HOUSE FLY (*MUSCA DOMESTICA*) INSPIRED COMPOUND VISION SENSOR AND BIO-MIMETIC SIGNAL PROCESSING

Sakshi Agrawal, Advisor: Dr. Brian K. Dean

Oakland University

1. ORIGINAL KEY IDEA/HYPOTHESIS OF THESIS

The idea of compound vision sensors is to create electronic devices and methods which could exceed the capability of existing vision sensor technologies. Previous research shows that motion hyperacuity, or better motion detection capability, of common house fly (*Musca domestica*) allows designing of better compound vision sensors for edge detection and near instantaneous object tracking. The reason for better results is preprocessing of image data; extracting motion, and object information from the background and then sending only limited desired information to the brain or CPU in an engineered system. The aim of compound vision sensor research is to develop novel sensors that outperform existing technologies in specific real world applications.

2. OVERVIEW OF EXISTING WORK IN THE AREA

A traditional CCD camera cannot detect motion in the object, if the distance moved is less than the pixel size. However, the fly eye vision sensors (FIVS) can detect inter-pixel movement. The photoreceptors image a point on the space with overlapping field of view, i.e. at a particular instant; more than one photoreceptor sees the object.

An analog circuitry was developed for the sensor, preserving motion hyperacuity characteristic of the fly eye. The introduction of light adaptation circuit was a key step to adapt to the changing light intensities, further making the design of fly-eye vision sensors more robust. The developed circuitry was tested and verified on the edge detection application providing better motion detection results than the traditional CCD cameras.

3. PROBLEM DOMAIN AND SPECIFIC PROBLEM ADDRESSED

The overall aim of this research work is to generate a digital equivalent fly eye vision sensor. Since, analog circuits are more prone to noise and most real world applications involving microprocessors, DSP boards, etc. use digital signals, our aim is to first develop the digital equivalent of the existing fly eye vision sensors, and then further develop algorithms to test the quality of the results achieved from these sensors in comparison to traditional CCD cameras.

4. METHODOLOGICAL APPROACH

A typical fly eye vision sensor consists of seven photodiodes generating overlapping Gaussian responses after following these steps:

a) Depending on the light intensity, a small output current from each photodiode is amplified and converted to voltage by *transimpedance amplifiers*.
b) The voltages are then filtered by nearly identical 50 Hz 4th order *Butterworth filters* and 60 Hz notch filters.
c) Then, the background light radiation is removed through the *light adaptation* circuit.

In order to digitize the analog fly eye vision sensors, we need to consider three major steps to decide on the analog to digital converter to be used in the circuit implementation. These steps are:

i. Location of Digitization
ii. Sampling rate
iii. Resolution

In order to achieve optimized results to the above mentioned steps in analog to digital conversion, some important constraints have to be taken care of:

a) Power Rails:

It has been found that in an indoor environment, the light intensity is usually in the range of 0-4000 Lux. Hence, the aim of this research is to digitize the existing analog fly eye vision circuit for an indoor environment. The original system was designed for 15V power rails. Higher power rails were chosen for higher resolution to changes in input light intensities. Lowering the power rails would reduce the amount of power needed, but at the same time, it results in a decrease of resolution of the desired output signal making it difficult to differentiate between signals using existing A/D converters. Therefore, with an aim to optimize the power rails needed for the application, depending on the easily available A/D converters, the optimum power rails were found to be 15V. For 15V power rails, the peak/trough of the output signal at 4000 Lux (maximum permitted light intensity) was found to be at approximately $\pm$1V.

b) Location of digitization:

Another important aspect to be considered is the location of A/D converter in the sensor designing. These A/D converters can be placed at three different locations i.e. after transimpedance amplifier, after filters, or after light adaptation block. Placing the A/D converter at either of these locations has a trade-off. If the A/D converter is placed after transimpedance amplifier or filter, we need higher dynamic range and resolution to view the changes due to light intensity in the output signal. Whereas, if the A/D converter is placed after the light adaptation block, we just digitize the signal of interest (after removing the background light intensity) which matches the dynamic range of the A/D converter, thereby improving the resolution of the output signal.

c) Minimum movement of object to detect motion

Further, for the digitization of fly eye vision sensor, the sampling rate has to be kept as low as possible without losing the motion hyperacuity characteristic of the sensor. Preliminary calculations show that for a fly eye sensor to detect motion in an object which is approximately 0.3 meters away from the sensor, the minimum distance that the object has to move is 72 μm.

The methodological approach to design the digital equivalent of the fly eye vision sensor design is to use an analog to digital converter keeping in mind the above mentioned constraints.

5. PRELIMINARY RESULTS

Initial calculations show that for 15V power rails, the generated output signal have a peak/trough at approximately $\pm$1V, when digitized after the light adaptation block. Hence, the A/D converter needed for this application of fly eye vision sensor should have a dynamic range of $\pm$1V. Also, for the above dynamic range, the minimum number of bits needed (resolution) to detect the change in light intensity due to moving object is 6 bits. As a result, the A/D converter should have a resolution greater than 6 bits.

Now, the maximum speed of object permissible for the sensor to detect motion is directly related to the sample rate of the A/D converter using equation (1). For example, if an A/D converter with 60MHz sampling rate is used, the maximum velocity of the object permitted is 4320 m/sec.

$$max.\,velocity\ of\ object\ = 72\mu m * sample\ rate \qquad (1)$$

where 72μm is the minimum distance moved by an object to detect motion when placed 0.3m away from the sensor.

Along with the above design of digital equivalent of fly eye vision sensor, an effort was also made to remove the artifacts present in the output of the system. In the implementation of fly eye vision sensors, it was discovered

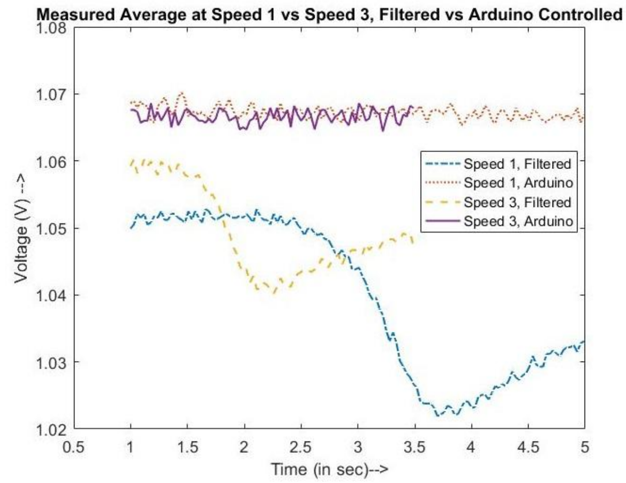

Figure 1: Average signals obtained after low-pass filtering and Arduino controlled digital sample-and-hold approach in light adaptation at speeds Speed3 i.e. 0.67 m/sec (left) and Speed1 i.e. 0.26 m/sec (right).

that the light adaptation circuit generated artifacts which were not completely removed by low-pass filtering. Hence, a digital sample-and-hold approach was designed and implemented to completely remove signal artifacts from the light adaptation circuit as shown in Figure 1. In the developed digital sample-and-hold approach, the ambient light was digitized and monitored using a microcontroller. As a result, these artifacts were successfully removed even with a limited number (seven) of input channels as compared to the fly.

6. FUTURE WORK IN THE THESIS

Future work in this area includes implementation of above designed digital equivalent of fly eye vision sensor. The implemented circuit will also be used to test the applicability of fly eye vision sensor on edge and motion detection applications. Further, the digital implementation of fly eye vision sensors would open many new avenues for exploration. Different algorithms could be developed to improve the results obtained from the existing algorithms for edge and motion detection. Efforts can also be made to digitize the signal after transimpedance amplifier or filter which would enable implementation of following blocks on a FPGA or DSP board. This would reduce the complexity of the system, size and power needed, noise due to analog circuitry, time needed to build the circuit design, and also improve the adaptability of the fly eye vision sensor to different environments.