Artificial Colour Insect Vision

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ABSTRACT

The Horridge template model[1] is a biologically inspired motion detection model which is simple and computationally efficient. This model has been successfully implemented on several micro-sensor VLSI chips[2–6] using greyscale pixels. The template model detects moving edges based on the difference in brightness between the edge of the moving object and the background in the spatial and temporal domains.

This paper introduces an extension of the template model to incorporate both luminance and colour templates in two spatial dimensions. The luminance-chrominance colour model is used to generate both luminance and colour chrominance templates which can detect moving edges based on changes in luminance as well as colour contrast associated with a moving edge.

A prototype of this extended model has been implemented from off-the-shelf components. Results from this prototype shows that luminance templates alone are unable to resolve between a group of objects moving at the same relative speed with respect to the sensor. This paper will also show that colour templates can facilitate the detection of colour boundaries. The combination of both luminance and colour templates allows more motion information to be extracted which leads to a more robust system.

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

1. INTRODUCTION

Conventional vision systems are based on complex mathematical models that are computationally intensive and require a digital computer to realise in hardware. Insect vision has been a keen area of research for vision researchers because insects are able to perform complex tasks such as navigation with relatively simple visual systems. This suggests that simpler biologically inspired insect vision models may be viable solutions for restricted tasks of motion detection.[7]

The Horridge Template Model[1] is a simplified model of the insect visual system based on motion detection neurons which infer directional motion in the small field. Several insect vision chips based on the template model have been developed by Moini *et al*[8,5] with greyscale photo-detectors. These Bugeye chips are useful in real time applications such as velocity estimation,[9] range estimation[10] and collision avoidance.[2] However as this paper will demonstrate, greyscale insect vision is unable to resolve objects that have the same brightness, moving in a group, at the same relative speed to the sensor.

An extension of the template model to process both brightness and colour information using the luminance-chrominance colour model has been developed and can detect motion in two spatial dimensions. Luminance is an indication of the brightness level of an object hence luminance templates are equivalent to the greyscale templates developed in the Bugeye chips.[11] Chrominance is a measure of colour contrast and therefore colour templates can detect moving colour edges. The extended luminance-chromiance model should extract more motion information than the original greyscale model alone.

A prototype of the extended colour template model has been developed from off-the-shelf components consisting of a CMOS camera interfaced to a personal computer. Results from this prototype show the ability of this extended model to use chrominance information to detect colour boundaries of moving objects; which would otherwise not have been detected in the original greyscale model.

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2. HORRIDGE TEMPLATE MODEL

The insect visual system can be simplified into 4 layers as shown in Figure 1. The first layer is the retina which consists of a large array of receptors. The lamina performs contrast detection and enhancement using biological band pass and high pass filters. The medulla is the most complex layer of the insect visual system. One type of neuron that exists in the medulla is the small-spatial-field motion detection neuron which can give directional motion information in the small field using information from adjacent receptors over two time instances. The Horridge template model was based on the small-spatial-field motion detection neurons in the medulla. The last layer is called the lobula which contains wide-spatial-field motion detection neurons for detecting whole frame motion.

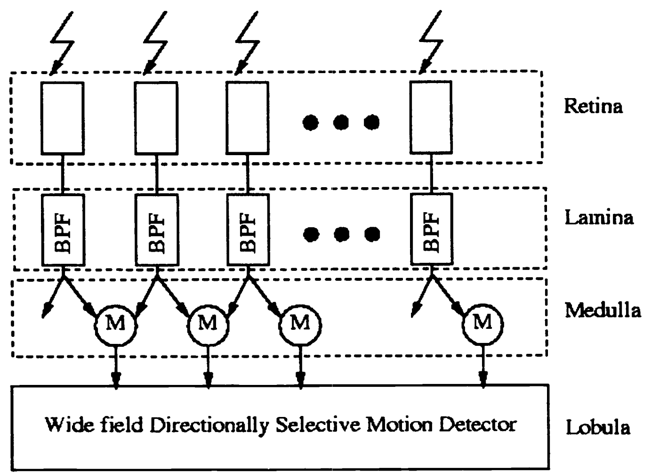

Figure 1. Simplified model of the insect visual system. After Moini *et al.*[5]

The Horridge template model is a simplified model of the insect visual system as shown in Figure 1. Intensity information is sampled from an array of photo-detectors which is then filtered through a differentiation operation. The intensities from each pixel are then quantised into three states through a simple thresholding operation. If the change in intensity is below a given threshold, the pixel is in the no change state (−). If the change in intensity has increased or decreased more that the threshold value, then it is in the increasing state (↑) and decreasing state (↓) respectively. Adjacent states are grouped at two successive sampling instances to form a template. Therefore there are 9 possible combinations for two adjacent pixels which are (- -), (- ↑), (− ↓), (↓↓), (↑↑), (↑ −), (↑↓), (↓ −), (↓↑).

This means that for 2 sampling instances, there are 81 possible templates. Fortunately there are only 8 templates that give directional motion information reliably.[9] These 8 templates are known as Directional Motion Sensitive Templates as shown in Figure 2 and Figure 3. These templates consist of three increasing or decreasing states and one no change state, with the increasing or decreasing states always occupying the diagonals. Hence, by scanning for these templates across the array, moving boundaries can be detected. This ability to detect moving edges can facilitate the tracking of objects.

In our prototype a CMOS camera was used as the sensor. This camera was interfaced to a personal computer where the filtering process was performed by simple frame differencing. Algorithms were developed to perform the thresholding and template generation stages of the model.

3. COLOUR TEMPLATE MODEL

The extended colour template model was inspired by the visual system of the honeybee. Honeybees possess a trichromatic colour system and they rely on achromatic and chromatic visual information alternatively depending on the visual angle of the target[12,13] . The achromatic information is obtained by comparing green contrast with respect to the background. Achromatic information is used when the visual angle to the target is small whilst chrominance is used for larger angles. Green contrast is used in honeybees because of the dominance of green in the bees' environment. However for the general case, luminance or brightness may be more suitable as the achromatic measure. The extension of the template to process both brightness and chrominance information may extract more useful information from the monitored environment than just greyscale vision alone.

The RGB colour scheme was used in our prototype CMOS camera. The RGB colour scheme assumes that each colour is a combination of three primary colours: red, green and blue. The RGB scheme can be converted to the luminance-chrominance model by the following equations:

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

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

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

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

where, Y is 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 an RGB pixel.

As can be seen from the equations above, chrominance is obtained by taking the difference between one of the primary colours red, green or blue with respect to the luminance or brightness. Luminance is a weighted sum of each of the three primary colours and thus chrominance is a measure of colour contrast.

Colour templates are formed by passing the chrominance values of a pixel through the same differentiation, thresholding and template formation stages as the original greyscale model. Therefore 4 sets of templates can be obtained which include the luminance and 3 chrominance templates. The luminance templates will give directional information when there is sufficient brightness contrast between the edge of a moving object with respect to the background. Similarly each of the 3 colour templates will detect moving edges if there is sufficient colour contrast between the moving target and the background.

The template model can also be extended to detect the direction of motion in two spatial dimensions.[14] This can be achieved by applying the same process to the rows and columns of the image independently. By taking adjacent horizontal pixels at two sampling instances, templates which detect horizontal motion can be formed. Similarly, vertical templates can be obtained by taking adjacent vertical pixels at two sampling instances. As in the greyscale case, directionally motion sensitive templates can give an indication of the direction of motion. Directionally motion sensitive templates for the horizontal and vertical orientations are illustrated in Figure 2 and Figure 3 respectively. The tracking of the luminance and colour directionally motion sensitive templates, in two spatial dimensions, can facilitate the detection of moving boundaries if there is sufficient brightness or colour contrast between the moving target and the background.

4. RESULTS: LUMINANCE TEMPLATES

The results in this section demonstrate that greyscale or luminance templates fail to detect moving edges from a group of objects with similar brightness levels, moving at the same relative speed to the sensor.

The test sequence used to generate these results comprises three rectangular objects moving across our prototype sensor at a slight angle to the horizontal axis as shown in Figure 4. The objects have similar luminance values but are coloured red, green and blue respectively.

As can be seen from the luminance templates in Figure 4, only one moving boundary is detected instead of three. Therefore it would *seem* to the sensor that only one object was moving. The greyscale template model has failed to detect the moving boundaries of the three individual objects because there was insufficient luminance or brightness contrast between the moving objects to generate greyscale templates. This result illustrates that greyscale templates alone, may not be sufficient to extract sufficient motion information for object tracking applications.

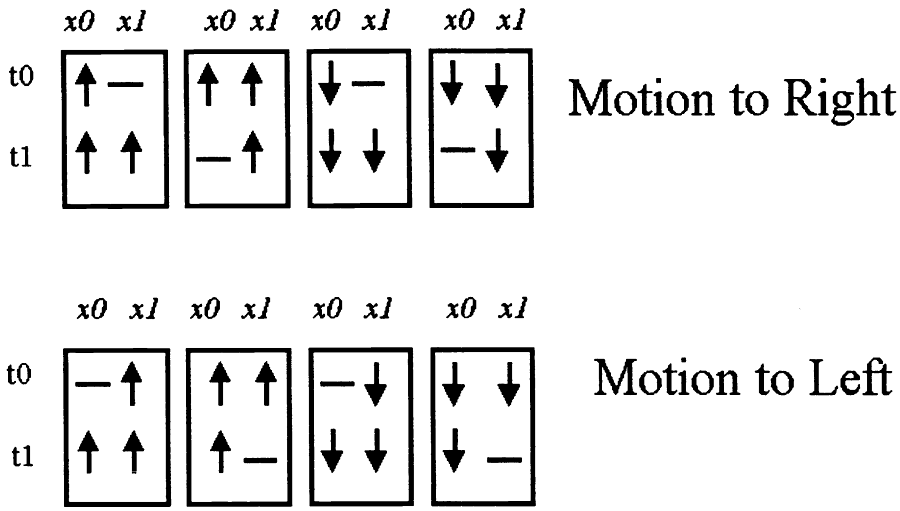

Figure 2. Directionally motion sensitive templates in the horizontal direction.

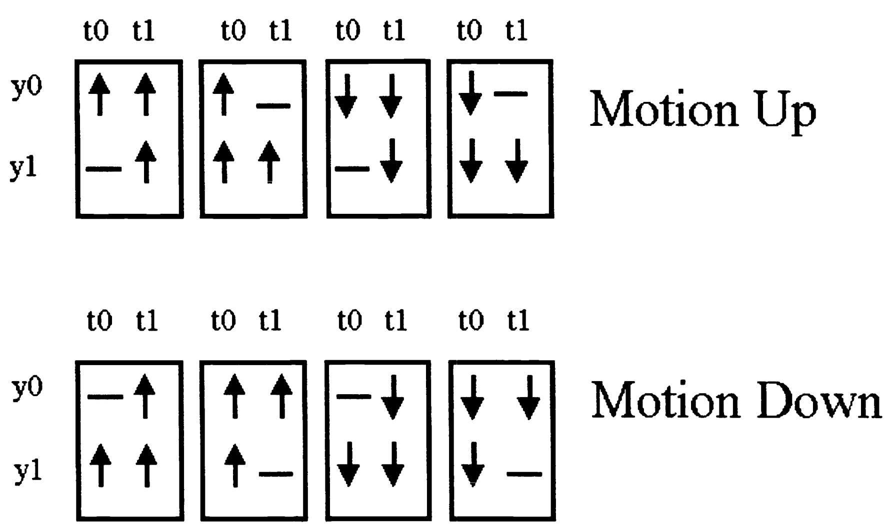

Figure 3. Directionally motion sensitive templates in the vertical direction.

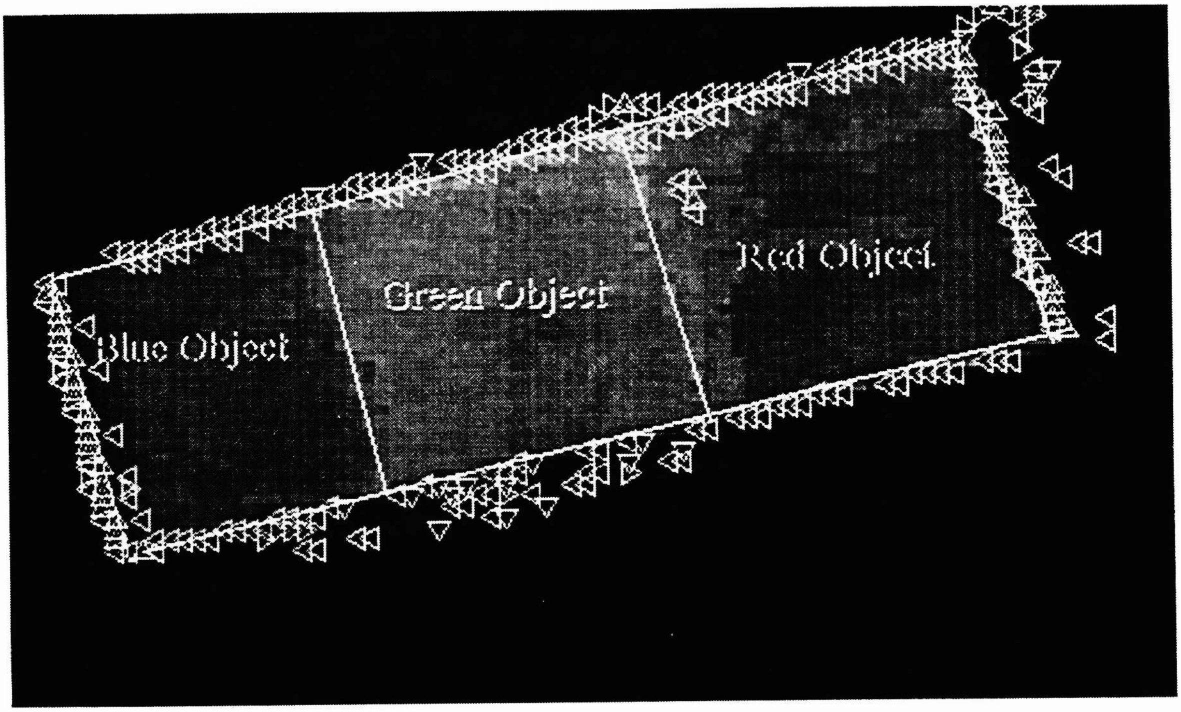

Figure 4. Luminance templates for the test sequence containing three coloured objects(red, green, blue) moving with the same relative speed to the sensor. The objects are moving from right to left across the sensor at a slight angle to the horizontal axis. The arrows $\triangleleft, \triangleright, \nabla, \triangle$ represent directionally motion sensitive templates as shown in Figure 2 and Figure 3.

5. RESULTS: COLOUR TEMPLATES

Figure 5, Figure 6 and Figure 7 show the output of each of the 3 colour templates for the same test sequence as the luminance templates shown in Figure 4. The chrominance templates clearly show that the moving colour boundaries of each of the individual objects can be detected. This is possible because there was sufficient colour contrast between the objects to facilitate the detection of colour moving edges. Note that for Figure 5, the red colour templates also allowed the vertical boundary between the green and blue object to be detected. This is because there is sufficient red colour contrast between the green and blue object to yield templates for the threshold level used. There are also templates whose indicated motion direction does not correspond to the movement of the objects. These templates are generated because just like in any sampled spatial temporal vision system, noise can be a factor. For a more detailed discussion on the problems of noise and aliasing in a two-dimensional template model refer to Beare *et al.*[14] Hence the introduction of colour templates in this sequence has allowed the correct detection of the colour moving edges. The luminance and 3 chrominance templates can be combined to identify boundaries of the objects in two dimensions hence potentially facilitating the tracking of multiple objects in certain environments especially when *a-priori* knowledge of the object shape and colour is available. The successful detection of moving colour edges would also suggest that the use of both colour and luminance information may be able to extract more motion features from a sequence hence making the vision model more robust to differing operating environments.

6. FUTURE WORK

This paper has presented an extension to the template model to process both colour and luminance information to give directional motion information in the small field across two spatial dimensions. These templates can be seen as the front end of an intelligent artificial visual system tailored for suitable real time applications. Therefore backend algorithms which process these templates to infer wide field information need to be developed.

Detailed investigations on the effects of different thresholding levels on the sensitivity of colour templates would be beneficial in determining the suitability of this model for different real time object tracking applications.

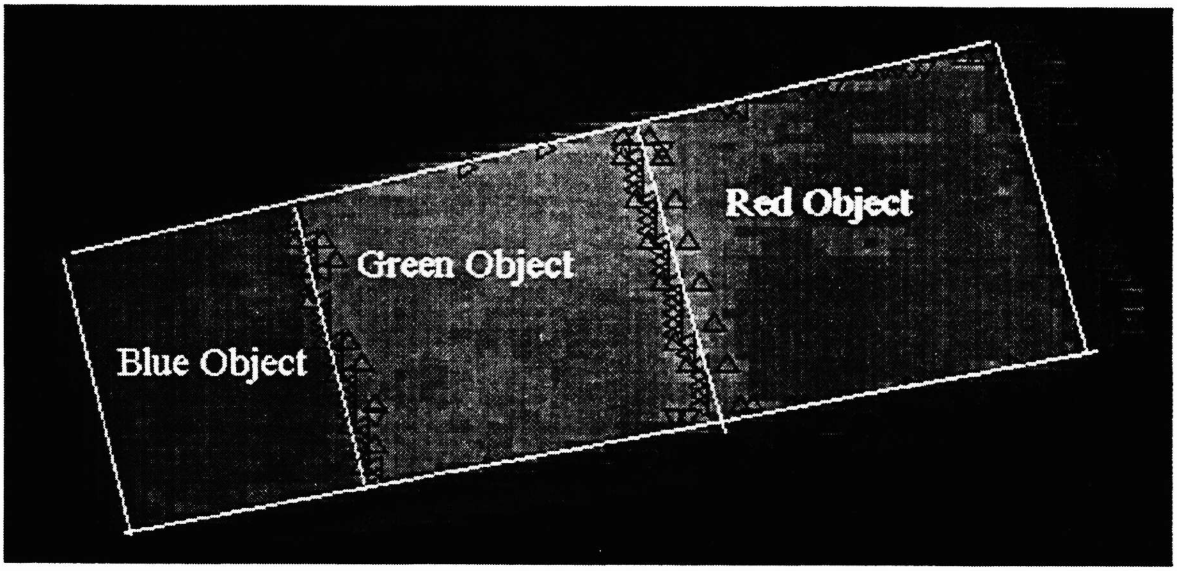

Figure 5. Red chrominance templates for the test sequence containing three coloured objects(red, green, blue) moving with the same relative speed to the sensor. The objects are moving from right to left across the sensor at a slight angle to the horizontal axis. The arrows $\triangleleft, \triangleright, \nabla, \triangle$ represent directionally motion sensitive templates as shown in Figure 2 and Figure 3.

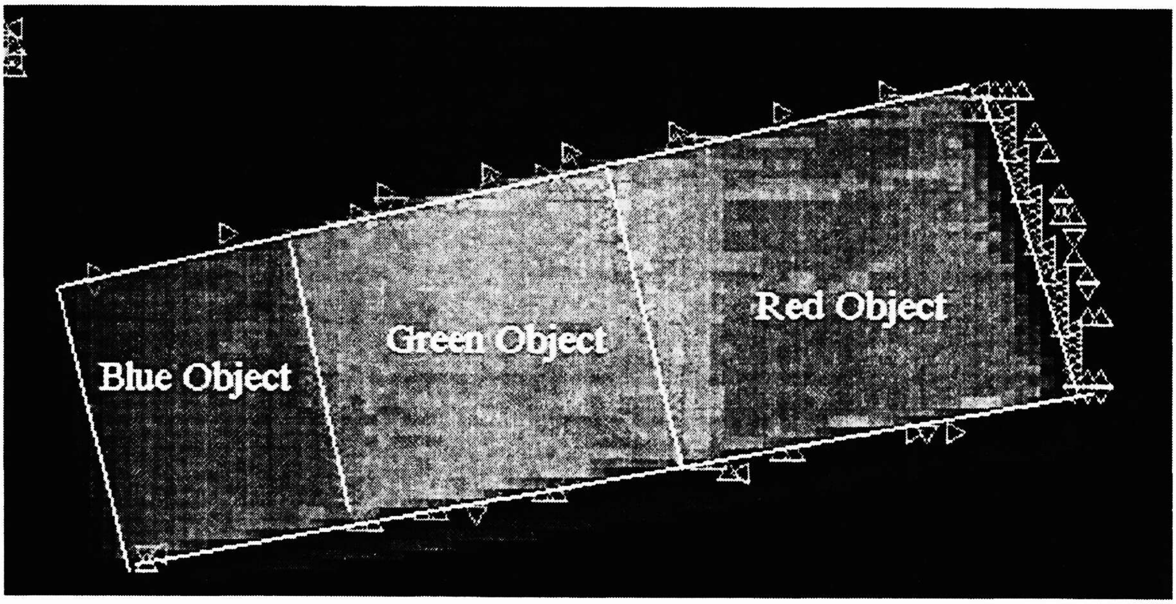

Figure 6. Green chrominance templates for the test sequence containing three coloured objects(red, green, blue) moving with the same relative speed to the sensor. The objects are moving from right to left across the sensor at a slight angle to the horizontal axis. The arrows $\triangleleft, \triangleright, \nabla, \triangle$ represent directionally motion sensitive templates as shown in Figure 2 and Figure 3.

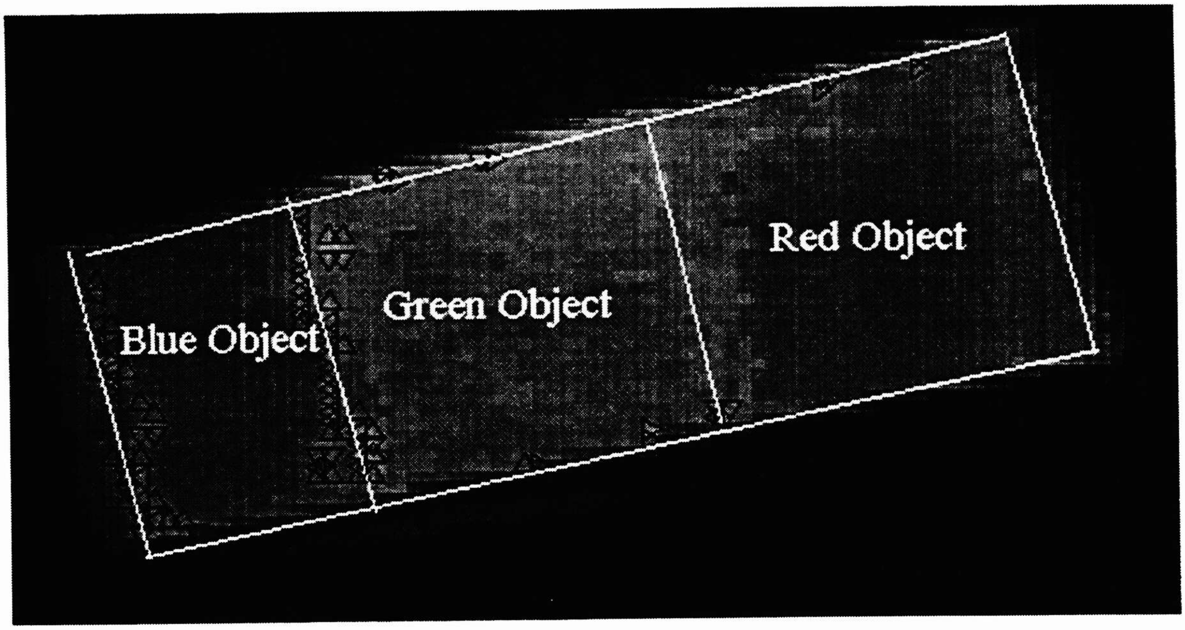

Figure 7. Blue chrominance templates for the test sequence containing three coloured objects(red, green, blue) moving with the same relative speed to the sensor. The objects are moving from right to left across the sensor at a slight angle to the horizontal axis. The arrows ◁, ▷, ▽, △ represent directionally motion sensitive templates as shown in Figure 2 and Figure 3.

The template model in the greyscale domain experienced problems that are common to many spatial temporal vision systems. Some of these problems include aliasing and the effect that noise has on the model. Hence studies into the effects of these common problems to colour templates would also be invaluable.

7. CONCLUSION

In conclusion this paper has introduced an extension to the Horridge Template model to process both brightness and colour information in two spatial dimensions. 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. The inclusion of luminance templates in this model means that moving edges can also be detected if there is sufficient brightness contrast. Results show that the combination of both luminance and colour templates suggests that more motion information can be extracted from a sequence than greyscale insect vision alone.

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