Motion Detection Using Colour Templates

Kevin Chin* and Derek Abbott

Centre for High Performance Integrated Technology
Systems (CHiPTeC)
Centre for Biomedical Engineering (CBME)
The Department of Electrical & Electronic Engineering
The University of Adelaide, SA 5005, Australia.

ABSTRACT

The Horridge template model[1] is an empirical motion detection model inspired by insect vision. This model has been successfully implemented on several micro-sensor VLSI chips[2–6] using greyscale pixels. The template model is based on movement of detected edges rather than whole objects, which facilitates simple tracking techniques. Simple tracking algorithms developed by Nguyen[7] have been successful in tracking coherent movement of objects in a simple environment. Due to the inherent edge detection nature of the template model, two closely spaced objects moving at the same speed relative to the template model sensor will appear to have a common edge and hence be interpreted as one object. Hence when the two objects separate, the tracking algorithm will be upset by the detection of two separate edges, resulting in a loss of tracking.

This paper introduces a low-cost insect vision prototype, based on a colour CMOS camera. Although this approach sacrifices auto gain control (AGC) at each pixel, results are valid for controlled lighting conditions. We demonstrate working results, for indoor conditions, by extension of the template model using the colour CMOS sensor to form colour templates. This enables the detection of colour boundaries or edges of closely moving objects by exploiting the difference in colour contrast between the objects. This paper also discusses the effectiveness of this technique in facilitating the independent tracking of multiple objects.

Keywords: Motion detectors, Collision avoidance sensors, VLSI Artificial Insect Vision

1. INTRODUCTION

Conventional vision systems are based on complex models which are often computationally intensive and hard to realise in VLSI. Insect vision has excited researchers for a long time because insects are able to *see* the world well enough to perform complex tasks such as navigation with relatively simple visual systems. This suggests that biologically inspired vision models may be viable solutions for restricted tasks[8] such as motion detection and collision avoidance.[2]

The Horridge Template Model is a simplified model of the insect visual system. This empirical model compares the contrast between two adjacent receptors at two sampling instances to form a *template*. Templates can give simple directional motion information. Interfacing is mainly between adjacent receptors only, which makes this model easy to implement in parallel. Several generations of insect vision chips based on the template model have been developed by Moini *et al.*[9,10]

As this paper will show, greyscale insect vision is unable to resolve between multiple objects moving at the same relative speed to the sensor. This paper introduces an extension to the Horridge Template model to incorporate colour information. A colour model in which colour information is expressed as colour contrast or chrominance is used to form *colour templates*. Like greyscale templates, colour templates can give directional information based on the change in chrominance in the time and spatial domain.

An off-the-shelf CMOS camera was interfaced to a personal computer to form a prototyping platform for the extension of the template model to colour. The colour extension also incorporates luminance templates which

*Further author information: (Send correspondence to Kevin Chin)
Kevin Chin: E-mail: klchin@eleceng.adelaide.edu.au

Part of the Conference on Design, Characterization, and Packaging for MEMS and Microelectronics
Royal Pines Resort, Queensland, Australia • October 1999
SPIE Vol. 3893 • 0277-786X/99/$10.00

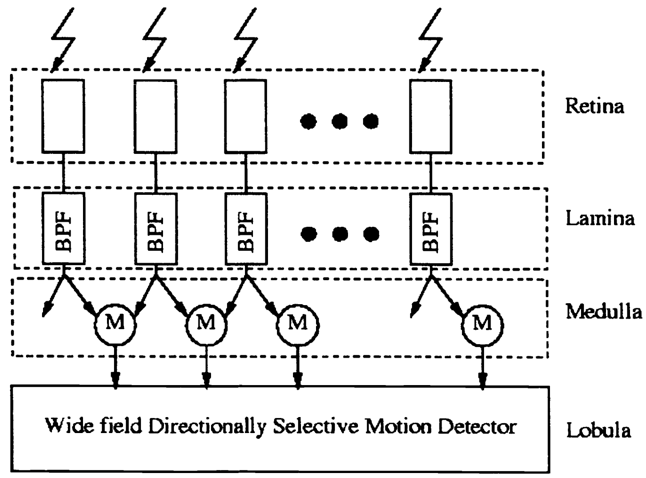

Figure 1. Simplified model of the insect visual system. After Moini *et al.*[5]

are equivalent to greyscale templates. Luminance templates from the prototype are compared to previous results obtained from the Bugeye chips[10] to verify that the prototype correctly models the functionality of the Bugeye chips in software. Colour template results are then presented to show the ability of this extended model to detect more moving edges than the greyscale model.

2. INSECT VISUAL SYSTEM

The insect visual system can be classified into four layers which include the *retina, lamina, medulla* and *lobula* as shown in Figure 1. The retina of insects is a compound eye which contains a large array of photo-receptors. The lamina consists of neurons which control the dynamic range of the photo-receptors thus allowing the sensitivity of the retina to be adjusted for different conditions. Contrast enhancement is also a vital function of the lamina and this is performed through biological band pass and high pass filters.

The medulla is one of the most complex layers of the insect visual system. It contains many motion sensitive neurons. Of particular interest are the directional motion sensitive neurons which perform small-spatial-field motion detection. The template model was inspired by small-spatial-field motion detection neurons in the medulla.

The lobula receives input from the medulla cells to perform higher level functions. The lobula also contains wide field directionally selective motion detection neurons which are responsible for the detection of whole field or whole frame motion.

3. THE HORRIDGE TEMPLATE MODEL

The Horridge Template Model[1,11] was inspired by the small-spatial-field motion detection neurons in the medulla. The visual field is split into an array of photo-detectors. Intensity information from each photo-detector is sampled and put through a simple thresholding operation. This thresholding operation quantises the intensity values into three states which are increasing $\uparrow$, decreasing $\downarrow$ and no change $-$. If the change in intensity is less than a given threshold level, the photo-detector is deemed to be in the no change state. Similarly if the change in intensity has increased or decreased more than the threshold, the photo-detector is given an increasing or decreasing state respectively.

A template is formed by taking the states of two adjacent photo-detectors at two sampling instances. Therefore for one sampling instant there are nine possible combinations which include

$$(- -), (- \uparrow), (- \downarrow), (\downarrow\downarrow), (\uparrow\uparrow), (\uparrow -), (\uparrow\downarrow), (\downarrow -), (\downarrow\uparrow).$$

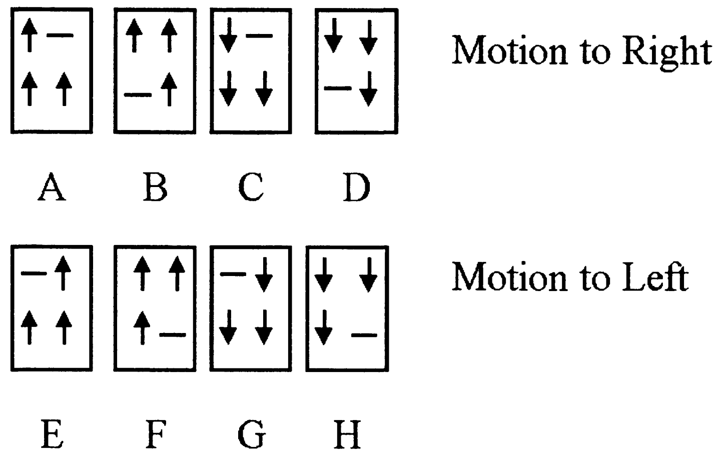

Figure 2. Directionally Motion Sensitive Templates

Hence over two sampling instances there are 81 possible templates. Fortunately through empirical observations there are only eight templates which indicate coherent directional motion reliably.[12]

These 8 templates are called Directionally Motion Sensitive Templates and are labeled with letters as shown in Figure 2.

The template model is easily implemented in VLSI because the thresholding and template formation operations are simple and can be done in parallel. The presence of only three states also reduces the bandwidth requirements compared to other vision systems.

4. PROTOTYPING PLATFORM

A series of Bugeye chips based on the template model has been implemented using greyscale photo-detectors.[10] As an initial proof of concept was needed for colour templates, it was decided to use off-the-shelf components instead of designing a custom VLSI chip in the first instance.

In the Bugeye chips, the retina was modeled using an array of on-chip photo-detectors with dynamic range control circuitry. This was replaced by an off-the-shelf CMOS camera in our prototype. It should be noted that the CMOS camera does not have Automatic Gain Control (AGC) circuitry at the pixel level, but this feature is not essential for controlled lighting conditions.

The filtering operation in the lamina layer was implemented using temporal differentiation in the Bugeyes, whilst in our prototype this was performed using simple frame differencing. Template generation in our prototype was again performed in software whereas some of the Bugeye chips have template generation elements in hardware.

5. COLOUR TEMPLATE MODEL

By tracking templates, moving edges can be detected and monitored. These edges can be very useful for applications such as estimating the velocity of a moving object[12] and calculating the time-to-impact of an object coming towards the sensor.[2] However closely spaced objects of similar intensity moving with the same relative speed with respect to the sensor can not be easily detected using the existing template model. This is because, in the greyscale template model, moving edges can only be detected if there is sufficient intensity difference between the moving objects themselves or with respect to the background.

Therefore to the sensor, it would *seem* that only a single object was moving making the greyscale template model less suited for object tracking applications.

The inspiration for the extension of the insect vision paradigm to colour comes from the visual system of bees. Bees use achromatic and chromatic information alternatively depending on the visual angle of the target that it is trying to track.[13] Bees rely on achromatic visual information to make decisions when the visual angle to the target is small whilst their chromatic visual system is used for larger visual angles.[14] Therefore by using both greyscale and colour insect vision, one hopes to extract more information about the scene than just using greyscale vision alone. The model proposed in this paper uses both chrominance and luminance information. This is different to the achromatic visual system of the bee which compares green contrast against the background. The choice of green contrast is believed to be due to the dominance of green in the visual environment of the bee but for the general case, the use of luminance or brightness as the achromatic measure would seem to be more suitable.

The CMOS camera in our prototype uses the RGB colour scheme. The RGB colour scheme works on the principle that each colour is comprised of different combinations of the three primary colours red, green and blue. The RGB scheme can be converted into the luminance-chrominance model using the formulae below:

$$Y = 0.299R + 0.587G + 0.114B \tag{1}$$

$$Cr = R - Y \tag{2}$$

$$Cb = B - Y \tag{3}$$

$$Cg = G - Y \tag{4}$$

where, Y is called the Luminance. Cr is the Red Chrominance, Cb is the Blue Chrominance and Cg is the Green Chrominance. R is the Red, G is Green and B Blue are the values of a RGB pixel.

As can be seen from the equation, chrominance represents the difference of a primary colour with respect to the luminance. Since luminance is a weighted sum of each of the primary colours, chrominance represents colour contrast. This is suitable for colour insect vision since it is the motion of different colour edges that we are aiming to detect.

The luminance and chrominance values of each pixel or channel are put through the same differentiating, thresholding and template generation stages as the original greyscale templates. Through the chrominance templates, *colour templates* can be formed. The same 8 directionally motion sensitive templates as shown in Figure 2 can be detected for the luminance and each of the three colour chrominances. This facilitates the tracking of moving edges due to changes of brightness as well as colour contrast.

6. RESULTS: GREYSCALE TEMPLATES

A prototyping platform was used to verify the effectiveness of colour templates. Therefore the logical first step would be to replicate the results of the Bugeye chips in the greyscale or luminance domain. The results in Figure 3 contain the output templates for one row of detectors from a Bugeye chip. The test sequence was generated by moving a small object (pen) across the Bugeye chip at close range.

A similar test sequence in which a small object (pen) was moved across our prototype camera at close range was used to generate the results shown in Figure 4 and Figure 5. Figure 4 corresponds to the states of the pixels after the quantising process produced by our prototype and Figure 5 corresponds to the templates that were generated by taking two adjacent states from Figure 4 at two sampling instances.

It is clear from Figure 5 and Figure 3 that leading and trailing edges for both small objects can be observed. Hence our prototype software produce similar results as the Bugeye chips for greyscale templates.

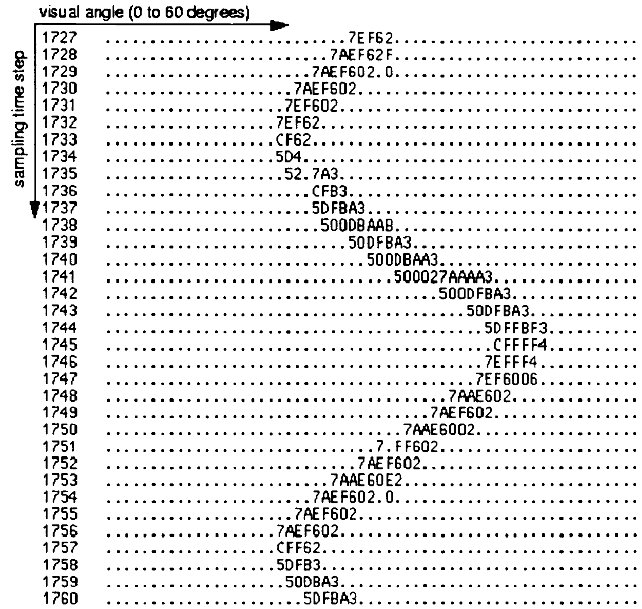

Figure 3. Templates for a small object (pen) moving across a Bugeye chip. After Moini *et al.*[5] The directionally motion sensitive templates, as shown in Figure 2 are represented using characters from 'A' to 'G'. '.' represents no templates whilst the other characters represent the other 73 possible templates.

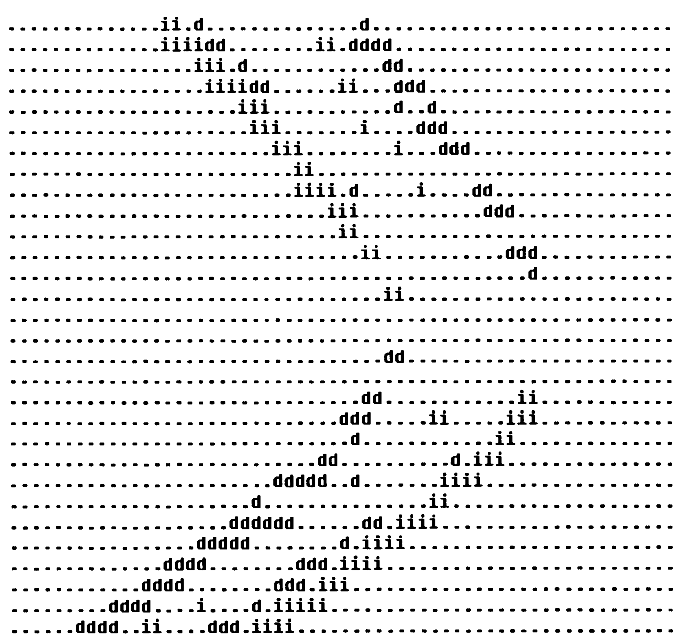

Figure 4. States of pixels for a small object (pen) moving closely across our prototype camera. '.' represents the no change state. 'i' represents the increasing state and 'd' represents the decreasing state, for greyscale.

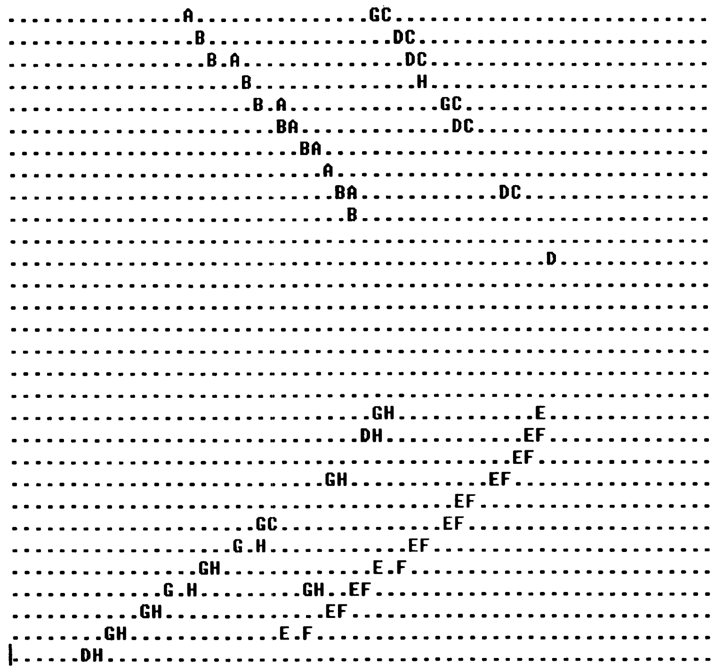

Figure 5. Greyscale templates for a small object (pen) moving across our prototype camera at close range. Note that only the 8 directionally motion sensitive templates ('A' to 'G') have been included in this result. The other 73 templates and no templates were represented by '.'.

7. RESULTS: COLOUR TEMPLATES

Figure 6 is the template output of a simplistic test sequence consisting of three coloured objects. The objects are moving one next to the other from left to right across the sensor with the same relative speed. The three different coloured objects have similar brightness or luminance values but are red, green and blue in colour respectively. From Figure 6 it can seen that the luminance or greyscale template model detected only one pair of leading and trailing edges. Therefore according to luminance templates alone, there *seems* to be only a single object moving. This result demonstrates the inability of the greyscale templates to detect the moving edges of the multiple objects when there is insufficient luminance difference between the moving objects or the background.

Figure 7 shows the colour templates for the same multi object test sequence. The moving colour edges can be clearly observed as illustrated in Figure 7. The moving edges of the three individual objects can be detected because there is sufficient colour contrast between the objects. This result shows that the extension of the template model to process colour information can facilitate the tracking of moving coloured edges.

8. FUTURE WORK

This paper has presented an extension to the template model to process colour information to produce *colour templates*. Colour templates and luminance templates give directional motion information in the small field. These templates can be seen as the front end of an intelligent artificial visual system tailored for suitable real time applications. Therefore backend algorithms are needed to process the templates for specific tasks.

The colour template algorithm in this paper is based on a single row of photo-detectors and only gives directional motion information in one spatial dimension. Therefore an extension that incorporates an array of pixels and detects motion in two dimensions would be valuable in assessing how the extended model performs in more complex environments.

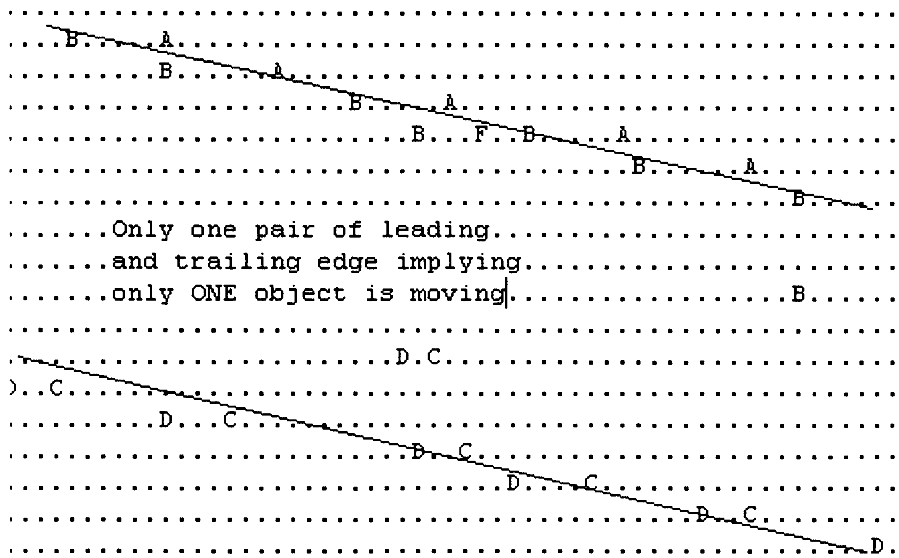

Figure 6. Luminance templates for the multi object test sequence from our prototype. There are three coloured objects with similar luminance levels that are moving one next to the other across the sensor with the same relative speed.

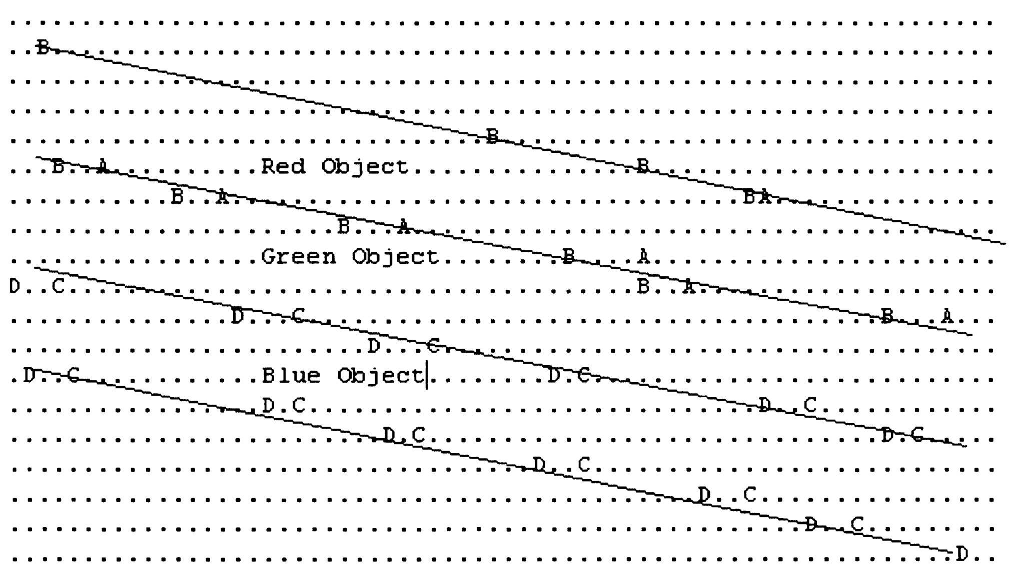

Figure 7. Colour templates for the multi object test sequence from our prototype. The sequence contains three objects that have the same brightness level but are of the colour red, green and blue respectively. These objects are moving across the sensor one next to the other with the same relative speed.

9. CONCLUSION

In conclusion this paper has introduced an extension to the Horridge Template model to process both brightness and colour information. Results presented indicate that the extension to colour can facilitate the tracking of moving colour boundaries provided there is sufficient colour contrast between the moving objects. Results also show that luminance templates perform similarly to results obtained from earlier Bugeye chips.

ACKNOWLEDGMENTS

This work was supported by the ARC and the Sir Ross and Sir Keith Smith Fund. We acknowledge the pioneering work of Ali Moini and the early Bugeye group at The University of Adelaide. Thanks are also due to M.V. Srinivasan of The Australian National University for helpful discussion on colour vision in honey bees.

REFERENCES

1. G. A. Horridge, "A template theory to relate visual processing," *Proc. R. Soc. Lond. B* **239**, pp. 17–33, 1990.
2. D. Abbott, A. Moini, A. Yakovleff, X. T. Nguyen, A. Blanksby, G. Kim, A. Bouzerdoum, R. Bogner, and K. Eshraghian, "A new VLSI smart sensor for voidance inspired by insect vision," *Proc. SPIE Intelligent Vehicle Highway Systems, Boston* **2344**, pp. 105–115, 1994.
3. D. Abbott, A. Yakovleff, A. Moini, X. Nguyen, A. Blanksby, R. Beare, A. Beaumont-Smith, G. Kim, A. Bouzerdoum, R. Bogner, and K. Eshraghian, "Biologically inspired obstacle avoidance – a technology independent paradigm," *Proc. SPIE Mobile Robots X* **2591**, pp. 2–10, 1995.
4. A. Yakovleff, D. Abbott, X. Nguyen, and K. Eshraghian, "Obstacle avoidance and motion-induced navigation," *Proc. Int. Workshop on Computer Architectures for Machine Perception, Como, Italy* , pp. 384–393, 1995.
5. A. Moini, A. Bouzerdoum, K. Eshraghian, A. Yakovleff, X. Nguyen, A. Blanksby, R. Beare, R. Bogner, and D. Abbott, "An insect vision-based motion detection chip," *IEEE JSSC* **32**(2), pp. 279–284, 1997.
6. D. Abbott, A. Bouzerdoum, and K. Eshraghian, "Future directions for motion detection based on the parallel computational intelligence of insects," *Proc. 23rd Euromicro Conference* , pp. 36–39, 1997.
7. X. Nguyen, A. Bouzerdoum, R. Bogner, K. Eshraghian, D. Abbott, and A. Moini, "The stair-step tracking algorithm for velocity estimation," *Australian and New Zealand Conf. on Intelligent Information Systems, Perth, Australia* , pp. 412–416, 1993.
8. G. A. Horridge, "Ratios of template responses as the basis for semivision," *Phil. Trans. R, Soc. Lond. B* **331**, pp. 189–197, 1991.
9. A. Yakovleff and A. Moini, "From seeing to preceiving: An overview of the bugeye project," *Advanced Focal Plane Arrays and Electronic Cameras, Berlin, Germany* , pp. 86–96, 1996.
10. A. Yakovleff and A. Moini, "Motion perception using analog VLSI," *Journal of Analog Integrated Circuits and Signal Processing* **2**, pp. 1–22, 1997.
11. G. A. Horridge and P. Sobey, "An artificial seeing system copying insect vision," *International Journal of Optoelectronics* **6**, pp. 177–193, 1991.
12. X. Nyugen, A. Bouzerdoum, A. Yakovleff, A. Moini, R. Bogner, and K. Eshraghian, "A VLSI robotic microsensor: Range-finder from self motion," *Proc. IEEE Int. Conf. Mechatronics and Machine Vision In Practice, Toowomba, Australia* , pp. 78–83, 1994.
13. M. Giurfa, M. Vorobyev, P. Kevan, and R. Menzel, "Detection of coloured stimuli by honeybees: minimum visual angles and receptor specific contrasts," *Journal Comp. Physiol. A* **178**, pp. 699–709, 1996.
14. M. Giurfa, M. Vorobyev, R. Brandt, B. Posner, and R. Menzel, "Discrimination of coloured stimuli by honeybees: alternative use of achromatic and chromatic signals," *Journal Comp. Physiol. A* **180**, pp. 235–243, 1997.