# Modelling of bio-inspired vision system for velocity estimation

by

**Sreeja Rajesh**

B.E. (Electrical and Electronic, First Class Honours),
Bharathiyar University, India, 1999

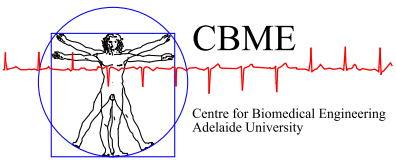
Thesis submitted for the degree of

**Doctor of Philosophy**

in

School of Electrical and Electronic Engineering,
Faculty of Engineering, Computer and Mathematical Sciences
University of Adelaide, Australia

November, 2007






# Contents

# Abstract

Although motion processing in insects has been extensively studied for over almost 40 years, velocity detection in insects and how the insect brain computes the velocity of a moving feature, independent of its size or contrast, is a major enigma that remains unsolved. This study examines the accuracy of velocity estimation using two biologically inspired models of motion detection, (i) the Horridge template model and (ii) the Reichardt correlator model. Various extensions and enhancements of these models are implemented with the goal of achieving robust velocity measurements.

The template model is one of the prominant models of motion detection, which was proposed by Horridge in 1990. This Thesis further extends this model with the aim of improving accuracy in velocity detection using chrominance as well as luminance channels with various error checking mechanisms using different stimuli. Then the template model response is compared with Dror's elaborated Reichardt model and electro-physiological experimental results obtained from the fly visual system using similar stimuli in each case. A modified Reichardt model is shown to give a more similar response to that of fly neurons.

In order to improve velocity performance of the Reichardt model, it is necessary to reduce contrast dependance of the correlator response as well as to make it independent of the structure of the visual stimuli. With this aim, the Reichardt model is then further elaborated to include contrast adaptation by a feedback adaptive mechanism and a clear reduction in contrast dependency is demonstrated. The deviation of the correlator response depending on the stimulus is termed as pattern noise. To reduce this pattern noise, the Reichardt correlator model is further extended to implement compressive nonlinearity or saturation. It is seen that saturation has a profound effect on the shape of the pattern noise. Further studies on pattern noise is then performed in this Thesis using different stimuli at different speeds and contrasts. Work carried out in this Thesis on the affect of various receptive field shapes on the pattern noise reveals circular sampled arrays reduce pattern noise and hence, based on this result, a small 16 pixel yaw sensor using our elaborated model is built that shows promising performance with various potential applications.

# Statement of Originality

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of the thesis, when deposited in the University Library, being available in all forms of media, now or hereafter known.

Signed _____ Date _____

# Acknowledgments

This PhD has been a very stimulating and a memorable experience and there are many people whom I have to thank for it. First and foremost I thank my supervisors for all their support and encouragement throughout out my course.

I will always be grateful to my supervisor Prof Derek Abbott for introducing me to the field of insect vision and for inspiring me to take up this Ph.D inspite of the various doubts and concerns I had. I thank him for his valuable ideas and guidance with the template model research and for encouraging me to write papers and attend conferences, which has helped me a lot.

I take this opportunity to express my immense gratitude to my supervisor Prof David O' Carroll for being a constant source of inspiration through out the tenure of my PhD. I extend my sincere thanks for his continuous support and guidance with the Reichardt correlator modelling and for helping me to understand insect neurology and electrophysiological experiments.

I thank my colleagues Dr Tamath Rainsford and Dr Andrew Straw for their physiological data and Dr Mark McDonnell, Dr Karin Nordstrom, Leonard Hall, Gretel Png, Eng-Leng Mah and Matthew Berrymann for making this a fun experience. Many thanks to Rado Guzinski, Khao Nguyen, and Zi H. Yong for their vision egg experimental data.

I gratefully acknowledge the funding provided by the United States Air Force Office of Scientific Research/Asian Office for Aerospace Research and Development, United States Air Force Research Laboratory, The Sir Ross and Sir Keith Smith Fund and the Australian Research Council. I would also like to thank the Cooperative Research Center for Sensor Signal and Information processing (CSSIP) for their top-up scholarship. Special thanks are also due to the staff of the School of Electrical and Electronic Engineering especially the computer support staff and the academic and general staff for their generous help.

I will forever stay indebted to my parents for their love and faith in me, my dad—for teaching me to believe in me, my mom—for being there always for me and my sister Sreeshma—for lightening things up.

Finally, I owe everlasting gratitude to my dear husband Raj for being an epitome of love, support and patience and for helping me in every possible way and my five year old daughter Riya for being my inspiration and for always giving me a reason to smile.

– Sreeja Rajesh.

# Thesis Conventions

**Typesetting.** This Thesis is typeset using the LaTeX 2e software. Processed plots and images were generated using Matlab 6.1 (Mathworks Inc.). Adobe Illustrator 10 was used to produce schematic diagrams and other drawings. Vision EGG software (http://www.visionegg.org) was used to generate stimuli for electrophysiological experiments.

**Spelling.** Australian English spelling has been adopted throughout, as defined by the Macquarie English Dictionary (A. Delbridge, Ed., Macquarie Library, North Ryde, NSW, Australia, 2001). Where more than one spelling variant is permitted such as biassing or biasing and infra-red or infrared, the option with the fewest characters has been chosen.

**Referencing.** The Harvard style is used for referencing and citation in this Thesis.

# Publications

Sreeja Rajesh, Tamath Rainsford, Russell Brinkworth, Derek Abbott and David O'Carroll (2007). Implementation of saturation for modelling pattern noise using naturalistic stimuli, *Proceedings of SPIE on BioMEMS and Nanotechnology II*, **6414**, Art. No. 641424.

Sreeja Rajesh, David O'Carroll and Derek Abbott (2006). A 16 pixel yaw sensor for velocity estimation, *Proceedings of SPIE on BioMEMS and Nanotechnology II*, **6036**, Art. No. 603618.

Rado Guzinski, Khao Nguyen, Zi Yong, Sreeja Rajesh, David O'Carroll and Derek Abbott (2006). Characterization of insect vision based collision avoidance models using a video camera, *Proceedings of SPIE on Biomedical Applications of Micro- and Nanoengineering II*, **6036**, Art. No. 60361D.

Sreeja Rajesh, David O'Carroll and Derek Abbott (2005). Man-made velocity estimators based on insect vision, *Smart Materials and Structures*, **14**, p. 413—424.

Sreeja Rajesh, Tamath Rainsford, David O'Carroll and Derek Abbott (2005). Modeling pattern noise in responses of fly motion detectors to naturalistic scenes, *Proceedings of SPIE on Biomedical Applications of Micro- and Nanoengineering II*, **5651**, p. 160—173.

Sreeja Rajesh, Andrew Straw, David O'Carroll and Derek Abbott (2005). Effect of spatial sampling on pattern noise in insect-based motion detection, *Proceedings of SPIE on Smart Structures, Devices, and Systems II*, **5649**, p. 811—825.

Sreeja Rajesh, Andrew Straw, David O'Carroll and Derek Abbott (2005). Effects of compressive non linearity on insect based motion detection, *Proceedings of SPIE on Smart Structures, Devices, and Systems II*, **5649**, p. 798—810.

Andrew Budimir, Sean Correll, Sreeja Rajesh and Derek Abbott (2004). Implementation of insect vision based motion detection models using a video camera, *Proceedings of SPIE on Smart Structures, Devices, and Systems II*, **5649**, p. 596—606.

Sreeja Rajesh, David O'Carroll and Derek Abbott (2004). Effects of nonlinear elaborations on the performance of a Reichardt correlator, *Proceedings of SPIE on BioMEMS and Nanotechnology*, **5279**, p. 287—303.

Sreeja Rajesh, David O'Carroll and Derek Abbott (2003). Velocity estimation and comparison of two insect-vision-based motion-detection models, *Proceedings of SPIE on Smart Materials, Structures, and Systems*, **5062**, p. 401—412.

Sreeja Rajesh, David O'Carroll and Derek Abbott (2002). Elaborated Reichardt correlators for velocity estimation tasks, *Proceedings of SPIE on Biomedical Applications of Micro- and Nanoengineering*, **4937**, p. 241—253.

Hung Nguyen, Sreeja Rajesh and Derek Abbott (2001). Motion detection algorithms using template model, *Proceedings of SPIE on Electronics and Structures for MEMS II*, **5279**, p. 78—90.

# List of Figures

# List of Tables