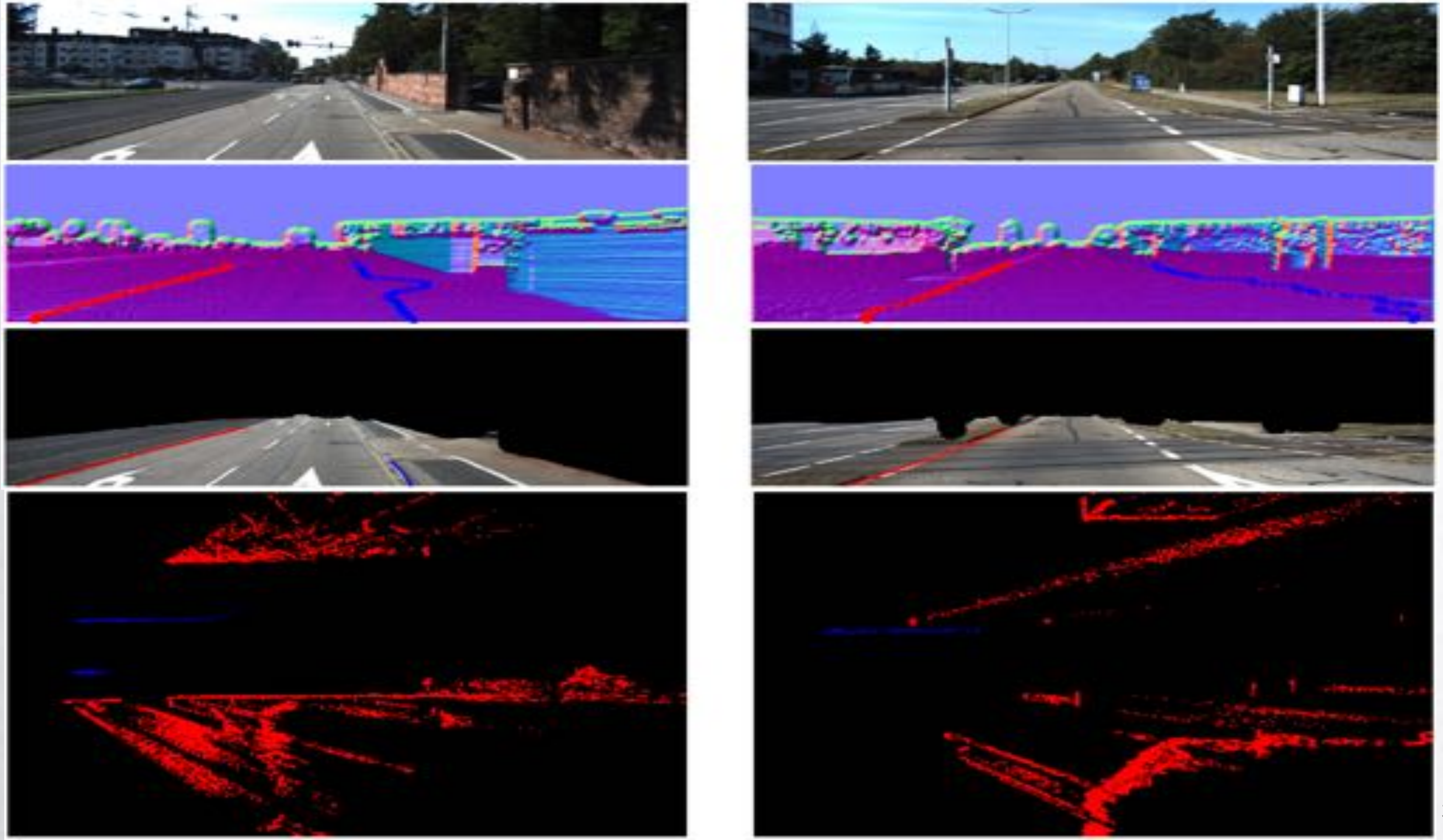
Straight and Curved Curbs of Different Lengths



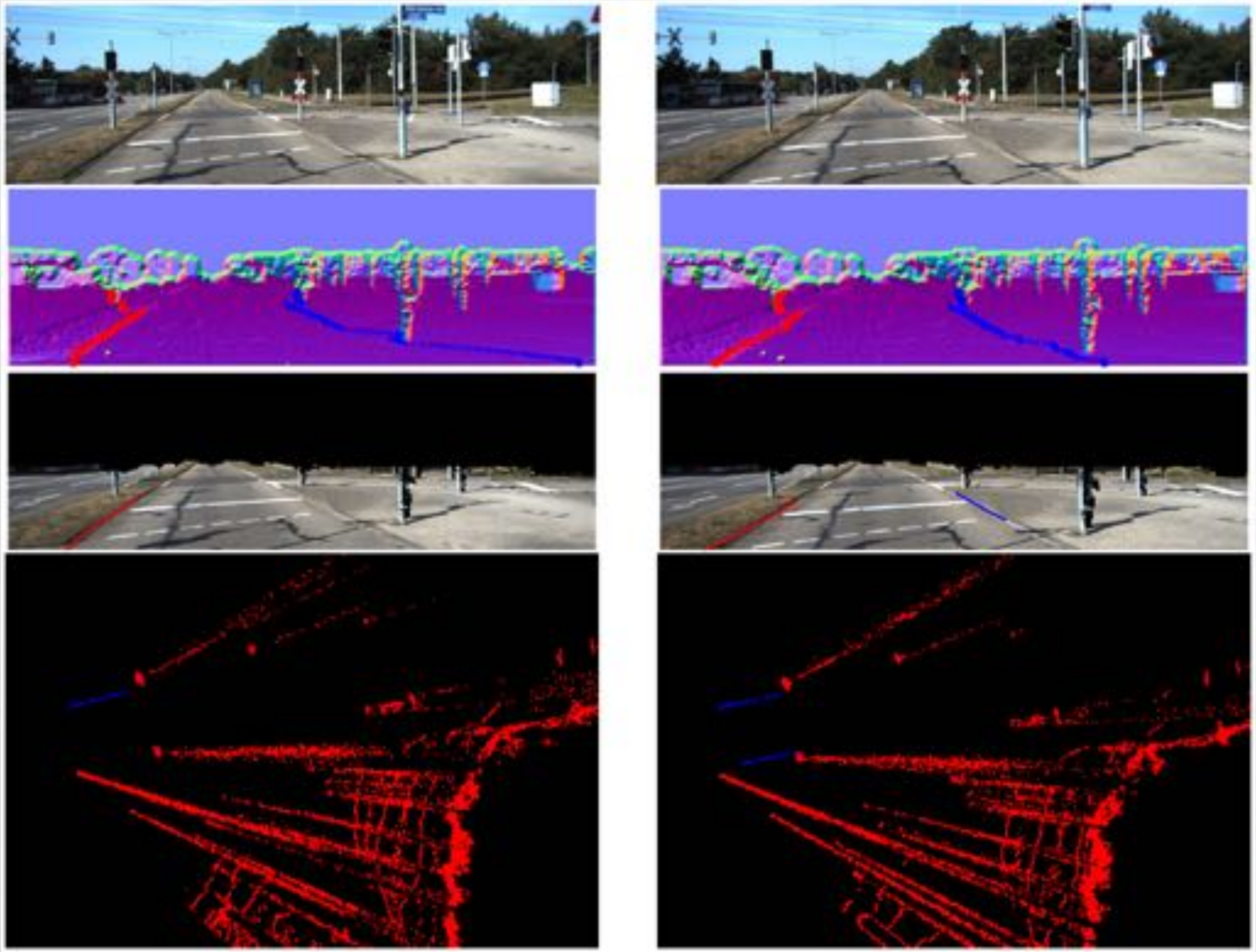
Vehicle Direction Change



Broken Curbs



Missed Curbs



Map building
Vehicle localization
Fusion with more sensors

THANK YOU