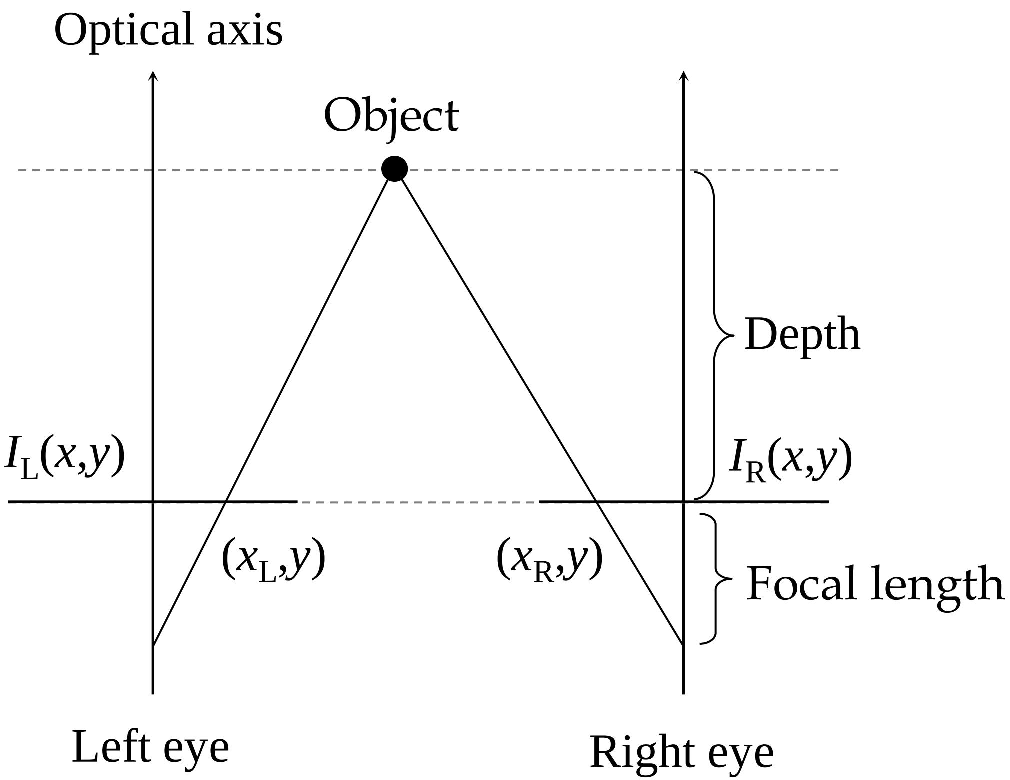
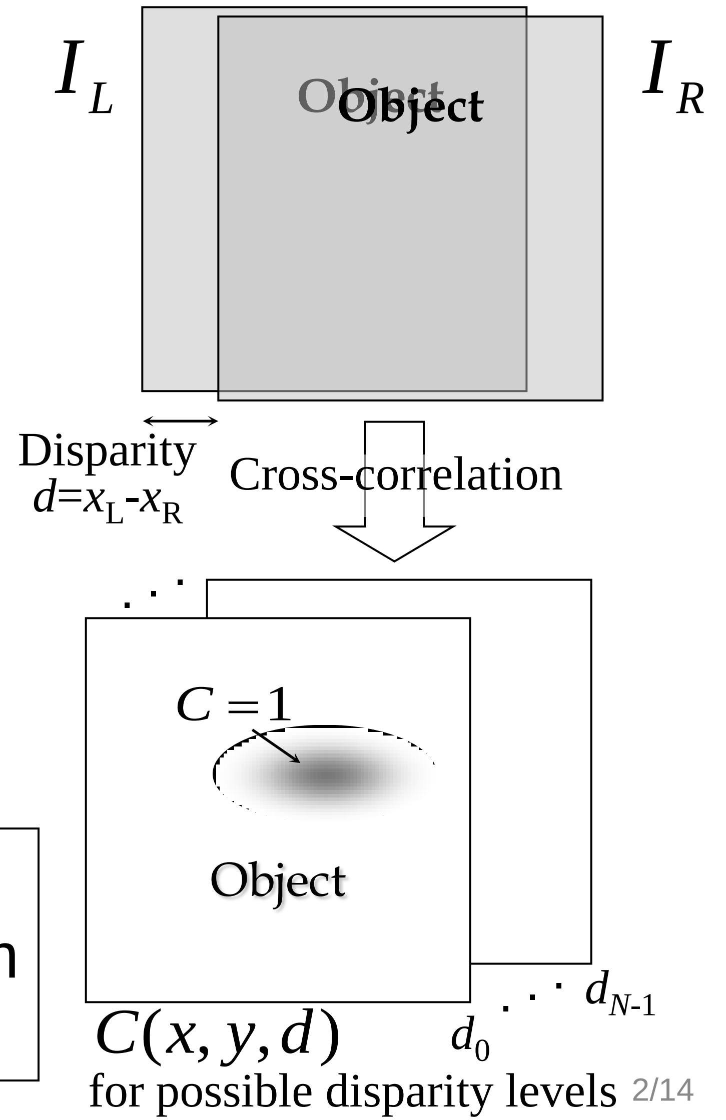
REACTION-DIFFUSION STEREO ALGORITHM WITH ANISOTROPIC INHIBITORY DIFFUSION

Atsushi Nomura[1)] Makoto Ichikawa[2)]
Koichi Okada[1)] Hidetoshi Miike[1)]
[1)]Yamaguchi University, Japan
[2)]Chiba University, Japan

Introduction: Binocular Stereo Vision





Stereo correspondence problem

⇒ Segmentation problem

Depth discontinuity areas cause error.

Previous Stereo Algorithms

- Marr & Poggio, *Proc. Roy. Soc. Lond.*, 1979
  - original cooperative algorithm
  - continuity & uniqueness constraints
  - bio-inspired algorithm
- Zitnick & Kanade, *IEEE-PAMI*, 2000
  - modern cooperative algorithm + occlusion detection
- Sun et al., *IEEE-PAMI*, 2003
  - belief-propagation algorithm
- Deng et al., *IEEE-PAMI*, 2007
  - graph-cuts algorithm

Diffusion Equation & PDE Approach in Image Processing & Computer Vision Research

- Koenderink, *Biol. Cybern.*, 1984
  - Diffusion equation = Gaussian filter
- Perona & Malik, *IEEE-PAMI*, 1990
- Black et al., *IEEE-IP*, 1998
  - Anisotropic diffusion
- Mrázek & Navara, *IJCV*, 2003
  - Stopping time for non-linear diffusion filtering

Isotropic diffusion equation:

$$\partial_t u = D\nabla^2 u + s$$

D: diffusion coefficient, *s*: source

=> uniform distribution

Anisotropic diffusion equation:

$$\partial_t u = \nabla \cdot [D(x,y)\nabla u] + s$$

D(x,y): anisotropic diffusion coefficient

diffusion depends on a position (x,y)

$$\partial_t = \partial / \partial t, \nabla^2 : \text{Laplacian Operator}$$

Reaction-Diffusion Algorithm

- Adamatzky et al., *Reaction-Diffusion Computers*, 2005
  - proposed novel computer architecture, by utilizing reaction-diffusion equations.
  - natural computing.
- FitzHugh-Nagumo reaction-diffusion equations

$$\partial_t u = D_u \nabla^2 u + \frac{1}{\varepsilon}\left[u(u-a)(1-u) - v\right]$$

$$\partial_t v = \underbrace{D_v \nabla^2 v}_{\text{Diffusion}} + \underbrace{u - bv}_{\text{Reaction}}$$

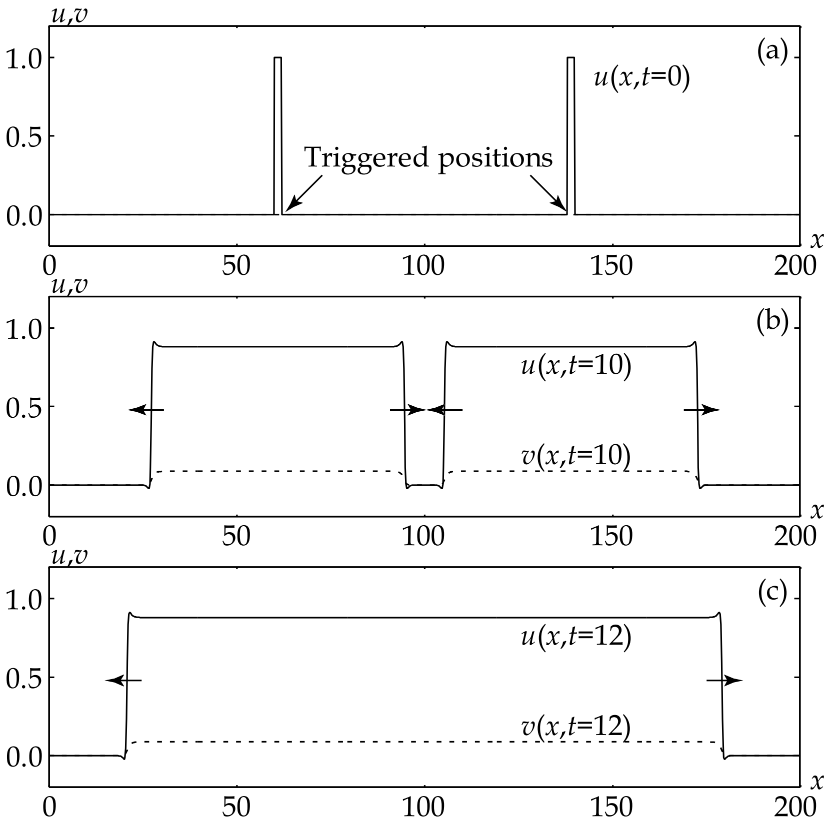
Constants:
$0<\varepsilon<<1$
a, b

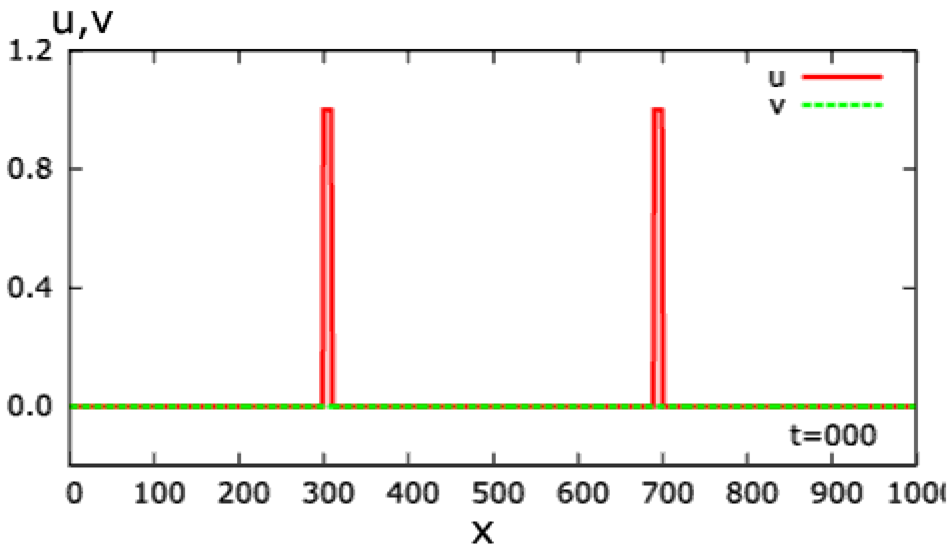
u: activator, v: inhibitor

FitzHugh, *Biophysical J.*, 1961
Nagumo et al., *Proc. IRE*, 1962

Reaction-Diffusion Equations in 1D Space

- FitzHugh-Nagumo equations: bi-stable system





Parameter settings:
D_u=1.0, D_v=3.0
a=0.05, b=10.0, ε=1/100

Reaction-Diffusion Stereo Algorithm

- Nomura et al., *Machine Vision and Applications* (2009)

$$\partial_t u_n(x,y,t) = D_u \nabla^2 u_n + f(u_n, v_n, u_{\max}) + \mu C(x,y,d_n)$$

$$\partial_t v_n(x,y,t) = D_v \nabla^2 v_n + g(u_n, v_n)$$

The diffusion term $D_u\nabla^2 u_n$ drives the propagation of region of the disparity level d_n.

$$f(u_n, v_n, u_{\max}) = \frac{1}{\varepsilon}\left[u_n(u_n - a(u_{\max}))(1-u_n) - v_n\right]$$

$$g(u_n, v_n) = u_n - b v_n$$

Disparity map:

$$M(x,y,t) = \operatorname*{argmax}_{n\in\{0,1,\cdots,N-1\}} u_n(x,y,t)$$

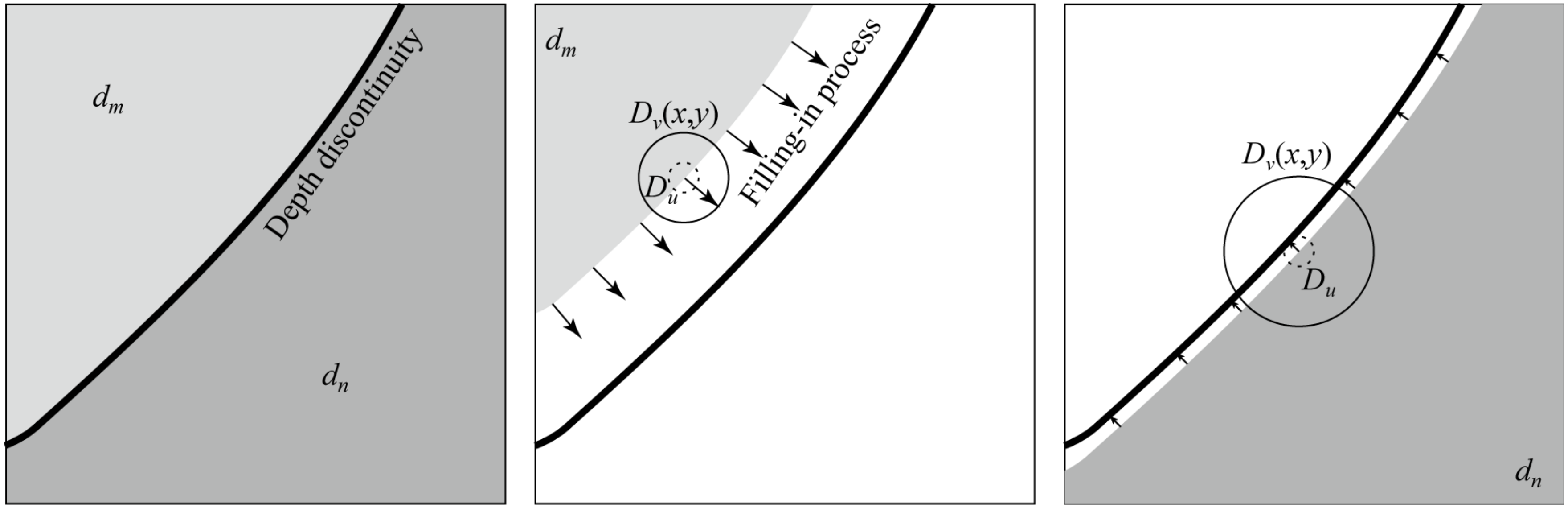
μ: constant
N: total number of possible disparity levels
C: similarity measure
d_n: disparity level

Proposed Reaction-Diffusion Stereo Algorithm

$$\partial_t u_n = D_u \nabla^2 u_n + f(u_n, v_n, u_{\max}) + \mu C(x, y, d_n)$$

$$\partial_t v_n = \nabla \cdot \underline{\left[D_v(x, y) \nabla v_n \right]} + g(u_n, v_n)$$

The diffusion coefficient $D_v(x,y)$ is set to be large around depth-discontinuity areas.



(a) Stereo disparity map (b) *m*-th reaction-diffusion system (c) *n*-th reaction-diffusion system

How to Estimate the Inhibitory Diffusion Coefficient $D_v(x,y)$

Initial disparity map

+

Edges detected from intensity image

Edge detection algorithm with reaction-diffusion equations:

- Nomura et al., *J. Phys. Soc. Jpn.*, 2003
  - Edge detection & Segmentation
  - Discrete version of reaction-diffusion equations
  - Thresholding
- Nomura et al., *Patt. Recog. Image Anal.*, 2008
  - Edge detection utilizing reaction-diffusion equations
  - Adaptive threshold level

Proposed Reaction-Diffusion Stereo Algorithm (cont.)

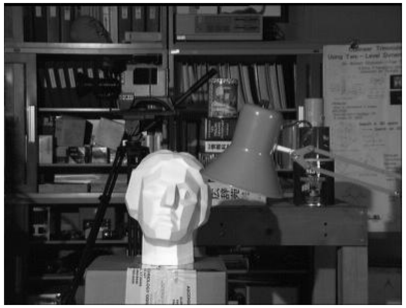
- Step 1: Compute cross-correlation functions.
- Step 2: Detect edges in the left image.
- Step 3: Estimate $D_v(x,y)$ with an initial disparity map and an edge map.
- Step 4: Compute reaction-diffusion equations iteratively.
- Step 5: Estimate a disparity map.

Experimental Results

- The Middlebury stereo vision page provides
  - stereo image pairs,
  - ground-truth data of disparity maps,
  - definition of areas (occlusion area & depth discontinuity),
  - scores of other stereo algorithms
  - http://vision.middlebury.edu/stereo/
- Example of stereo image pairs

CONES 450X375 pixels
60 disparity levels

TEDDY 450X375 pixels
60 disparity levels



TSUKUBA
384X288 pixels
15 disparity levels

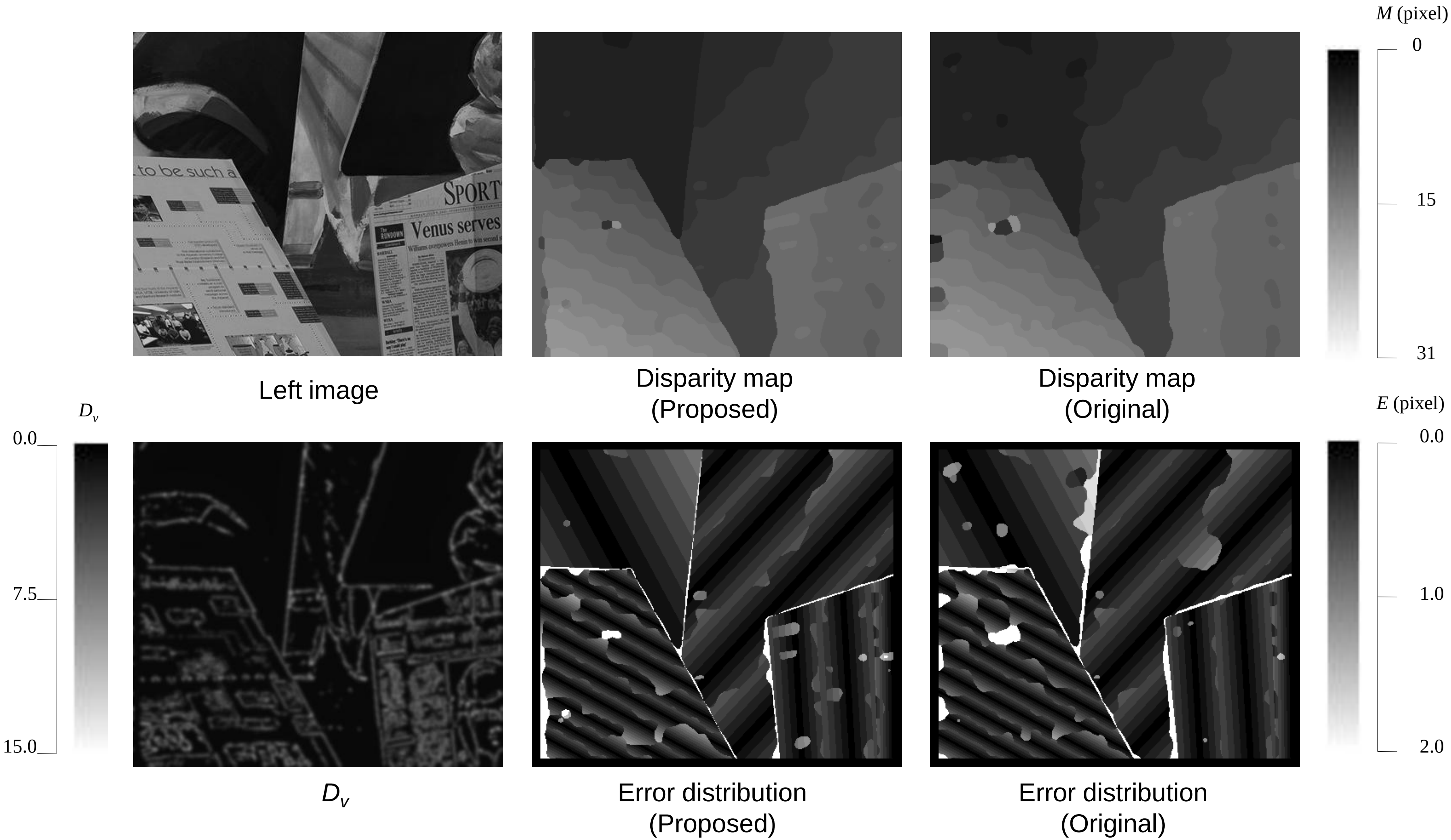
VENUS 434X383 pixels
30 disparity levels

Results on the Middlebury Stereo Data

Algorithm		Reaction-diffusion stereo algorithm						Adapting BP (Klaus et al., *Proc. ICPR*, 2006)
version		Original (Nomura et al., *Mach. Vis. Appl.*, 2009)		IIEI (Nomura et al., *Proc. VISAPP*, 2009)		Proposed		
Image pair	Area	BMP (%)	RMS (pixel)	BMP (%)	RMS (pixel)	BMP (%)	RMS (pixel)	BMP (%)
TSUKUBA	nonocc.	6.77	1.42	8.51	1.54	7.02	1.47	1.11
	all	8.53	1.61	10.23	1.72	8.54	1.64	1.37
	disc.	18.68	2.47	19.42	2.52	18.55	2.60	5.79
VENUS	nonocc.	2.81	0.75	3.17	0.77	1.21	0.59	0.10
	all	3.97	0.92	4.33	0.92	2.44	0.80	0.21
	disc.	**21.64**	**2.01**	**19.62**	**1.88**	**8.12**	**1.52**	1.44
TEDDY	nonocc.	14.26	2.19	14.00	2.38	14.56	2.29	4.22
	all	20.26	3.23	20.00	4.36	20.64	3.32	7.06
	disc.	29.19	3.36	28.89	3.48	27.98	3.45	11.8
CONES	nonocc.	5.03	1.94	5.08	1.85	5.21	1.88	2.48
	all	12.13	3.08	12.35	5.45	13.34	3.15	7.92
	disc.	14.06	3.34	13.67	3.03	14.08	3.17	7.32

nonocc.: non-occlusion area, all: all area, disc.: depth discontinuity area
BMP: bad-match-percentage, RMS: Root Mean Squares

Example: VENUS



Conclusion & Future Work

- Conclusion:
  - We proposed integration of intensity edge information into the reaction-diffusion stereo algorithm.
  - Key point: inhibitory diffusion coefficient is set to be large around depth discontinuity areas.
  - We confirmed performance of the proposed algorithm.
- Future work:
  - How to estimate depth discontinuity areas.
  - Dynamic interactions between disparity detection and edge detection.

Acknowledgments:
The present study was supported in part by the Grant-in-Aid for Scientific Research (C) (No. 20500206) from the Japan Society for the Promotion of Science.