

One Dimensional Motion Detector ----Multiplicative Inhibitory Velocity Detector(MIVD)

Aiqun Wang, Nanning Zheng, IEEE senior member, and Lixing Yuan

Institute of Artificial Intelligence and Robotics,
Xian Jiaotong University, Xian, P.R.China, 710049

Abstract

Motion perception is one of the most important aspect of the biological visual system, from which we get a lot of information of the natural world. From the physiological and anatomical study on biological vision system, it is shown that the perception of two dimensional (2D) motion is in two steps: one dimensional (1D) motion detection and 1D motion information fusion. This paper we pay attention on the first step. Trying to simulate the neurons in MT (motion area in visual cortex) who respond selectively both in direction and speed, we propose a novel multiplicative inhibitory velocity detector (MIVD) model, whose spatiotemporal joint parameter K determines its optimal velocity. Based on the Response Amplitude Disparity (RAD) property of MIVD, we construct the 1D motion detection layer as a multi-velocity motion perceptron layer, using MIVD(K) as its perceptron.

1 Introduction

Vision is one of the most important senses to animals. One early and fundamental visual task is the processing of motion information. From 1960's C. Enroth-Cugell and J. G. Robson's great study [1] of the retinal ganglion cells of the cat, to 1980's great works of D. Marr [2], S. Ullman [3], J. A. Movshon [4] in perception of motion. The mechanism of biological motion perception has become more and more clear for us, even though there are still some secrets remain.

The neurons in the motion area of visual cortex (Middle Temporal -- MT) have their great feature--the velocity selectivity. Most neurons have their great responses only to a motion with a certain moving direction (direction-selectivity) and with a specific speed (speed- selectivity), which means it has its own optimal perceptual velocity[5][6].

Based on physiological and anatomical findings, many scientists tried to perceive the scene artificially, using the

current limited knowledge about the biological system. For motion perception, early in 1961, Reichardt proposed his famous Autocorrelation model [7]. This model is still interesting for us in explaining the biological motion perception.

After a long time, now scientists discover that the inhibitory is the mechanism underlying direction selectivity of neurons. In A. Bouzerdoun and P.B. Pinter's paper [8], they used the nonlinear multiplicative lateral inhibitory mechanism (MLI) to simulate the inhibitory in biological visual system.

Both Reichardt's [7] and Pinter's models [8] deal with direction selectivity, but both lack speed selectivity in some sense. In this paper we build a new motion detector model which have the velocity- selectivity, using modified MLI michanism to simulate the inhibitory mechanism of biological system.

In this paper, simulating the characteristics of the motion perceptual neurons (the direction-selectivity, the speed-selectivity, the lateral inhibitory mechanism), we proposed a novel motion detector with velocity-selectivity, the multiplicative inhibitory velocity detector (MIVD) , whose spatiotemporal parameter K determines its optimal velocity. The motion direction will express by the sign of its output; and if the speed is higher or lower than its optimal speed , its output will fall off. There is a good property of MIVD, the response amplitude disparity (RAD), which means for a certain moving stimulus, the responses of MIVDs with different optimal velocities are comparable. The MIVD which optimal velocity fits the stimulus velocity will give out the maximum response amplitude. According to this property we can recognize the stimulus velocity easily.

2 The Physiological and Anatomical Finding of Motion Perception

2.1 Selectivity

Studies in cats and monkey indicate that the visual

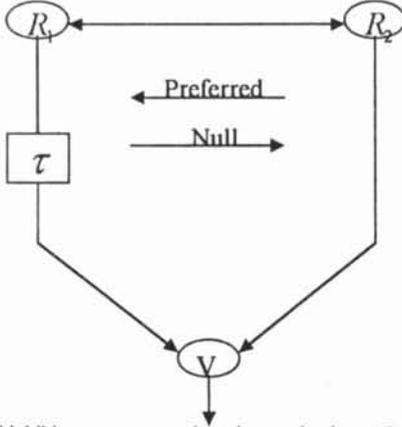


Fig 2.1 Lateral inhibitory movement detection mechanism. (Copied from A. Bouzerdown and R. B. Pinter [8]) The visual field is sampled at two receptor regions, R1 and R2, separated by a distance ΔS . The signal from one receptor is passed through an "appropriate" time delay, before interacting with the signal from the adjacent channel. V represents for veto scheme. If the two signals reach V concurrently (null direction), they cancel each other and no motion is signaled. However, if the two signals arrive at V separately (preferred direction), the veto signal is unable to suppress the other signal, which indicates motion.

cortex is organized in a topographic, laminas and columnar fashion. Neurons with similar orientation and direction selectivity are stacked in discrete columns which are perpendicular to the cortical surface. All the neurons such as simple neurons, complex neurons and hypercomplex neurons within a column have the same receptive field axis orientation. The simple neurons are orientation-selective. For the complex neurons, not only the orientation of the line but also the stimulus speed and motion direction are important. If the speed is less or greater than the optimum of that neuron, the neuron firing frequency tends to fall off sharply [5]. The optimal speed varies from neuron to neuron. The range of velocities is almost four log units, starting at 0.1deg/sec (only slightly more than the average drift velocity of the direction of gaze) up to 200 deg/sec (only a little less than the velocities reached during saccadic eye movements) [6]. Hence, the complex neurons are direction and speed selective, i.e. velocity selective.

2.2 Inhibitory mechanism in motion perception

Many models of directional selectivity rely on time-delayed inhibition in the null direction as first proposed by Barlow and Levick [9] for the rabbit retina and by Reichardt et al. [10] for the fly. They discovered that inhibition is the mechanism underlying direction selectivity of ganglion cells in the retina. They suggested that inhibition is triggered selectively in such a way that at each subunit of the receptive field a delay inhibitory mechanism vetoes the excitatory response in the null direction, but appears too late to cancel the response in the preferred direction (Fig. 2.1).

3 The Motion Detector with Velocity-Selectivity

3.1 Multiplicative inhibitory velocity detector (MIVD)

Pinter's MIMD is a good model of direction-selective motion detector. But it doesn't have the velocity-selectivity to some extent[8]. Actually the complex neurons in MT not only respond selectively in direction, but also respond selectively in velocity. So based on Pinter's model, we change its temporal characteristics by substituting its low-pass filter $\frac{1}{s+k}$ by a spatial-related band-pass filter $\frac{\Delta \omega s}{[s+(\omega_0-\Delta \omega/2)][s+(\omega_0+\Delta \omega/2)]}$, where ω_0 is inverse-proportional to the spatial distance ΔS ($\omega_0 = \frac{K}{\Delta S}, \Delta \omega = \frac{\omega_0}{M}$); we change its multiplicative lateral inhibition (MLI) by substituting its low-pass pattern by a high-pass pattern. This change will add the velocity-selectivity characteristics into the original model. The analysis of the velocity-selectivity of this model will appear in next section. Now, at first we describe our model (Fig. 3.1).

The ordinary differential equations which describes each subunit of MIVD are:

$$\begin{aligned} \ddot{e}_{\xi,1}(t) &= \frac{K}{M\Delta S} \dot{L}_p(t) - \frac{2K}{\Delta S} \dot{e}_{\xi,1}(t) - (1 - \frac{1}{M^2}) \frac{K^2}{\Delta S^2} e_{\xi,1}(t) \\ \dot{e}_{\xi,2}(t) &= \dot{L}(t) - k_2 e_{\xi,2}(t) [1 + k_{\xi,2} f(e_{\xi,1}(t))] \\ m(t) &= e_{r,2}(t) - e_{l,2}(t) \end{aligned} \quad (3.2)$$

Where $\xi = l, r$ depending on which leg (left or right) is being described; if $\xi = r, p = 1$; otherwise $p = 2$.

3.2 The velocity selectivity of MIVD

In this lateral inhibitory model, the response of one motion depends on the inhibitory amplitude of that motion. If it gives a great inhibition at one leg, then the response of the motion will be great; if neither legs give inhibition, the two legs will cancel each other and give no response at $m(t)$. At first we discuss the relationship between the inhibition and the motion velocity.

Suppose we have a motion of step stimulus at velocity v (and ideal model of moving edge), and it reach $L_1(t)$ at $t = 0$, then it run to $L_2(t)$. We describe it as:

$$\begin{aligned} L_1(t) &= \begin{cases} 1 & t \geq 0 \\ 0 & \text{else} \end{cases} \\ L(t) &= \begin{cases} 1 & t \geq \Delta S/v \\ 0 & \text{else} \end{cases} \\ L_2(t) &= \begin{cases} 1 & t \geq 2\Delta S/v \\ 0 & \text{else} \end{cases} \end{aligned} \quad (3.3)$$

Assume the $f(e_{\xi,1}(t)) = e_{\xi,1}(t)$, $k_{\xi,2} = 1$. At $t_1 = \frac{\Delta S}{v}$, the

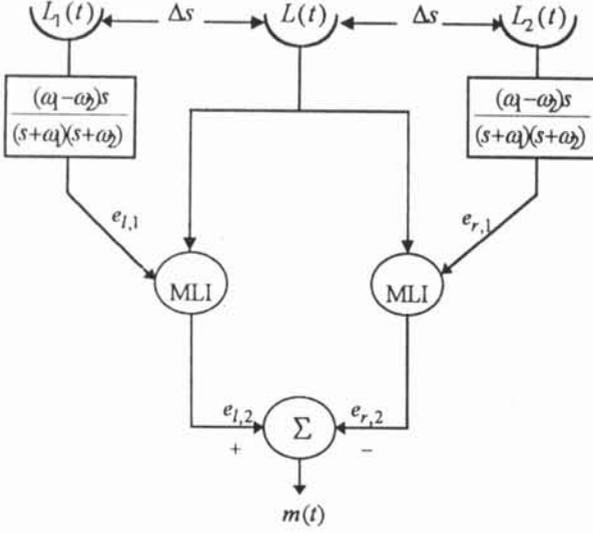


Fig. 3.1 Multiplicative inhibitory velocity detector (MIVD). Where $\omega_1 = \omega_0 + \Delta\omega$, $\omega_2 = \omega_0 - \Delta\omega$, $\omega_0 = K / \Delta s$, $\Delta\omega = \omega_0 / M$, $M \gg 1$

point reach $L(t)$, the inhibition that $L_2(t)$ gives $L(t)$ is null, and the inhibition that $L_1(t)$ gives $L(t)$ at this time is :

$$\begin{aligned} \text{Inhibition}(t_1) &= k_{r,2} f(e_{r,2}(t_1)) = e_{r,2}(t_1) \\ &= \int_0^{t_1} \frac{M+1}{M} \frac{K}{\Delta s} e^{-\frac{M+1}{M} \frac{K}{\Delta s} t} - \frac{M-1}{M} \frac{K}{\Delta s} e^{-\frac{M-1}{M} \frac{K}{\Delta s} t} dt. \quad (3.4) \\ &= -e^{-\frac{M+1}{M} \frac{K}{\Delta s} t_1} + e^{-\frac{M-1}{M} \frac{K}{\Delta s} t_1} \end{aligned}$$

Here $t_1 = \frac{\Delta s}{v}$. Assume Δs is constant. So, $\text{Inhibition}(t_1)$ is a function of v . Let t_1 in (3.4) be substitute by $\frac{\Delta s}{v}$.

$$\text{Inhibition}(v) = -e^{-\frac{M+1}{M} \frac{K}{v}} + e^{-\frac{M-1}{M} \frac{K}{v}} \quad (3.5)$$

At the optimal velocity, v_{opt} , the $\text{Inhibition}(v_{opt})$ is the maximum, that is, the $\text{Inhibition}'(v_{opt}) = 0$. So,

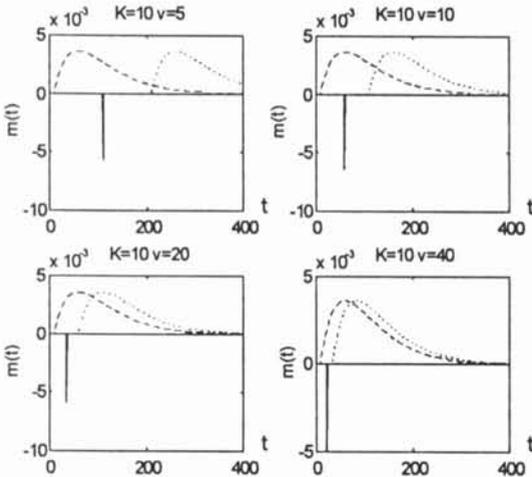


Fig. 3.3 For $K=10$, $m(t)$ (the solid curve) gives out the greatest respond -7×10^{-3} at $v=10$. $e_{1,1}(t)$ are shown as double dashed curve, $e_{r,2}(t)$ are shown as dashed curve. At this time $L_1(t) = u(t-10)$, $L(t) = u(t-10 - \Delta s / v)$, $L_2(t) = u(t-10 - 2\Delta s / v)$. $M = 10$, $\Delta s = 500$.

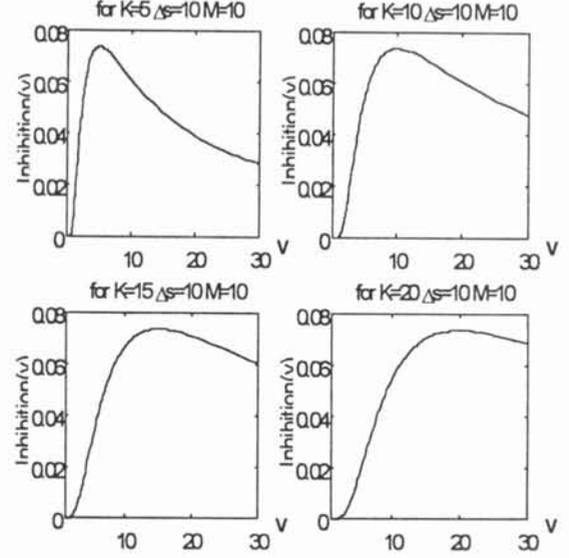


Fig. 3.2 The inhibitory amplitude of velocity, for $K = 5, 10, 15, 20$. The greatest inhibition is at $v_{opt} = K$.

v_{opt} is :

$$\frac{2K}{v_{opt}} = -M \ln \frac{M-1}{M+1}. \quad (3.6)$$

for $M \gg 1$, $-M \ln \frac{M-1}{M+1} \approx 2$, then $v_{opt} \approx K$. (3.7)

When the velocity of stimulus is $v_s \approx K$, the inhibition reaches its maximum, and the final response output $m(t)$ reaches its maximum. That is, the optimal velocity of this model is determined by the spatiotemporal parameter $K = \omega_0 \cdot \Delta s$.

Just as in Fig 3.2, for $K = 5, 10, 15, 20$, the greatest inhibition is at $v_{opt} = 5, 10, 15, 20$ respectively. The final results of $m(t)$ at some specific v of $K = 10$ are illustrated in Fig 3.3, it can be seen that $m(t)$ gives the biggest response to $v = 10$. Fig 3.4 shows four curves of

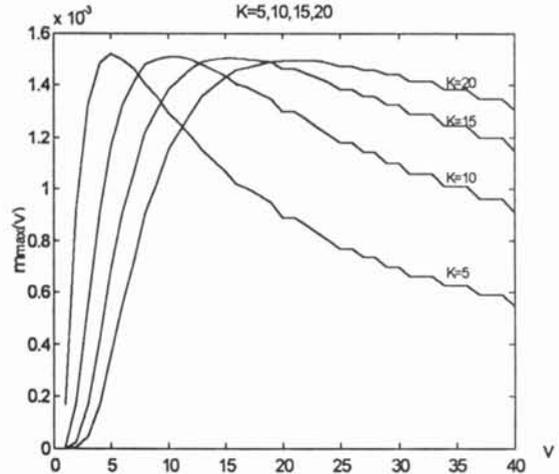


Fig. 3.4 The curve $m_{max}(v)$ reports the greatest respond of $m(t)$ at V . It shows that the optimal velocity of this model is $v_{opt} \approx K$, and it can be classified easily by its response amplitude.

$K = 5, 10, 15, 20$ respectively. Every curve shows the maximum response of $m(t)$ at every v of certain K . From these four curves, we see that at $v_{opt} = 5, 10, 15, 20$, this model gives its greatest response, which we deduced from $Inhibition'(v_{opt}) = 0$. Fig 3.4 illustrates that this model has the velocity-selectivity, which optimal velocity is changed according to the $K = \omega_0 \Delta s$, where K determine the joint spatiotemporal characteristic of this model. From Fig. 3.4, we see another important property of MIVD, the response amplitude disparity (RAD): for a certain stimulus motion, the response of MIVDs with different optimal velocities is comparable, the MIVD which optimal velocity fits the stimulus velocity will give out the greatest response amplitude. According to this property we can recognize the stimulus velocity easily.

4 1D Multi-Velocity Perceptron Layer of 2D Image Sequence

We divide the 2D velocity space into P directions and Q levels of velocity. Along each direction of every image point (i, j) , there are Q different 1D velocity detectors, MIVD, which optimal velocity is the Q levels of velocity respectively. If in the positive direction of p th direction, there is a motion at q th level of velocity, then the perceptron $M(i, j, p, q) = 1$; If in the negative direction of p th direction, there is a motion at q th level of velocity, then the perceptron $M(i, j, p', q) = 1$, where direction p' is the opposite of p ; If there is no motion, then the perceptron $M(i, j, p, q) = M(i, j, p', q) = 0$.

Then the relationship between $M(i, j, p, q)$ and $MIVD(k_q)$ is: If there are Q MIVD in the p th direction of pixel (i, j) , and there exist q_{max} , which satisfied:

$$MIVD(q_{max}) = \max_{q=1, Q} MIVD(q).$$

Then the output of the $2*Q$ 1D velocity perceptrons in p th direction are:

- 1) if $|MIVD(q_{max})| < \text{threshold}$, then $M(i, j, p, q) = M(i, j, p', q) = 0, 1 \leq q \leq Q$.
- 2) if $|MIVD(q_{max})| \geq \text{threshold}$, then $M(i, j, p, q) = M(i, j, p', q) = 0, 1 \leq q \leq Q, q \neq q_{max}$, and if $MIVD(q_{max}) > 0$, $M(i, j, p, q_{max}) = 1$, if $MIVD(q_{max}) < 0$, $M(i, j, p', q_{max}) = 1$.

In this layer the motion in 2D image sequence is detected by $2*P*Q$ 1D velocity detectors.

5 Conclusion

In this paper, we propose a velocity-selective motion detector model MIVD, based on the lateral inhibitory mechanism, which was believed to be suitable to explain the motion detection mechanism in biological visual

system. The selectivity of MIVD depends on its spatiotemporal joint parameter K . The good response amplitude disparity property of MIVD makes it a good detector while we use it as velocity-sensitive motion detection neuron in the 1D multi-velocity perceptron layer.

In this paper we just discuss problem in 1-Dimension field. In the future, we want to use this MIVD in 2-Dimension field, which have more problems to solve, such as the "aperture problem" mentioned by Marr [2] and Movshon [4]. But 1-D velocity detector is still the base for 2-D motion detection. We think the MIVD model will also be a good velocity detector in 2-D case.

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