

A Directionally Selective Small Target Motion Detecting Visual Neural Network in Cluttered Backgrounds

Hongxin Wang

University of Lincoln



29-09-2017

Content

- 1 Introduction
- 2 Biological Background
- 3 Motivation
- 4 Directional Selective Small Target Motion Detector (DSTMD)
- 5 Experimental Results

Introduction



Figure 1: A representative frame of an input image sequence. A small target is located in the red circle. Red arrow V_B denotes the motion direction of the background.

Introduction

Figure 2: An input image sequence

Biological Background

- Detecting small targets in naturally cluttered backgrounds is critical for many insect species to search for mates or track their prey.
- In fly visual system, a class of specific neurons, called small target motion detectors (STMDs), have been identified showing exquisite selectivity for small target motion.

Biological Background

- STMD neurons give peak responses to targets subtending $1 - 3^\circ$ of the visual field, with no response to larger bars (typically $> 10^\circ$) or to wide-field grating stimuli. (**Size Selectivity**)
- Some STMD neurons respond strongly to small target motion oriented along a preferred direction, but show weak or no response to null-direction motion. Null direction is 180° from the preferred direction. (**Direction Selectivity**)

Motivation

- Wiederman et. al. [1] proposed elementary small target motion detector (ESTMD) to account for size selectivity of STMD neurons.
(No Direction Selectivity)
- Little has been done on systematic modeling these directional selective STMD neurons.
- In the first part of our work, we proposed a directional selective STMD-based neural network (DSTM D) for small target detection in cluttered background.

DSTMD

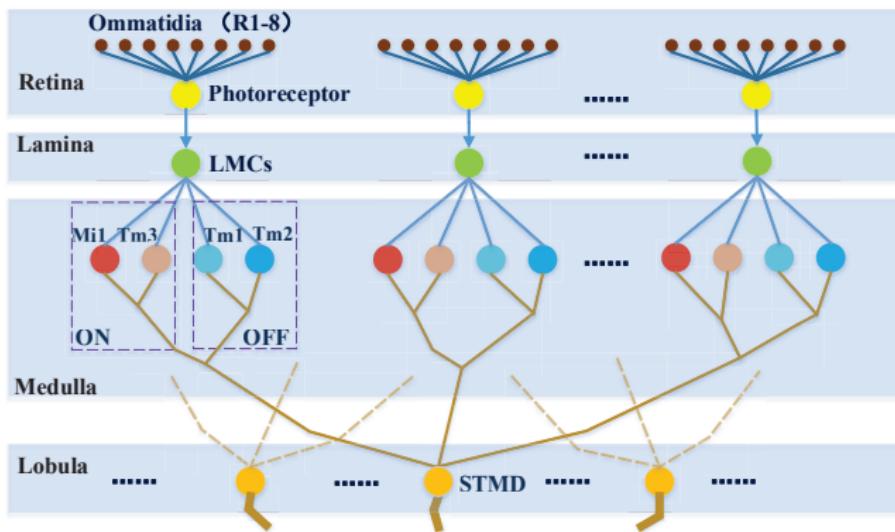


Figure 3: Schematic illustration of fly visual system.

DSTMD

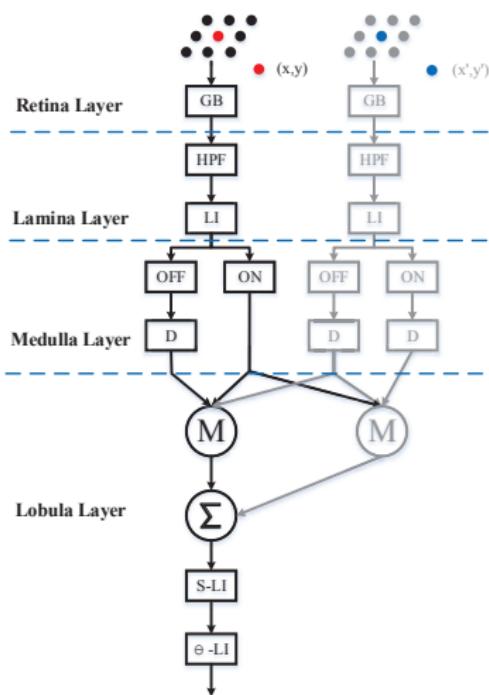


Figure 4: Schematic illustration of one DSTMD with receptive field centered at (x, y) and a preferred direction θ .

DSTMD

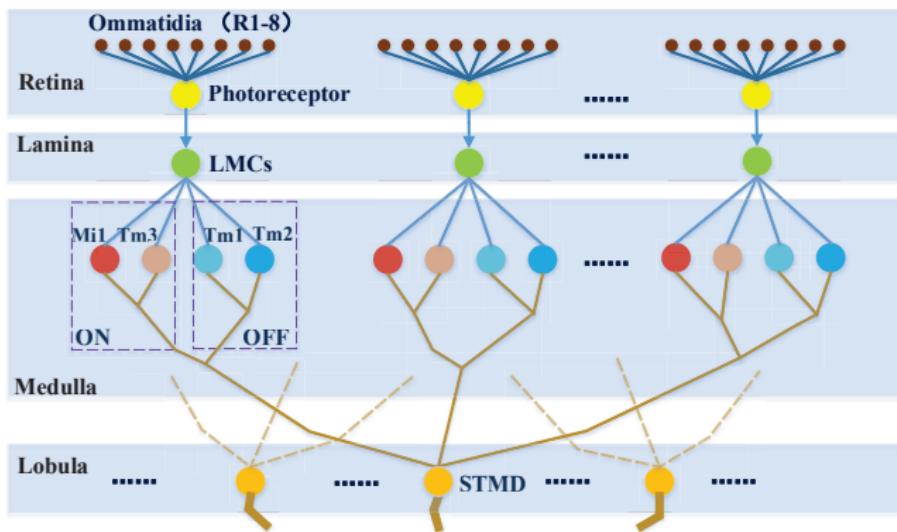


Figure 5: Schematic illustration of fly visual system.

DSTM (Retina Layer)

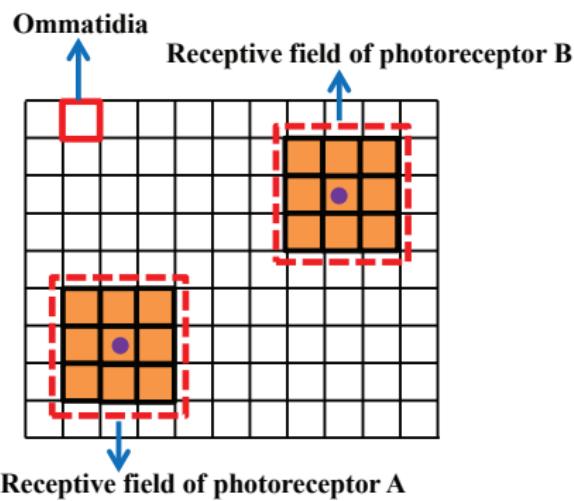


Figure 6: Schematic illustration of the mapping from pixels to ommatidia. Each small square denote a pixel, corresponding to an ommatidia. Each red dotted rectangle which contains multi pixels, represents the receptive field of a photoreceptor.

DSTMD

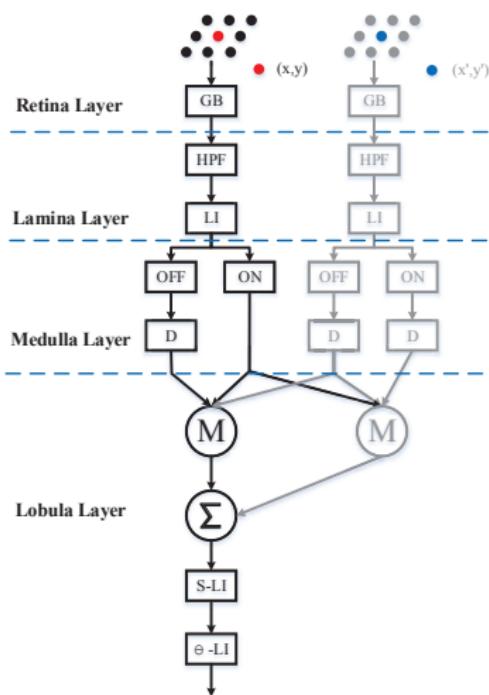


Figure 7: Schematic illustration of one DSTMD with receptive field centered at (x, y) and a preferred direction θ .

DSTM D (Retina Layer)

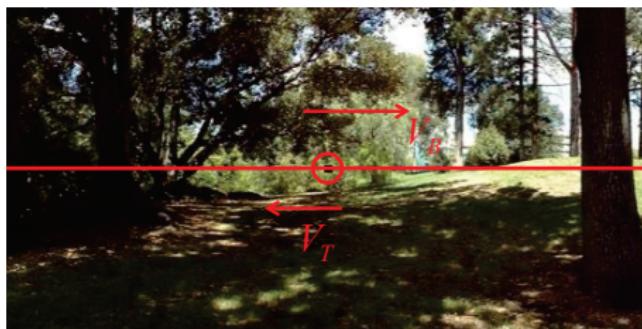
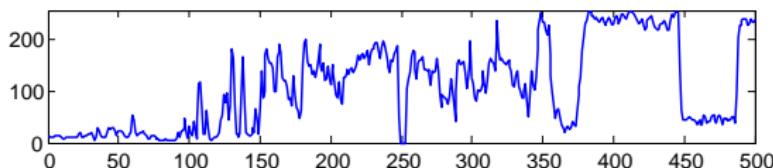
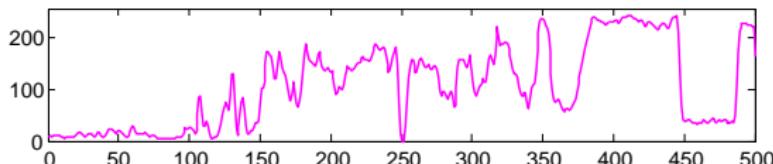


Figure 8: DSTMD responses to the motion along the red line are extracted for clear presentation of model processing results at each layer.

DSTM D (Retina Layer)



(a) Luminance Signal $I(x, y_0, t_0)$



(b) Photoreceptor Output $P(x, y_0, t_0)$

Figure 9: Neural Layer Outputs

DSTM (Lamina Layer)

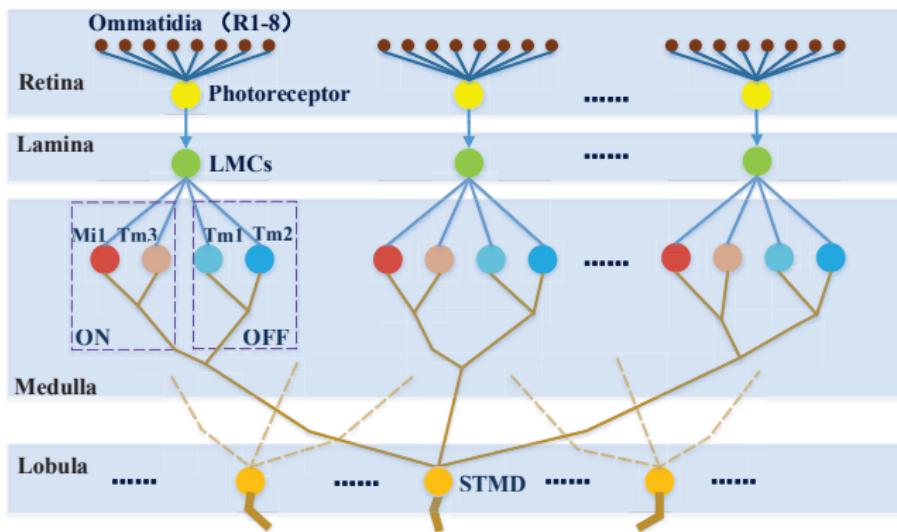


Figure 10: Schematic illustration of fly visual system.

DSTM (Lamina Layer)

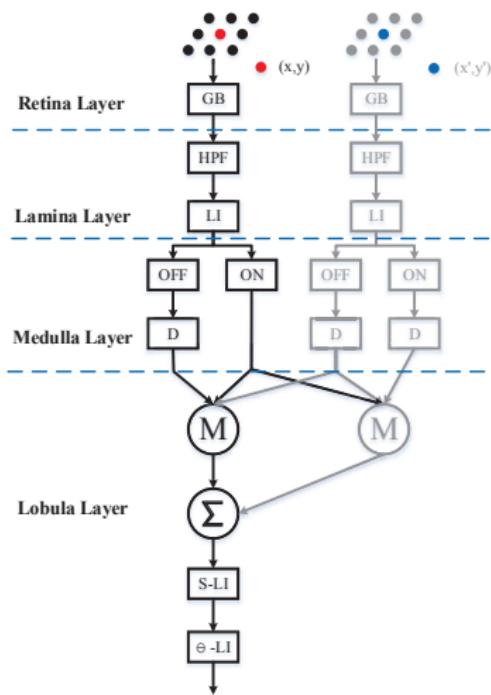


Figure 11: Schematic illustration of one DSTMD with receptive field centered at (x, y) and a preferred direction θ .

DSTM D (Lamina Layer)

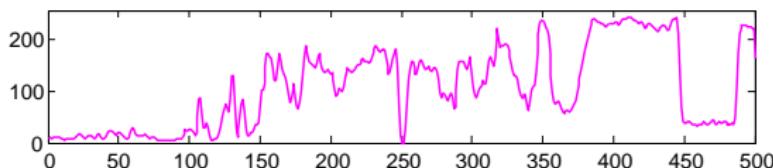
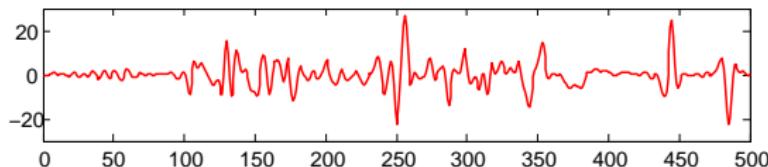
(a) Photoreceptor Output $P(x, y_0, t_0)$ (b) LMC Output $L_I(x, y_0, t_0)$

Figure 12: Neural Layer Outputs

DSTM (Medulla Layer)

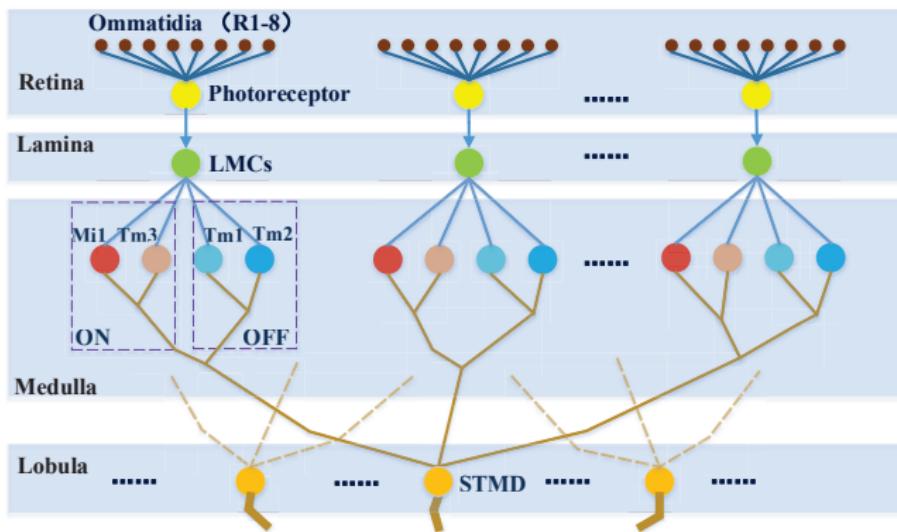


Figure 13: Schematic illustration of fly visual system.

DSTM (Medulla Layer)

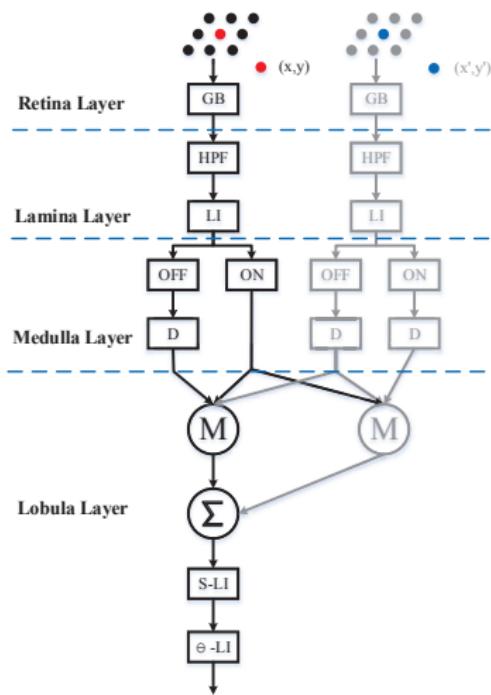


Figure 14: Schematic illustration of one DSTMD with receptive field centered at (x, y) and a preferred direction θ .

DSTM D (Lobula Layer)

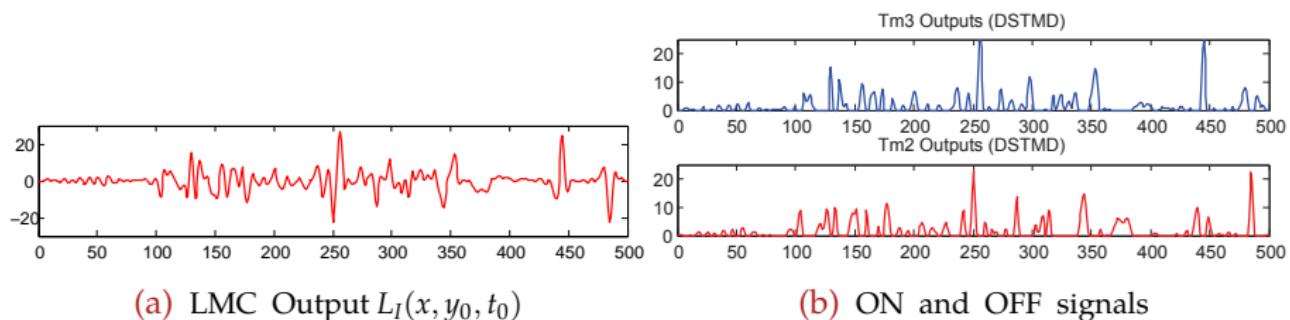


Figure 15: Neural Layer Outputs

DSTM (Medulla Layer)

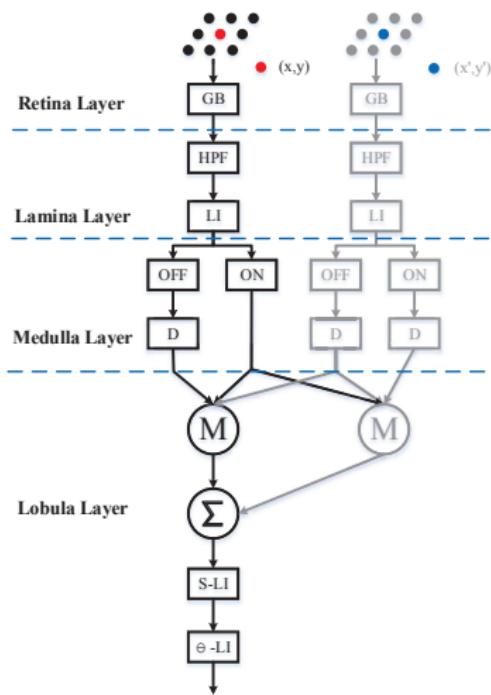


Figure 16: Schematic illustration of one DSTMD with receptive field centered at (x, y) and a preferred direction θ .

DSTM (Lobula Layer)

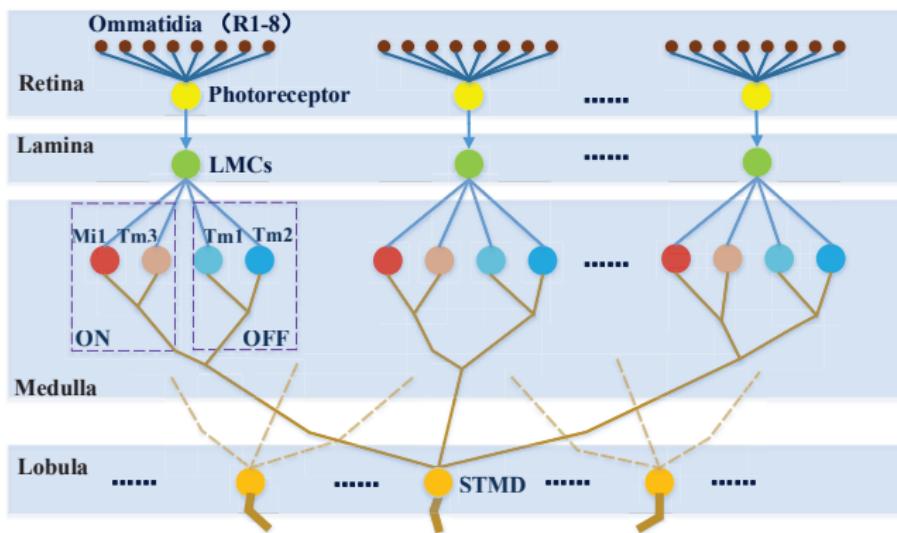


Figure 17: Schematic illustration of fly visual system.

DSTM (Lobula Layer)

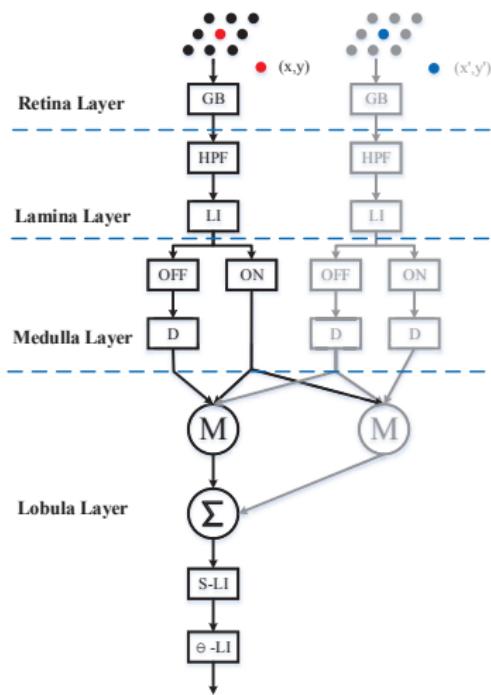


Figure 18: Schematic illustration of one DSTMD with receptive field centered at (x, y) and a preferred direction θ .

DSTM (Lobula Layer)

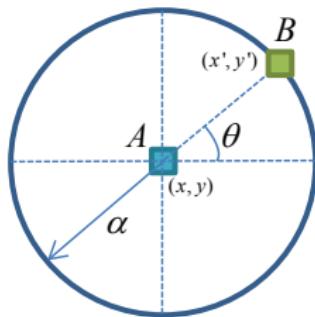


Figure 19: Illustration of relative position between (x, y) and (x', y') .

DSTM (Lobula Layer)

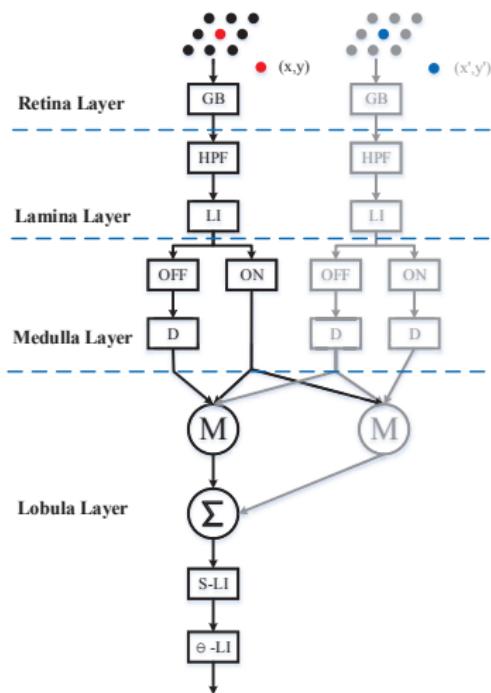


Figure 20: Schematic illustration of one DSTM with receptive field centered at (x, y) and a preferred direction θ .

DSTM (Lobula Layer)

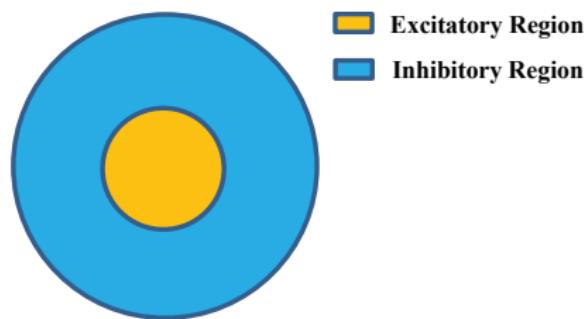
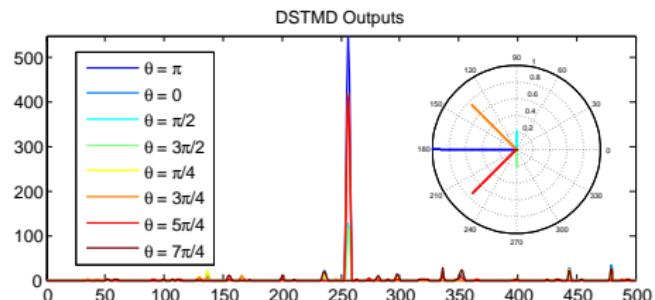
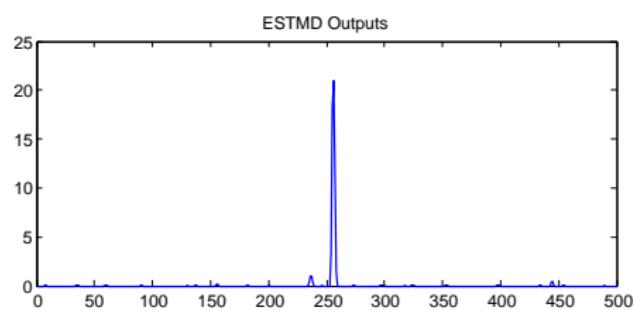


Figure 21: Illustration of excitatory and inhibitory regions of the second-order lateral inhibition mechanism.

DSTM (Lobula Layer)



(a) DSTM Output



(b) ESTMD Output

Figure 22: Neural Layer Outputs

Experimental Results

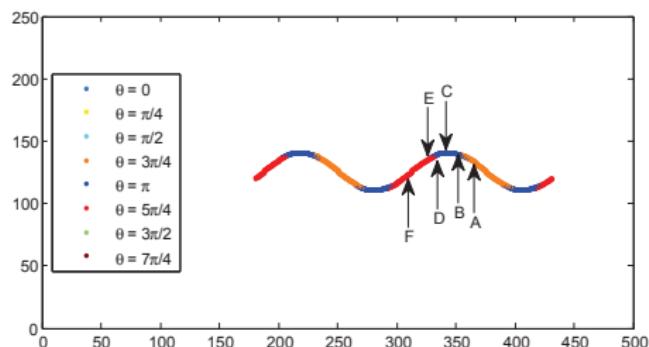


Figure 23: The motion trace of the small target where color denotes direction of the strongest response of DSTMD.

Experimental Results

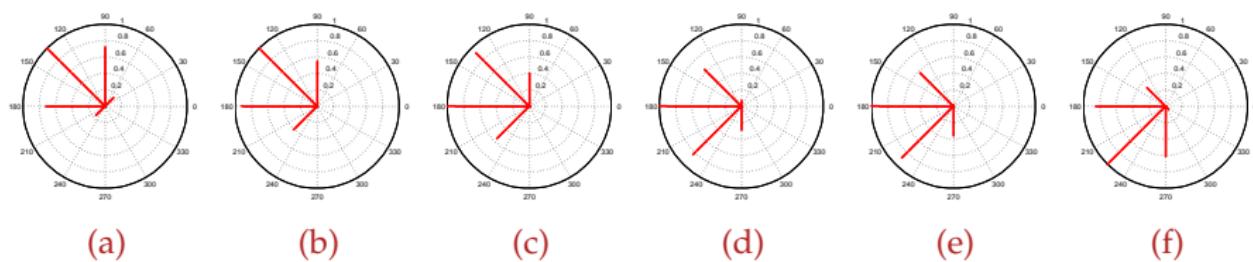


Figure 24: (a)-(f) Normalized DSTMD outputs at position A,B,C,D,E,F. In each subplot, the angular coordinate denotes the preferred motion direction of DSTMD (θ) while the radial coordinate denotes the strength of DSTMD response tuned to this preferred direction.

Experimental Results

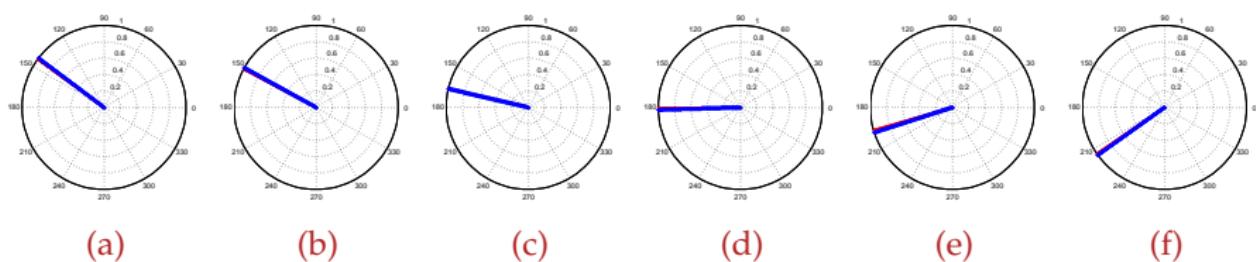


Figure 25: (a)-(f) Estimated motion direction (red) and actual motion direction (blue) at position A,B,C,D,E,F.

Experimental Results

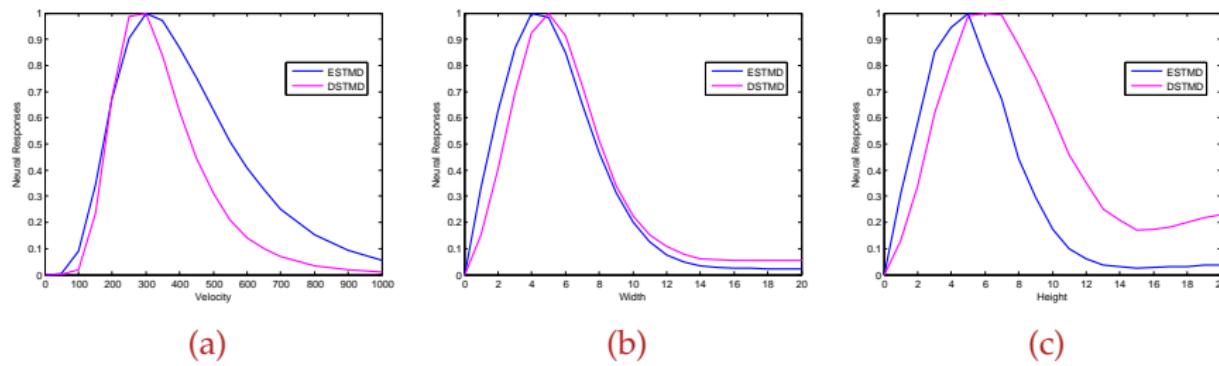


Figure 26: Tuning properties of ESTMD and DSTMD. In each subplot, horizontal axis denotes one of target parameters (velocity, width and height) while vertical axis denotes neural responses. (a) velocity tuning curves. (b) width tuning curves. (c) height tuning curves.

Experimental Results

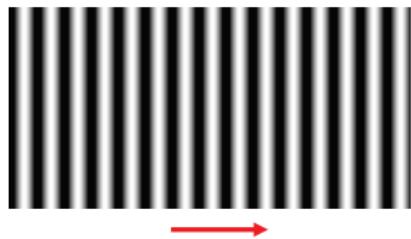


Figure 27: A representative frame of grating stimulus. Red arrow denotes motion direction.

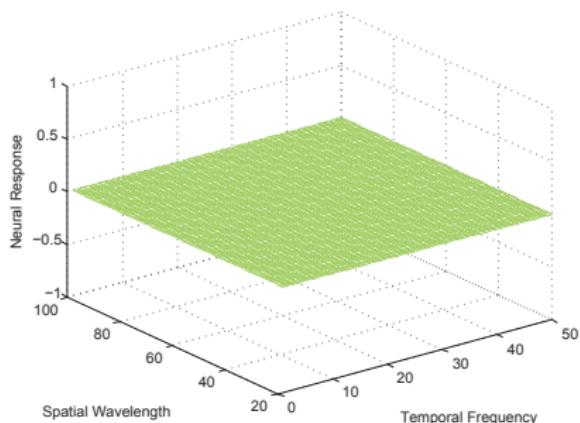


Figure 28: DSTMD model shows no response to grating stimuli as expected.

References

-  S. D. Wiederman, P. A. Shoemaker, and D. C. O'Carroll, "A model for the detection of moving targets in visual clutter inspired by insect physiology," *PloS one*, vol. 3, no. 7, p. e2784, 2008.
-  S. D. Wiederman and D. C. O'Carroll, "Biologically inspired feature detection using cascaded correlations of off and on channels," *Journal of Artificial Intelligence and Soft Computing Research*, vol. 3, no. 1, pp. 5–14, 2013.