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Research on Imaging System of Artificial Compound-Eye and Moving Object Detection

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Abstract

To solve the problem of moving object detecting in the wide field, this paper establishes a new artificial compound imaging system and proposes moving object detection algorithm. According to the unique principle of receiving and processing of visual information from animal compound-eye, the model of artificial imaging system consists of a micro-lens array and CCD device with planar array, captures dynamic image sequences in the different azimuth, and assures its advantages of long-distance and wide-range detection and good image effect. In order to get the motion vector of moving object, researches the characteristics of background in the relevant imaging sequence, discusses the mechanism of processing visual information, the estimation algorithm adopt the high-pass filter processing after making the three-dimensional space transformation to reduce the disturbance of noise and enhance the effect of background suppression firstly. The motion vectors of dynamic object is obtained by processing the relevant imaging sequence with the maximum correlation coefficient, refers to the EMD array. Preliminary experimental results for target tracking shown that the artificial compound imaging system and moving object detection algorithm is practical and effective, and which has a highly practical application value.

Keywords*: compound-eye, micro-lens, object detecting, EMD*

1. Introduction

In the target detection system, speed and accuracy have become increasingly demanding, with the development of image processing technology [1]. The multi-angle image sensor and target detection technology has become a research hotspot [2]. The traditional object motion estimation algorithm includes major time difference, background subtraction and optical flow, which belong to the field of machine learning.

In recent years, with the development of bionics theory in image processing technology, it has been widely applied to the field of moving object detecting. There are many of advantages in receiving and processing visual information of the insect's compound eye after millions of years' evolution, which help it to extract the information of moving objects quickly and accurately from the complex environment, and estimate the target's direction of movement easily [3].

Based on the principles of animal compound-eye and the unique mechanism of receiving and processing of visual information, a new artificial compound imaging system and moving object detection algorithm is proposed. So if the target motion and rapid estimation mechanism of the compound eye can be applied to the comprehensive survey of target detection, location estimation, target tracking, *etc.*, we will receive a profound impact on the visual navigation and machine vision and other fields.

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2. Insect Visual Target Detection Mechanism

In the nature, through a long evolutionary process, fly has formed its own set of visual system, which can locate target objects quickly, relay on the unique skills of the receiving and processing of visual information from the surrounding environment. There is a pair of symmetrically hemispherical compound eye on the fly's head, and each of that consists of 3200 eyes with the same physical structure and visual function exactly [4]. The detecting view of each eye is independent and limited. Combing all these field of each eye, the fly get a large field where it can detect any trends on the orientation of the attackers quickly.

2.1. The Physical Structure of Fly Visual System

In physical optics, the face of each eye equivalent to a small independent imaging lens. All these faces' symmetry axis intersects in the center of the compound eye surface. A hexagonal array of multi-lens are formed by combining these small eyes' face arrangement regularly, and then constitutes a large visual imaging system. The physiological structure of fly's compound eye is shown in Figure 1. The structure of the ommatidinm was highly complex, and made up of cornea, corneagenous cells, crystalline cones, crystalline cone cells, pigmental cells, retinular cells [5].

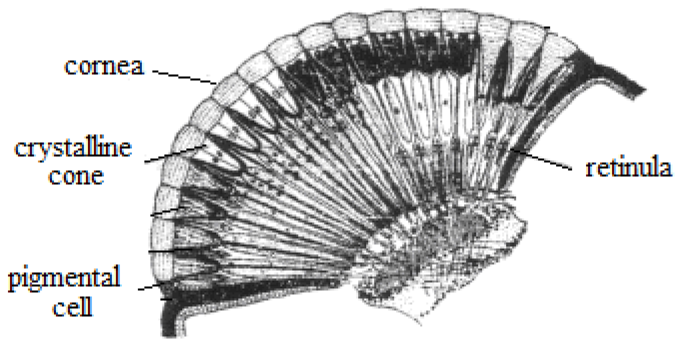


Figure 1. Physiological Structure of Fly's Compound Eye

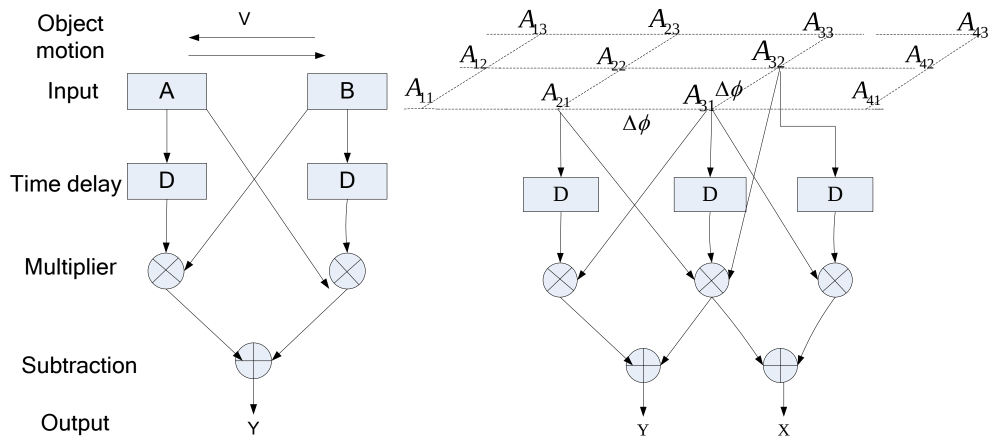
Each eye is divided into four parts, that is a cornea, a photoreceptor, light-lock doors and visual center, according to exert different functions in imaging process. These small eyes perceive any movement accepted by different space distribution of light intensity. The coding of moving objects' information including environmental structure, spatial location and texture, not only remain at the level of retinal images, but also reprocessed by via multi-dimensional photoreceptor array of itself eye [6]. Single photoreceptor receives only the partial brightness information of the moving object, but its information can not be integrated and processed independently.

As a result, the effective moving information of objects can not be able to calculate accurately. However, the effective information can be capture by integrating, from an array of photoreceptors in different directions. Flies have a high speed and azimuth resolution capability, and can capture the target quickly.

2.2 Target Detection Model of the Fly's Nervous System

There are many detectors named EMD in the fly's nervous system, and that they are responsive to any motion but also for direction of motion. The moving information processing of the fly's visual nervous system by EMD, include several stages: (a) A local optical receivers get the information, and then pass it to the corresponding detector; (b) The local detectors detect the moving information perpendicular to its own local edge; (c) Integrate and calculate these results from all the detectors, and get the real moving object information finally.

The simplified mode of elementary motion detector (EMD) is shown in Figure 2 (a) below. EMD model is extremely sensitive to the direction of motion, and the velocity can be estimated. In this figure, A and B represent two signal channels, corresponding to different points in space vision, which spatial separation is $\Delta\phi$ that is small. D represents a delay unit. If the goal moves from A to B, the signal from A processed through D, multiply the signal from B, and then produce a positive output. The result is negative when the goal moves from B to A. Finally, the total output R of the entire motion detector will be produced by adding two signals' output. When the velocity and the delay time are matched, the maximum output of EMD model is obtained.



(a) The Model of Elementary Motion Detector (b) Two Dimensional EMD

Figure 2. EMD Model and Processed Moving Signal Diagram

Due to the lightness pattern in the nature is two-dimensional, and the moving direction is arbitrary, the EMD model extended from the one-dimensional theory to two-dimensional space is beneficial. Two-dimensional EMD is shown in Figure 2 (b), is composed of two orthogonal EMD facing different directions. Dimensional moving information, including speed and direction, is named motion vector. To obtain motion vector, several pairs of detectors should be placed in different directions at each corresponding position on the retina. Since the motion can only be represented by a vector, and thus movement information can not be calculated and characterized from a single light receiving unit. Mathematical theory of EMD as follows:

Each orthogonal EMD is composed of two primary motion detectors, respectively located at the X and Y directions. Suppose V^* is a the output vector for EMD, and V is a graphics motion vector of the target, then we have

$$V^* = -\varepsilon T V \tag{1}$$

V^* is defined by

$$V^* = \begin{bmatrix} V_x^*(x,y,t) \\ V_y^*(x,y,t) \end{bmatrix} \tag{2}$$

And

$$V = \begin{bmatrix} V_x(t) \\ V_y(t) \end{bmatrix} \tag{3}$$

Where ε represents the delay constant, and T relate to brightness function of moving object information and its primary and secondary differential [7].

Suppose m is the mode of V^*, satisfies

$$m = \sqrt{(V_x^*)^2 + (V_y^*)^2} \tag{4}$$

Let M denote the mode matrix, defined by

$$M = [m(x, y, t)] \tag{5}$$

Suppose that A is the output matrix of the moving image filter

$$A = [a(x, y, t)] \tag{6}$$

$$A = F \Theta E \tag{7}$$

Where F is A two-dimensional image matrix the $(t - \tau)$ time,

$$F = [f(x, y, t - \tau)] \tag{8}$$

Θ is the correlation operator, and τ is defined the time computing the motion for EMD.

E is a binary matrix , satisfies

$$E = [e(x, y, t)] \tag{9}$$

e is defined by

$$e = I[m(x, y, t) - \delta] \tag{10}$$

Where δ is threshold, and I is the unit step response function. Then equation (11) can be approximated by:

$$a(x, y, t) = f(x, y, t - \tau) \Theta e(x, y, t) = \begin{cases} f(x, y, t - \tau) & e(x, y, t) = 1, \\ 0 & e(x, y, t) = 0, \end{cases} \tag{11}$$

To achieve the moving detection in a wide environment, use a certain size of two-dimensional array of EMDs. Integrate all of output' vector, we can characterize the object's movement [8].

3. Imaging System of Artificial Compound-Eye

The simulation imaging system of compound eye is designed in this paper, based on studying the structure of the fly visual system physiology and mathematical model, emulated through software, and later the function of motion detection is established. Figure 3 shown is important component of the entire test system. The target image captured by the camera, and later the motion vector can be obtained and shown after preprocessing the information, filtering out noise, suppressing the background, calculating through EMD mode.

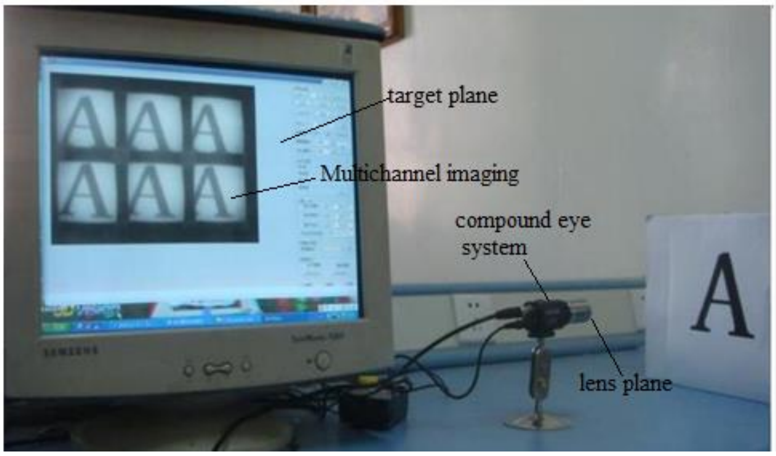


Figure 3. Imaging System of Compound Eye

Reference on structure of compound eye, the imaging system is constituted of planar micro-lens array and CCD devices. And then use the function of a computer and the method of moving object detection to achieve image acquisition easily and effectively.

The multi-aperture system is shown in Figure 4, with a micro-lens array (2×3). These 6 micro-lens have the same parameters, as follows: focal length is 2.2mm, aperture diameter is $1.8\ mm$, the center spacing of two adjacent lens is $0.48\ mm$, FOV is 30^o, length is $0.5cm$, and is named $a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}$ respectively. Without considering the interference of the image forming process and the information loss, there will be 2×3 image array appear on the detector array when target signal through the lens array. And then the imaging function of parallel type compound eye can be achieved by using the appropriate processing.

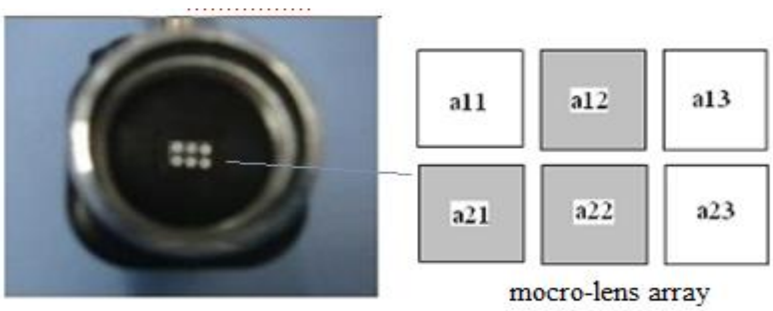


Figure 4. Structure of 2×3 Micro-Lens Array

To achieve good imaging results，not only to meet the physical parameters of each lens is the same，but also to meet the same transfer matrix, *i.e.* All of the lens elements have the same image distance and its image plane must be coplanar when lie on the same object plane. Generally speaking，for a target object, N discrete sub-image can be obtained through the lens array consisting of N micro-lens, which is multi-image [9].

The compound-eye imaging system is shown in Figure 3, which important structural is an object, micro-lens array and the detector array. The overlapping area of image is formed through the focusing lens array by adjusting the relative position between these three parts. The imaging characteristics and principle of image acquisition with the imaging system this system can be described as [10-11]:

(a) Field goal is divided to $n \times m$ units, as a result, which image formed is a two-dimensional one. Let O_{ij} be any one target cell image, *i=1,2,...n, j=1,2,...m*. Target image can be used throughout the matrix *O*, which can be expressed as:

$$O = \begin{bmatrix} O_{11} & O_{12} & \cdots & O_{1m} \\ O_{21} & O_{22} & \cdots & O_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ O_{n1} & O_{n1} & \cdots & O_{nm} \end{bmatrix} = \left[O_{ij} \right]_{n \times m} \tag{12}$$

(b) For the lens array composed of micro-lenses, the spatial location L can be calculated by:

$$L = \begin{bmatrix} L_{11} & L_{12} & \cdots & L_{1M} \\ L_{21} & L_{22} & \cdots & L_{2M} \\ \vdots & \vdots & \vdots & \vdots \\ L_{N1} & L_{N1} & \cdots & L_{NM} \end{bmatrix} = \left[L_{pq} \right]_{N \times M} \tag{13}$$

$p = 1, 2, \cdots N, q = 1, 2, \cdots M$.

(c) What can be obtained by optical imaging principle as follows: After the micro-lens array light reflected by the object, $n \times m$ inverted image on the detector surface can be transformed to:

$$I_{pq} = L_{pq}\left[O_{ij}\right]_{n\times m} = \begin{bmatrix} I_{pq}^{11} & I_{pq}^{12} & \cdots & I_{pq}^{1m} \\ I_{pq}^{21} & I_{pq}^{22} & \cdots & I_{pq}^{2m} \\ \vdots & \vdots & \vdots & \vdots \\ I_{pq}^{n1} & I_{pq}^{n2} & \cdots & I_{pq}^{nm} \end{bmatrix} \tag{14}$$

Object imaged effect from the micro-lens array is same. At the same time, the information of an arbitrary portion of the object not only exist independently, and also not lost any more. Owing to the following two points made in simulation experiments: every different photosensitive unit can be imaged independently, and that, all of the photosensitive pixels can be constructed with the order of the object [12].

This method solves the problem of achieving the three main aspects describes as follows:

(a) The integration issue with a large number of eyes has been solved. However, there are many shortcomings of using the conventional lenses that the volume is huge and the number is limited.

(b) It is effective to solve the issue that all the simultaneous imaging and processing with all of small eyes.

(c) It is a low-cost way to achieve a solution with the compound imaging system.

4. Moving Target Detection Simulation

The scenario of interest for the experiment is a small moving object, which is close to the imaging system. It is moving in uniform linear motion, and the direction of movement parallel to the face of the system. In order to solve the problem of the image extraction, according to the distribution of its structure on the CCD sensor, images captured from the system should be to partition division, and then a consistent length and width of the target image formed. The diagram of moving object detection is shown in Figure 5.

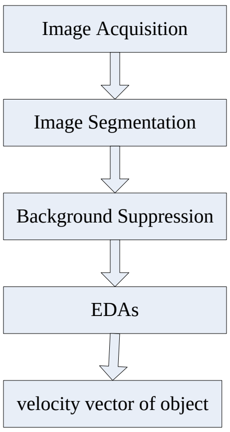


Figure 5. Moving Object Detection Diagram

4.1. Image Acquisition and Image Segmentation

When we get the image sequence, slightly movement of background happened resulting from the camera trembling position. Because EMD motion detector for any movement within the detection range is extremely sensitive, increase the difficulty of background interference in target detection. Research focus of this paper is to achieve detection of moving targets rapidly, basing on the characteristics of the movement sequences under complex background, using the algorithm combining background suppression and EMD model, and then validate through the software emulation [13-14].

An improved dynamic image sequence segmentation method based on the physical structure of the imaging system is proposed in this paper. Original Frames dynamic image sequences from a_{21} and a_{22} in shown in Figure 6. The 4th image of a_{22} is named "zje4.bmp", and the 4th one of a_{21} is named "yje4.bmp", and so on.

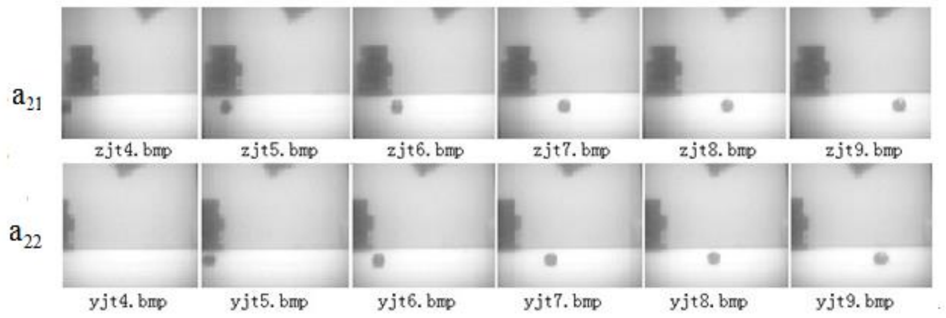


Figure 6. Original Frames in Two Image Sequence from a_{21} and a_{22}

4.2. Background Suppression with High-Pass Filter and Morphological Filter

In order to get moving image, a special high-speed camera has to be used, but still there exists more noise when taking photos of moving subjects than the static ones. In addition, image signal is often interfered by many kinds of noise when produced, transmitted and recorded. The quality of image must be improved by filtering technology before other processing [15]. It is important to decrease noise，and extrude the object from complex background in image preprocessing.

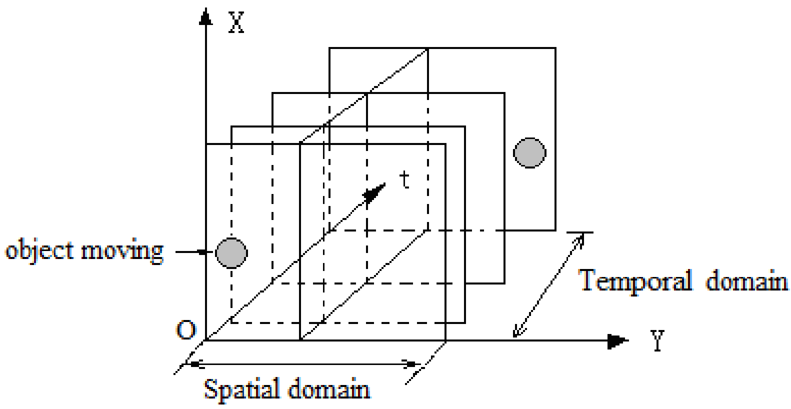


Figure 7. Image Sequence in Temporal-Spatial Domain

Learn from visual information processing method of the nervous system from the compound eyes, the target detecting system proposed consist of two parts: background suppression and target detection. Background suppression module is a prerequisite, to protect the subsequent detection. In the stage of background suppression, the processing mechanism is similar to XOR operation, completed between the nerve cells. After the suppression of network processing, the same information can be weakened or even completely removed at different time and space, and the contrast ratio of the spatial information is improved.

To insure the reliability of target detection, we adopt the logical arithmetic of mathematical morphology, gray-gradient method, in terms of features of sequential images shown in Figure 7. The noise and interference restrain effectively in the image, and then we get the moving track of small target [16-17]. It can be observed in the adjacent two images from images sequence, the gray value of pixel at the location of the ball is different clearly. But the other remains unchanged. In this paper, the image on the compound eye reduction processing can take advantage of this critical information [18]. Figure 8 shows background suppression flow chart, the concrete operating procedure as follow:

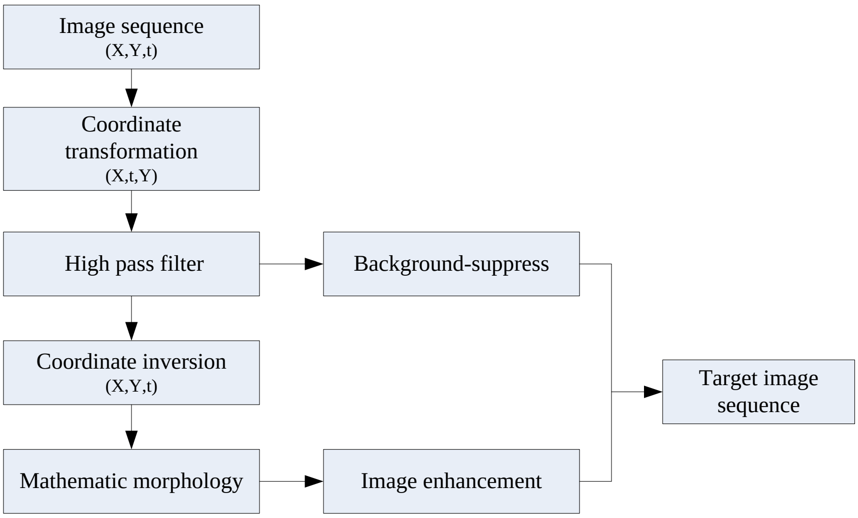


Figure 8. Background Suppression Flow Chart

(a) Take advantage of the feature with significant change between moving object and background, we make the transformation of coordinates in 3-dimensional.

In other words, provided the original image sequence is represented as (X, Y, t), where X is the length, Y is the width, and t is the number of that. Extract each column of pixels of all the images, after realignment, the number of images changes to be Y. The 3-dimensional of the new image sequence represent (X, t, Y) [19]. The change of gradient of gray image (X, t) between the moving object and background is significant. A partial sequence of new images is obtained, and the horizontal axis represents time axis, the vertical is the x-axis coordinate axes. How to get these pixels which gray values changes?

(b) High-pass filter processing is useful to get these pixels which gray values changes. According to the imaging difference of object, and background clutter, a high-pass filtering method based on and N-frame track accumulating of the moving object is presented.

(c) Do the inverse processing for these images after the above treatment, (X, t, Y) to (X, Y, t). Images processed by background-suppressed are obtained. Seen from Figure 9, high-frequency components such as small targets are retained, while the target with a certain area suppressed.

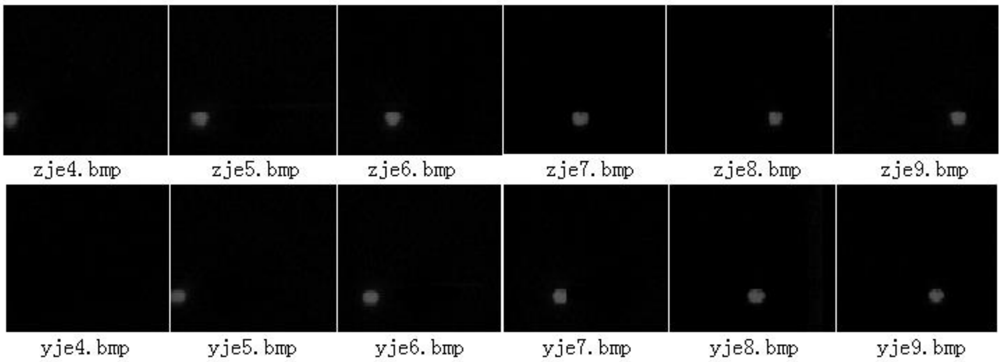


Figure 9. Images Processed by Background-Suppressed

(d) Delete the false targets according to the continuity of target motion and use a variety of logic operations of mathematical morphology to enhance object information, and later we get the real image, as shown in Figure 10.

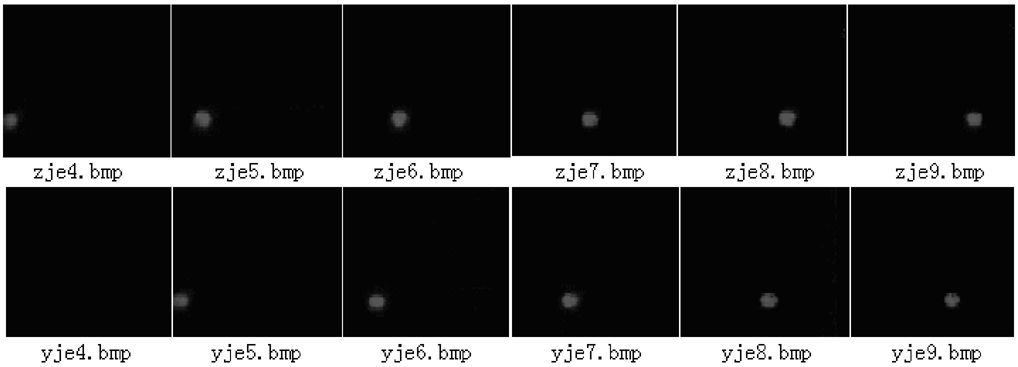


Figure 10. Target Image Sequences Processed by Enhancement

As can be seen from the figure, background suppression algorithm proposed is effective. Gray information has been retained, the same to the other structural information of the image. This will be of great benefit for the accuracy and speed of motion detection.

4.3. Motion Vector Information Processed by EMD

In order to obtain the motion vector information， the paper presents the relevant class Reichardt series model algorithm for a imagine sequence, based on the primary motion detector mode shown in Figure 11. Compare these two groups of image sequences from different eyes, and then find out two images with the maximum correlation coefficient, that contain the target information.

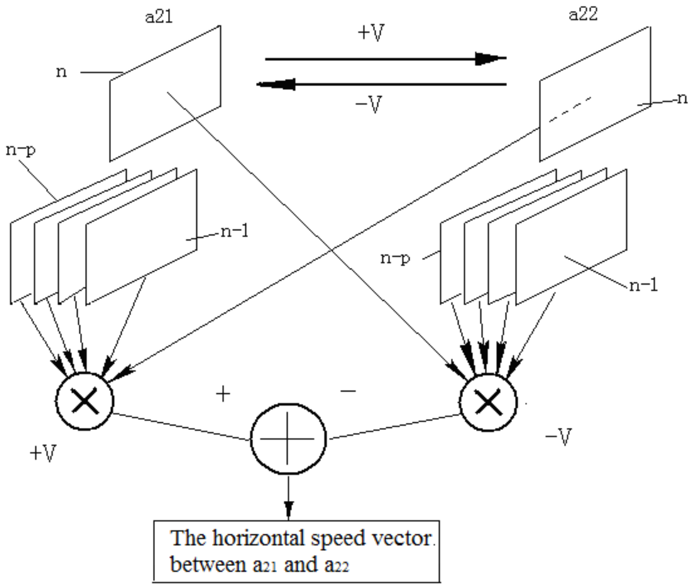


Figure 11. Diagram of Speed Vector Calculated by EMD

In order to obtain a clear and intuitive description of target motion, the velocity magnitude is represented by different gray values. Based on the law of that, the delay time is inversely proportional to the target moving velocity. More rapidly the target move, the greater gradation display.

As the example of a_{22} , which mode of velocity calculated as follows:

Set X and Y as the vector mode of velocity in the $+V_h$ and $-V_h$ direction respectively, are defined by

$$\begin{aligned} X &= W_1 * [a_{22} \times (n-1)] + W_1 * [a_{22} \times (n-2)] + \cdots + W_p * [a_{22} \times (n-p)] \\ Y &= V_1 * [a_{21} \times (n-1)] + V_1 * [a_{21} \times (n-2)] + \cdots + V_p * [a_{21} \times (n-p)] \end{aligned} \tag{15}$$

Where $W_1 \sim W_p$ is the weight of velocity, and W_1 is the maximum, W_p is the minimum. The horizontal speed vector S_h between a_{21} and a_{22} satisfies

$$S_h = (X - Y)m \tag{16}$$

If change a_{21} to a_{12} , set D as the vector mode of velocity in the $+V_v$ and $-V_v$ direction respectively, are defined by

$$\begin{aligned} C &= M_1 * [a_{22} \times (n-1)] + M_1 * [a_{22} \times (n-2)] + \cdots + M_p * [a_{22} \times (n-p)] \\ D &= N_1 * [a_{12} \times (n-1)] + N_1 * [a_{12} \times (n-2)] + \cdots + N_p * [a_{12} \times (n-p)] \end{aligned} \tag{17}$$

Where $M_1 \sim M_p$ is the weight of velocity, and M_1 is maximum one, M_p is minimum one [20]. Suppose S is the vector mode of dimensional velocity, we have

$$S = (X - Y)m + (C - D)n \tag{18}$$

So calculated, we can draw the whole velocity vector.

According to the above processing, the result of two groups of images sequences shown in Figure 11 is present. For example, compare the 4th from of a_{22} and the 4th, 5th, 6th, 7th, 8th and 9th frames from a_{21}, make the correlation calculation, and then find out and add up two images with the maximum correlation coefficient, we can get the target information. In order to obtain a clear and intuitive description of target motion, the velocity magnitude is represented by different gray values. Based on the law of that, the delay time is inversely proportional to the target moving velocity. More rapidly the target move, the greater gradation display.

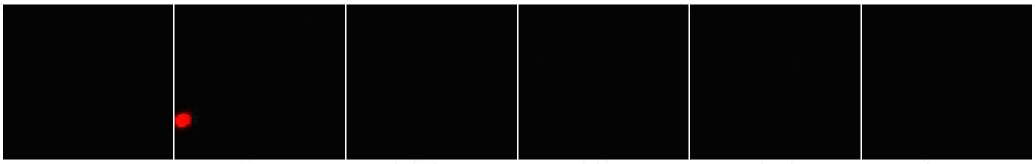


Figure 12. 4th Frame from a_{21} Processed by EMD

In the Figure 12, the processed image with the maximum correlation between the 4th frame from a_{21} and 5th from a_{22}. And so on, we get part of the maximum correlation image shown in Figure 13.

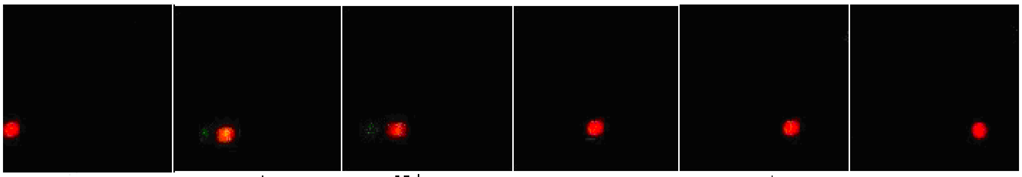


Figure 13. Object Image Sequence Processed by EMD

Add the above images with max correlation coefficient, and then we get the trajectory map in the whole movement time, shown in Figure 14.

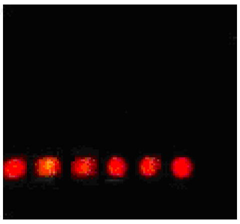


Figure 14. Diagram of Object Moving State

The coordinate of each center point of these targets calculated is 8, 25, 41, 56, 72, 87 (pixels). The distance between two adjacent targets is 17, 16, 15, 16, 15 respectively. The computing result accords with the general law of uniform motion.

As can be seen from the experiments, imaging systems and target detection algorithm proposed in this paper, which can detect moving targets on the two-dimensional plane accurately, and showing the actual state of motion in the target environment basically.

5. Conclusions

In this paper, we demonstrate a new artificial compound imaging system, which consists of micro-lens array and planar array CCD devices, refers on the insect model. For the object-detecting function, a simplified two-layer model is presented as follows: (a) On the background suppression models, firstly we used the feature of gray gradient on background and moving image, three-dimensional space transformation is processed on these image sequences firstly, and then through high-pass filter and morphological filter processing. As a result, background information is suppressed and object enhanced. (b) On the object detection model, the algorithm of target tracking in relevant imaging sequence are proposed, takes a motion detector (EMD) as a reference. Preliminary experimental results for target tracking show that detect moving targets on the two-dimensional plane and show the actual state of motion in the target environment accurately.

Based on the discussion the visual system of compound eyes of insects, the imaging system of artificial compound-eye and algorithm of moving object detection proposed in this paper is feasible, and has a highly practical application value.

References

[1] B. Guo, "Performance estimation of oversampled bio-inspired velocity estimator based on Reichardt correlator", Australia, The University of Adelaide, **(2010)**, pp. 43-47.
[2] M. F. Land, "The optical geometry of euphausid eyes", Journal of Comparative Physiology, vol. 30, no. 1, **(1979)**, pp. 49-62.
[3] H. B. Barlow, "The size of ommatidia in apposition eyes", J. Experimental Biology, vol. 29, no. 4, **(1952)**, pp. 667-674.
[4] D. I. Barnea and H. F. Silvverman, "A class of algorithms for fast digital image registration", IEEE Trans on Computers, vol. 21, no. 2, **(1972)**, pp. 179-186.
[5] R. A. Harris, D. C. Carroll, S. B. Laughlin, "Adaptation and the Temporal Delay Filter of Fly Motion Detectors", Vision Research, vol. 39, **(1999)**, pp. 2603-2613.
[6] H. S. Li and Y. Li, "Target Damage Distribution Probability Calculation Arithmetic Based on Space Tangential Differential Unit Area", IEEE sensors journal, vol. 15, no. 1, **(2015)**, pp. 240-247.
[7] T. Svobda, H. Hug and L. V. Gool, "Vi Room – Low Cost Synchronized Multi-camera System and its Self-Calibration", Proceedings of 24th DAGM Symposium on Pattern Recognition, **(2002)**, pp. 515-512.
[8] R. Pless, "Discrete and Differential Two-View Geometry for General Imaging Systems", Proceedings of Third Workshop on Omnidirectional Vision, **(2002)**, pp. 53-59.
[9] G. Stange, "Rangefinder based on intensity gradient measurement", Applied Optics, vol. 30, no. 13, **(1991)**, pp. 1695-1700.
[10] F. Q. Song and M. Li, "A target extraction method in disordered and dynamic background based on visual congnition theory", Journal of Optoelectronics Laser, **(2012)**, pp. 366-372.
[11] J. Yin, D. G. Li, "Moving Objects Detection by Imitation Biologic Vision Base on Fly's Eyes", IEEE International Conference on Robotics and Biomimetics, Shenyang, **(2004)**, pp. 763-766.
[12] W. Wang, P. Shui and G. Song, "Multi-focus image fusion in wavelet domain", Systems Engineering and Electronics, vol. 26, no. 5, **(2004)**, pp. 668-671.
[13] T. Wan, N. Canagarajah and A. Achim, "Compressive image fusion", In: Proceedings of the International Conference of Image Processing, **(2008)**, pp. 1308-1311.
[14] S. Mallat, "Theory for multi-resolution signal decomposition: The wavelet representation", IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 11, no. 7, **(1989)**, pp. 674-693.
[15] J. Duparre, P. Schreiber and A. Matthes, "Microoptical telescope compound-eye", Optics Express (S1094-4087), vol. 13, no. 13, **(2005)**, pp. 889-903.
[16] X. M. Liu, S. C. Wang and J. Zhao, "Infrared image moving object detection based on image block reconstruction", Infrared and Laser Engineering, vol. 22, no. 4, **(2011)**, pp. 170-180.
[17] H. S. Li, Z. M. Wang and Z. Y. Lei, "Analysis and calculation object detection capture rate in multi-sky-screens across measurement system", vol. 25, no. 1, **(2014)**, pp. 4369-4373.
[18] Y. J. Li and K. Zhan, "Vision Bionics Image Guidance Technique and Application", M. Beijing: National Defense Industry Press, vol. 32, no. 1, **(2006)**, pp. 91-115.
[19] W. Reichardt, M. Egelhaf and A. Guo, "Processing of figure and background motion in the vision system of the fly", Biological Cybernetics, **(1989)**, vol. 61, pp. 327-345.
[20] L. J. Fleishman and A. C. Pallus, "Motion perception and visual signal", Biological Sciences, **(2010)**, pp. 3547-3554.

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