Elaborated Motion Detector based on Hassenstein-Reichardt correlator model

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Abstract: Many of the motion detectors are based on identifying and tracking spatial or temporal features. The main disadvantage of these circuits is the uncertain detection at low SNR conditions. In 1956 Hassenstein and Reichardt tried to explain the mechanism of the insect vision and proposed an alternative to motion detection with an intensity-based spatiotemporal correlation algorithm. Based on this type of algorithm we implemented an improved motion detector that not only detects a moving object but also gives some additional information such as the sense and direction from where the object is coming. This system is intended to be used as front-end processing for a more complex visual motion computation models, like the ones performed by insects such as flies or locusts.

Key-Words: motion detection, motion computation, Reichardt correlator, EMD, insect vision, sense and direction detectors

1 Introduction
The flying insects visual systems is a good inspiration in creating a robust motion detector, that works in a natural environment. Even if insects are considered simple organisms compared to vertebrates because of their nervous systems structure, they have this extraordinary ability to fly and adapt as a result of genetic inheritance characteristics of previous generations, that is why not in vain it has been given them the name of “perfect flying machines”. They can land or take off vertically, move backward or laterally, and also fly upside-down. The Reichardt or correlation motion detector has been inspired by the experiments that followed the behavioral of the optomotor response of insects.
This type of motion detector has a parallel architecture that compute in very different ways from traditional digital computers. In practice two channels detects motion in a preferred direction by comparing a signal from one receptor with a delayed signal from the other receptor.
The Reichardt detector, also known as Hassenstein-Reichardt detector or Elementary Motion Detector (EMD) seems to be the fundamental part in all insect motion processing.
This paper present an architecture that combine this basic motion detectors inspired by the insect visual system and add new features like the localization in space of the moving object.

2 The “basic” Reichardt detector
The simplified version of the Hassenstein and Reichardt correlator model is made from two symmetrical sub-units (Fig.1).

Fig.1 The elementary motion detector (EMD) block diagram
In each sub-unit the signals received from their neighboring entries are multiplied each other after one of
them was delayed against the other using a delay line or a low-pass filter. The final response of the detector is given by the difference output signals of the two subunits. The combination of time delay and a multiplication is why this type of detector measures the degree of coincidence of signals in the input channels, making a space-time inter-correlation.

If an object passes through the detector, from right to left, left channel is activated first, and after a time is activated the right channel. This time depends on the speed of the object and spatial distance between the two input channels. Using a delay line, the two signals $i_1(t)$ and $i_2(t)$ arrive simultaneous in the multiplication stage left subunit, resulting in a higher response signal $m_1(t)$ compared with $m_2(t)$. After the two output signals $m_1(t)$ and $m_2(t)$ are subtracted from the two subunits, it gives a strong selective response towards the direction $o(t)$ (positive for motion from left to right and negative if the motion is from right to left).

This type of EMD will give a strong response when a visual stimulus moves in a preferred direction and weak response when the stimulus moves in the opposite direction.

### 3 An improved motion detector with spatial localization feature

Using the EMD cell we implemented a motion detector which can distinguish between an object moving towards the front direction of an object moving horizontally. In Fig.2 we have the block diagram of the improved elementary motion detector.

#### 3.1 Description of the elaborated motion detector block diagram

The preprocessed image received from the image sensor at pixel level is distributed at two channels where is computed differently.

In the channel 1, the image is divided into two identical parts, symmetrical by the vertical axes. The EMD cell computes the correlation between this parts pixel by pixel. The summation of all pixels provided by the EMD’s output is an excitation signal that contains the information about the sense of the motion in the horizontal line (motion from right to left or from left to right).

In the second channel, the image is divided also into two parts, but in this case, one part remains unchanged and the other part enlarges the image by both axes. The summation of the correlated pixels brought by de EMD’s output between these parts is an excitation signal that shows the closeness or distance of a moving object. In this way we know if the object is approaching or, contrary it moves away.

The summation of the pixels from the image sensor preprocessed output represents a reference signal or an inhibition signal against which is reported the excitation signal from the EMD. The difference between these signals is compared with an upper limit and a lower limit ($V_{thH}$ and $V_{thL}$) resulting the sense of the moving object direction by the case.

The output results of the comparators from Fig.2 which represent the sense and the direction of the moving object are gathered in one multiplexor to be available for more computing processes.

![Fig.2 The proposed motion detector block diagram](image_url)

#### 3.2 Simulation of the proposed motion detector

For the simulation of the proposed motion detector we used Simulink tool.

The image sensor used for the simulation was a low resolution webcam (160x120 pixels) and the preprocessing part was made with an edge detection algorithm to be more appropriate with the insect’s visual system.
In Fig.4 and Fig.6 there are the results of the simulation. The object of the simulation was a hand that moves in front of the camera in different directions. In the first case the hand is moving in horizontal plane from right to left and from left to right with a rest time between successive movements. As shown in the diagram from Fig.4, channel 1 has a more intense activity resulting in a pulse train. The sign of the pulses indicates the sense of the motion, in this particular case +1 indicates the right-left movement and -1 the left-right movement.

In the second experiment, in Fig.5, the hand moves back and forth in front of the camera. In this case the diagram from Fig.6 shows a more intense activity at channel 2. The negative sign of the pulse shows that the object is approaching and the positive sign the contrary.

When the differential signal from Fig.4, diagram A., exceeds the upper threshold $V_{thH}$, the comparator will generate a positive pulse as seen in diagram B., meaning that it was a move from right to left in front of the sensor. In the same way, when the differential signal from Fig.4, diagram A., goes below a lower limit $V_{thL}$, the comparator will generate a negative pulse as seen in diagram B., meaning the sensor detected a left to right motion. In an ideal case, the differential signal from Fig.4, diagram C. should not exceed $V_{thH}$ or to go below $V_{thL}$, but in a real environment this situation occurs because of the correlation process, so the comparator will generate a few spikes as shown in Fig.4 diagram D.
diagram C, that goes below a lower limit VthL, or exceeds a upper limit VthH. Also, the opposite channel will generate some spikes due to the correlation process.

4 Conclusion

In this paper we presented an elaborated motion detector using as main unit the Reichardt correlator model. Using as source of inspiration biological motion detectors of the insects we gain many of the advantages that comes from it.

The elaborated motion detector is considered to be a proof of concept of what possibilities are for the usage of the elementary motion detector. The purpose of this paper was more to highlight the fact that using this type of EMD can be achieved besides simple motion detection also some very important additional information like the sense and the direction of the moving object.

To put these proprieties in evidence and for the simplicity of the experiments we used for the simulation a controlled environment with an appropriate signal-to-noise ratio, knowing the fact that Reichardt correlators have some problems when they are used in a wide range of luminance levels and contrasts.

It is important to mention that for the simulation is used a low resolution sensor of only 160x120 pixels, because this aspect matters if we want a system to compute in real time.

To use this motion detector in a real environment, it has to be integrated in a more complex system that can interpret the results provided by it, but this is a subject for a future research.

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