Chapter 10

Modelling a yaw sensor using our elaborated model

IN this chapter, our elaborated Reichardt model is used to model a compact yaw sensor. We have just used 16 elaborated EMDs and it is seen that this sensor can detect rotational motion at angular velocities up to several thousand degrees per second. The modelling of these sensors make us realize that the VLSI implementation of such simple detectors can have varied applications for flight control in different fields.

Fig. 10.1. Panoramic images given as stimuli. The panoramic natural image given as stimulus to the EMD model. A panorama of the image is formed by 'warping' 12 image tiles at 30° intervals to remove lens distortions and then by wrapping its ends together using Apple Quicktime VR software on a Macintosh computer.

10.1 A 16 pixel yaw sensor

As explained in Chapter 5, the basic Reichardt correlator model is elaborated to include spatial and temporal filtering. But since only 16 elaborated EMDs are used here, spatial pre-filtering is implemented by two-dimensional convolution of the image with a Gaussian kernel of half width of 21.8°, which approximates ten times the acceptance function of typical fly photoreceptor and thus will be tuned to speeds approximately ten times the usual speed. Then contrast adaptation (as explained in Chapter 5) is implemented and saturation also is implemented at the correlator input, arms and output (as is seen in Chapter 7). This fully elaborated 16 EMD array model is simulated using the natural image stimuli shown in Figure 10.1. To test the motion adapted responses, velocity is increased step-wise, with interleaved bursts of adapting motion (constant speed). The velocity is increased in steps with time as shown in Figure 10.2. The total mean correlator response without implementing output saturation and with output saturation is shown in Figure 10.3.

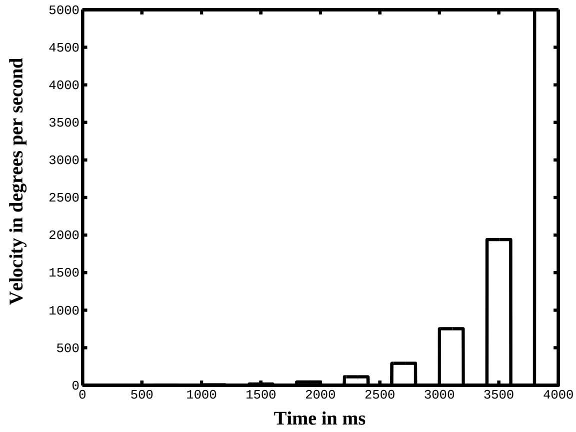

Fig. 10.2. Test speeds with interleaved bursts of adapting speeds. To test motion adapted responses, the velocity is increased step-wise, with interleaved bursts of adapting motion (constant speed). The velocity is increased in steps with time.

Figure 10.4 shows the mean correlator response of three rows of EMDs. The dotted line which shows the mean EMD output of the first or top row of 16 EMDs could be considered as the response of the HSN neuron of the fly tangential cell, the second row or the middle row shown by the dashed line could be the response of the HSE and the third row or the bottom row mean correlator response could be the response of the HSS neuron of the fly tangential cell. The mean response of each row is sensitive to the degree of contrast that is seen in the elevation of the natural scene that it is oriented towards. And finally Figure 10.5 shows the velocity response curve of EMD array for the three different images shown in Figure 10.1. It is seen that since Image 1 and Image 2 have high contrast features, their velocity response curves overlap. For Image 3 which has little in terms of high contrast features, the velocity response curve is consequently slightly lower as seen in Figure 10.5. The naturalistic three images which are chosen differ in aggregated natural contrast (global contrast) approximately by a factor of 3 (Image 1 has a global contrast, $C_n = 0.65$, Image 2 has $C_n = 1$ and for Image 3, $C_n = 0.38$ as calculated by Straw (2004)). Since it is known that the response of a simple Reichardt correlator model varies quadratically with contrast [Dror, 1998], it is seen that the addition of the non-linear elaborations in our elaborated model decreases the contrast dependency of the correlator response considerably. And it is also seen that this small sensor can detect angular velocities up to several thousand degrees per second [Rajesh et al., 2006].

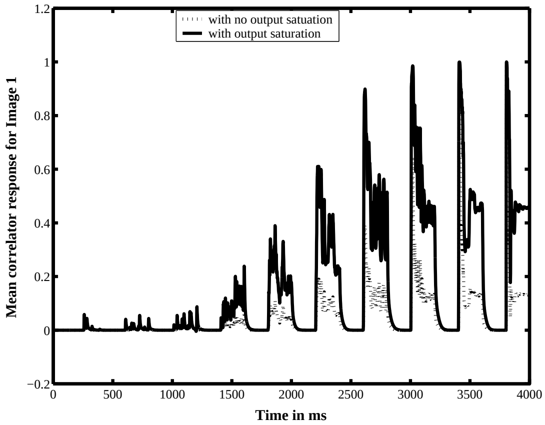

Fig. 10.3. Mean correlator response with and without saturation. This figure shows the total mean correlator response without implementing output saturation and with output saturation. Inclusion of output saturation will flatten the peaks of the velocity response curves effectively allowing neuron to use more of its dynamic range to signal low velocities.

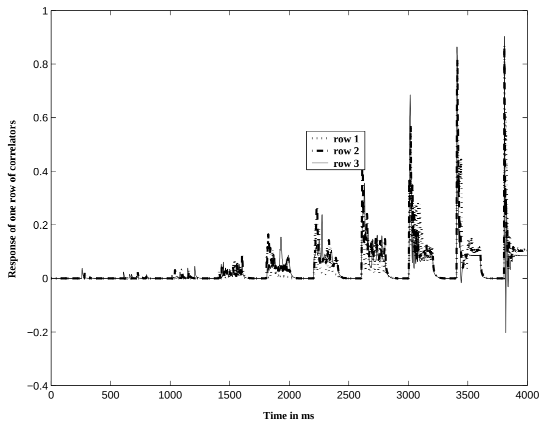

Fig. 10.4. Mean correlator response of three rows of EMDs. The response of each row is seen to vary with the contrast found at that elevation.

10.2 Conclusion

In this chapter, new variants of the Reichardt correlator model, elaborated to incorporate additional non-linearities that mimic known properties of the insect motion pathway, including logarithmic encoding of luminance, saturation and motion adaptation (adaptive gain-control) is developed. Here, the response of a small circular detector array model consisting of 16 elaborated EMDs is configured in such a way as to provide a sensor tuned to the yaw component of optical flow. Although this small detector array has limited spatial resolution, this confers an advantage (at least using reasonably short time constants for the delay element) that it can provide monotonic responses to yaw stimuli at angular

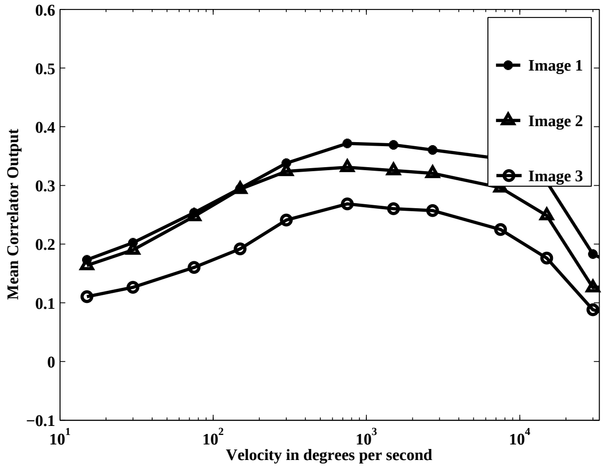

Fig. 10.5. Velocity response of the small yaw sensor. This figure shows the velocity response curves obtained from our 16 pixel sensor for three images shown in Figure 10.1. The addition of the non-linearities decreases the contrast dependency of the sensor and this small detector array is capable of estimating angular velocities up to several thousand degrees per second.

velocities up to several thousand degrees per second. The circular configuration of the detector array is capable of rejecting the phase-specific variation in response to complex patterns that typifies Reichardt-type motion detectors. Although a simple 1-dimensional (circular) array of Reichardt EMDs would still be sensitive to the degree of contrast that prevails in a scene at the elevation it is oriented towards, the non-linear elaborations to our modelled array largely negate such variation. Hence, our model demonstrates that it would be feasible to base a biomimetic motion detector for sensing rotational components of optical flow on a very small number of sampled pixels. A group of such sensors, implemented in analog VLSI would have applications for flight control in ultra-miniature unmanned aerial vehicles.

The next chapter concludes this Thesis by putting together all the main points discussed so far in all the chapters and throws light on the some of the main contributions made by this Thesis in this field of research.

Chapter 11

Conclusion

INSECT vision technology has application in a variety of platforms serving a range of different needs. Optic-flow based guidance of autonomous and micro air vehicles, small moving target detection and tracking, collision avoidance based on the capabilities of insects to control landing and obstacle avoidance that can be used for blind people, automobiles and traffic monitoring systems for smart highways, tactical and strategic surveillance using large number of low-cost, highly compact fixed surveillance devices based on visual motion detection, moving object segmentation and tracking applications for autonomous robots, various security purposes and automated manufacturing and control are a few to mention.

This Thesis has developed many models and algorithms for more accurate bio-inspired velocity estimation tasks and it has explored the performance of each of these models and has discussed the improvements over previous models in order to achieve further robust speed measurements for more advanced applications. The Reichardt correlator model is elaborated by elucidating the properties of the fly visual system and the effect of various elaboration is studied and it is demonstrated that the implementation of saturation at different points and contrast adaptation has significant effects on the performance of the model. All these elaborations combined gives us a model which has prominently enhanced performance with wide applicability.

This chapter concludes the Thesis by bringing together all the prominent areas of research discussed in the previous chapters and showing the way to future research in this promising field.

11.1 Introduction

Section 11.2 gives an overview of the research topics dealt with in this Thesis and the major conclusions obtained from all the new contributions in this field of study. Section 11.3 then gives way to the path led by this Thesis for further exploration and future research and points out the next steps to build upon the contributions of this Thesis.

11.2 Thesis Summary

The goal of this Thesis is to enhance and advance the two models of motion detection namely the Horridge template model and the Reichardt correlator model to improve its performance of speed detection. The first part of this Thesis describes the Horridge template model and extension of this model to colour and comparison of the performance of such an extended model with Dror's elaborated Reichardt model and the physiological data obtained from fly neurons. The second part of the thesis discusses the Reichardt correlator model and the various elaborations implemented to obtain improved performance, the most prominent ones being contrast adaptation and saturation. A study is also performed on pattern noise and various ways of reducing pattern noise to enhance accuracy of velocity measurement is also done. The Thesis conclusion is presented in these three categories.

11.2.1 Horridge Template Model

Chapter 2 describes the Horridge template model and the use of chrominance templates along with the luminance templates to detect angular velocity. Various error checking methods are also investigated to get more robust real time performance.

The red chrominance and blue chrominance response is compared with the luminance template response and the four different error checking method is investigated namely (i) spatial filtering, (ii) multiplicative noise cancellation, which perform the pre-template filtering, and (iii) windowing method and (iv) template pair method which perform the filtering after the formation of the template (post-template filtering). It is found that the combination of spatial filtering and template pair method gives optimum performance and the use of chrominance templates helps to remove the uncorrelated noise in each case. The performance is also compared with natural stimuli and other stimuli using the Andrew Straw's vision egg software.

Chapter 3 and 4 then describes the Dror's extended Reichardt model and the compares it with the performance of the extended Horridge model and the physiological data obtained from fly neurons. It is seen from the results in Chapter 3 that the Reichardt model displays greater similarity to the physiological data than the Horridge model.

11.2.2 Reichardt model

In order to improve the performance of the Reichardt model so as to enable it to perform robust velocity estimation, it is very important to make it contrast independent and make it independent of the structure of the visual scene. With this goal in mind, contrast adaptation is implemented in our elaborated Reichardt model by a feedback adaptive mechanism where the magnitude of the output is fed back to control the gain of the input. This elaboration demonstrates a significant reduction in the dependance of the response to contrast.

In regards to reducing the dependance of the correlator response to the structure of the visual scene, which is also called pattern noise, it is found that implementation of saturation at different positions of the model had a significant affect on the shape of the pattern noise. Various experiments were conducted comparing the physiological data with modelling results to understand the correct implementation of saturation with the aim of reducing pattern noise.

The effect of each of these elaboration on pattern noise is studies by plotting relative error graphs and the performance of each of the models is evaluated using the cross correlation technique.

11.2.3 Pattern noise

Deviation of the correlator response depending on the structure of the visual scene is called pattern noise. The effect of various receptive field shape on pattern noise is studied. The performance of rectangular sample of EMDs is compared with circular sample and a random sample of EMDs with error bars and it is found that the circular sampled array of EMDs reduces pattern noise considerably. Based on these results, a small 16 pixel yaw sensor is built which can have varied applications in flight control of miniature UAVs.

11.3 Future Work

Research activities in any area is never complete. It always has open questions, room for further extension and enhancement and more promising applications. As this work extends and modifies previous models, there is a lot of scope for further elaboration as the answers to many of the amazing properties that nature has bestowed upon insects for its remarkable flight control is still unknown. It is still a mystery in many ways and a lot of work is needed to be carried out to enable mankind to closely emulate insects.

11.4 Horridge model

The Horridge model is a very prominent model for motion detection and much work has been carried out in the area of Horridge model. The use of colour templates is useful in the de-noising techniques described in this Thesis as it provides a more independent platform for noise reduction. Future work would be to vigorously quantify performance enhancement via colour templates. The next challenge would be to consider extending the colour template idea to colours other than the three primary colours, red, blue and green by extending the three dimensional field to n dimensional to get multi-colour information. The trade-off between n and speed performance will need careful consideration.

The Horridge model is seen to show less similarity to the physiological response of the fly neurons compared to the Dror's extended Reichardt model. But future engineering-based elaborations to the template model such as implementation of automatic threshold control and more de-noising techniques can further improve its performance.

11.5 Reichardt model

The implementation of contrast adaptation is found to decrease the dependance of the response to contrast in this Thesis. But the response is still not contrast independent, which is very important for accurate velocity detection. So more work is required in this domain to achieve velocity constancy and an alternative method where the feedback signal gates the feed-forward contrast normalisation as proposed by Shoemaker et al. (2001) could be further explored.

The work carried out in this Thesis demonstrates that saturation or compressive non-linearity has a significant effect on pattern noise, i.e. the dependance of the response to the structure of the stimuli. But it is still not clear where this saturation mechanism occurs within the visual system of insects. This Thesis has explored the implementation of saturation at the input, at the correlator arms and at the output based on previous research carried out on the fly. But it could be that saturation may be present in other areas of the fly visual system and modelling of other areas or combination of different kinds of saturation needs to be explored to make velocity response independent of the structure of the visual scene.

11.5.1 Pattern Noise

The study on pattern noise conducted by this Thesis shows that circular sampled arrays of EMDs reduces pattern noise. Even though this finding seems trivial, based on this result a 16 pixel yaw sensor is modelled, which shows promising applications. The hardware implementation of this small yaw sensor is very simple and it can have tremendous applications in various fields and more work is being carried out in this area by my colleagues to build such an optical sensor.

11.6 Summary of original contributions

The original contributions represented by this work are given in Chapter 1. In summary they are,

1. Extension of the Horridge template model to include chrominance template analysis and various de-noising techniques and improvement in angular velocity estimation is demonstrated with the combination of spatial filtering (pre-template filter) and template pair algorithm (post-template filtering).

2. This extended Horridge model response is compared with the Dror's elaborated Reichardt model and the actual response of fly neurons. This comparison evaluates the performance of the Horridge model and the Reichardt model with respect to fly response. The experimental results reveal the Horridge model has less similarity with the fly neuron response as compared to the Reichardt model.

3. With the goal of improvement in velocity response, the Reichardt correlator model is further elaborated to include contrast adaptation by a feedback adaptive mechanism. This addition demonstrates reduction in the dependance of the response to contrast.

4. The Reichardt correlator model is further enhanced by implementation of compressive non-linearity or saturation at three different positions (input, arms and output) and the affect of it on the performance of the model is elucidated.

5. The effect of various receptive field shapes on pattern noise is studied and it is clear that circular sampled arrays reduces pattern noise in insect based motion detection.

6. Further studies on pattern noise throws light to the fact that saturation has a significant affect on the shape of the pattern noise. Many experiments with different images at different speeds and different contrasts are performed to investigate the effect of this compressive non-linearity on pattern noise.

7. A small 16 pixel yaw sensor is modelled using our elaborated model and its promising performance facilitates various significant applications.

11.7 In closing

Nature has taught mankind a lot of things and we still have a lot more to learn from it. Likewise insects with their very simple visual system are able to perform such complicated tasks that man has still not been able to understand fully how they perform. Yet a lot more research and study need to be performed to uncover the secrets that are still buried in the insect eye. But with what has been revealed about the insect visual system, the research shows promising applications in the field of autonomous robots, defence where it can applied in UAVs, target detection, in the area of video surveillance, in motion detectors that can be used as blind spot detectors in cars, in wheelchairs for disabled people, and for many varied applications [Abbott et al., 1994]. Towards the goal of accurate velocity estimation, the work carried out in my Thesis has contributed to extend and improve the two motion detection models namely the Horridge model and the Reichardt correlator model. This Thesis has investigated the implementation of feedback adaptation and saturation at different parts of the model and has developed a yaw sensor by studying pattern noise and ways of reducing it. These contributions add to the varied applications of this bio-inspired technology, leads to the betterment and improvement of an already existing framework, and paves a way for further study.