

# Design and Implementation of an Autofocusing Algorithm for the Goniometric Robotic Apparatus for Compound Eye

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## Abstract

The Goniometer Robotic apparatus for compound eye at the Computational Physics Laboratory at the University of Groningen is requiring an autofocus algorithm that is able to capture focused images for the analysis of compound eye insect for characterization. In the absence of an adequate algorithm that manages to place the camera in the right place, GRACE automation has difficulty searching for the respective image.

Through the present article you will find the design and implementation of algorithm autofocus structured in modules which improve the organization of the process to achieve an adequate analysis of compound eyes.

An algorithm has been proposed which executes five techniques of autofocus capability to determine the sharpness in images in several channels, as well as to use some of those techniques to improve the positioning of the camera and acquire focused images.

## Keywords

Autofocusing Algorithm; compound eye; GRACE.

## Introduction

Nature shows an awesome life cycle which has been the subject of research to explain and to deepen in areas that lack information in the scientific and technological communities. An important discovery has been made in the vision field. The striking vision system in arthropods, a kind of insect, has come to be an attractive subject for the discovery of its optical properties.

Compound vision, present in arthropods, means there are thousands of smaller eyes called *ommatidia*. Each *ommatidia* is a facet that works as an independent optical system [1]. The ommatidia are sensorial units formed by photoreceptor cells capable of distinguishing the presence of light from lack of light [2]. Each ommatidia has a cylindrical shape which generates an image from adjacent fields with a range of around 270 or 360 degrees of vision that form a vision called a mosaic vision. In other words, the different light intensities which come from multiple directions and together with other environment properties is how image is formed in compound eyes [3].

The well-developed visual system is found in butterflies and flies which are highly visual animals. The characterization of compound vision has been done manually with conventional microscopes that do not have the appropriated movements producing a process that has been time consuming. The Department of Computational Physics of The University of Groningen has developed many studies based on the eyes of the butterflies and flies leading to a long process which has created a specialized device known as Goniometric Robotic Apparatus for Compound Eyes (GRACE) [4].

GRACE goniometer is a robotic scanner with six degrees of freedom (DOF) [5], it means, has six movement axes, used to characterize the vision space of butterflies and flies' eyes. The machine is conformed by two parts, the first is the positioning system where stepper motors are used for all mechanical movements which consider both XYZ direction [6] and two rotations known as azimuth and elevation axis and second part is the visual system which include cameras, lens and microscope with a good optical system. GRACE has been improvement since its creation, conducting to create two GRACE versions that the main difference between them are the camera position now is the azimuth and elevation axes and it is independent of the XYZ system where in the previous GRACE (that continue in use) the camera is dependent of the XYZ system.

Visual system is taken over by autofocus and auto-center algorithms to capture the image. An important aspect is to get focused images so that we have searched for an autofocus algorithm

that satisfies suitable images for an appropriate analysis. This research is based on improve the autofocus algorithms processes image to search sharpest image within the set of images captured by the GRACE device.

Besides, to validate their current five techniques due to there is no explanation why these algorithms work to determine if the image is in or out of focus and in that way find one technique that could acquire the best focus image. Another lack aspect is determined a good camera position [7] which help to obtain a good quality image. So far both the autofocus and the camera position must be the main purpose in the article to help getting a suitable images analysis and contribute to improve the visual part of the GRACE second version machine to obtain compound eyes images.

## Methods and Materials

The development of the design process, validation of autofocus algorithms and implementation proposal to improve the focus level of the acquisition images through the GRACE instrument have been addressed through three design solutions capable of giving an optimum development that they satisfy the desired project.

**Solution 1:** Full custom autofocus algorithm, it consists to the fully adapted autofocus algorithm which includes a goniometer easy to use for the person handling the machine, a flexible program allows an integration of focusing algorithm that is able to receive some adjustment such as the camera parameters which is entered into the system by means of an easy graphic interface with the user producing a time- optimized device, it means an entirely new design that includes very specific details.

**Solution 2:** Autofocus algorithm using frameworks for image processing, analyzing image processing programs on the market, a library called Open Computer Vision (known as OpenCV), which works in C/C++ language, has predefined, specialized functions, methods and features for processing images. The new development seeks an adaptation of the autofocus algorithm capable of performing the search for the best image focused within a set of images through the use of Open CV libraries.

**Solution 3:** Autofocus algorithm adaptation, taking into account the algorithms used so far with the GRACE device, a solution would be sought to improve them by means of modifications required by the device, this could include performing an image analysis in the three channels at the same time, to obtain the graphed focus measure as well as a standardized graph (normalized graph) for each of the proposed algorithms.

The previous solution have been assessed using a comparative table 1 base on some evaluation criteria in order to clarify the choice of the design proposal. It uses a score evaluation where Very Good is 4, Good with 3, Regular with 2, Inefficient with 1.

**Table 1.** Solutions Comparison

Evaluation Criteria	Solution 1	Solution 2	Solution 3
Functionality	4	4	4
Time Implementation	1	2	3
Cost Implementation	1	3	3
Integrability	3	2	3
Algorithm Complexity	2	3	3
<b>Average</b>	<b>2.2</b>	<b>2.8</b>	<b>3.2</b>

The table 1 has shown that the *functionality* of all three solutions has a good acceptance, they are able to perform a focus search on the set of insect compound eye images. Regarding the *time implementation* that involves the time consumed to develop the focus algorithm so that it goes into operation, solution 3 worked best. It showed to be easily adaptable, using GRACE algorithm and software, and it takes less time than the other solutions. The *cost implementation* is based in the materials, software, arrangement and all the aspects which get involve carrying out the autofocus algorithms. The Solution 1 has a very high cost taking it to get a punctuation of one, the second solution has an average cost because it utilizes a new platform and compiler and third solution runs on the same software that GRACE first version has used, so its implementation is the most favorable. The *integrability* refers to the adaptation of the solution with the system that exists, in this case with the GRACE goniometer second version, the criterion is accepted by option one as it would help the autofocus process by its specialized orientation to the system, solution 2 is the furthest from integration due to the new compiler with the library and third option is able to run on the same old platform but with added procedures to improve the performance of the autofocus.

The last criterion is the *algorithm complexity* which is the algorithmic procedure gets the focus measure (FM) and achieves the necessary programming for the objective. The solution 1 is more difficult mathematically because the complexity of designing an algorithm with a new procedure can carry a lot of study, solution 2, the complexity became less as a result of the image processing dedicated library and third solution shows a favorable average due to having already performed the mathematical procedures of autofocus on the platform and is known to work well.

As discussed above, solution number 3 meets the appropriate conditions and obtains the best evaluation (3.2 score) for the design development and the functional autofocus algorithms implementation.

## Algorithm Design

According to the selected proposal, for the fulfillment of the project, the autofocus algorithm have been developed toward a modular system which is explained below make use of figure 1.



**Figure 1.** High-level module solution of autofocusing algorithm design, own authorship.

The figure 1 represent a high-level description of the autofocus algorithm where five modules describe the procedure.

### Get an Insect

Insect has to be collected with compound eyes, like flies and butterflies, for research analysis. A fundamental aspect is to identify the species with which it is going to work. The insect must be placed properly, remain still and alive during image acquisition analysis. The species that base the tests performed have been chosen due to the availability of the season which are *Sarcophaga sp.* depicted in figure 2.a, *Scathophaga stercoraria sp.* showed in figure 2.b and *Calliphora sp.* In figure 2.c



**Figure 2.** Front view photos of the flies use in the project which is appreciated the head and the compound eyes, photograph taken by H.L.Leertouwer.

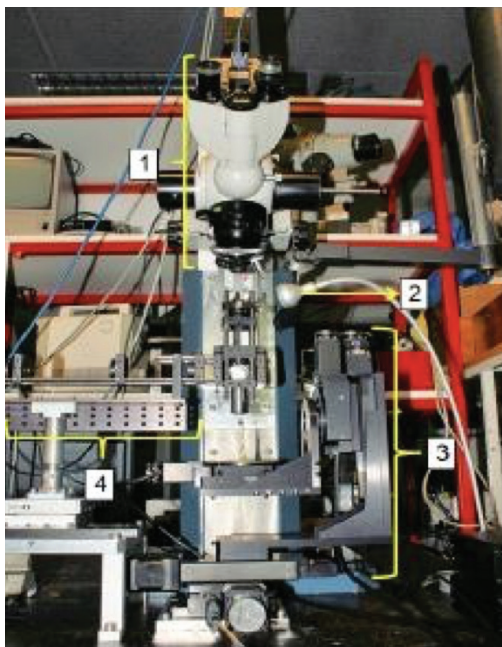
### Setting Camera

The insect eye must be aligned to the visual axis of the camera with GRACE in order to obtain a good reference of image, then algorithm design requires initialized camera settings, specifically image parameters (shutter, gain and white balance indicate). GRACE second version use a F7 BayerRG12 1920x1200 Mode0 [8] camera model which is connected to USB 3.0 because the transfer rate is faster and avoid a frozen image. Camera needs to be moved up and down, mechanism that is performed using ELERO engine which through voltage receive in the ENCODER of the motor, it knows the distance and direction should be placed.

The image dimensions are chosen in a region of 200 x 200 for an appropriate selection which is needed to process the image. The size aspect had not been chosen before, it helped to only include in the image the insect composed eyes and thus avoid having any part of the insect skin and cause wrong results. Finally, the streaming video has to appear in the screen, to show the region of the image that it uses to analyze.

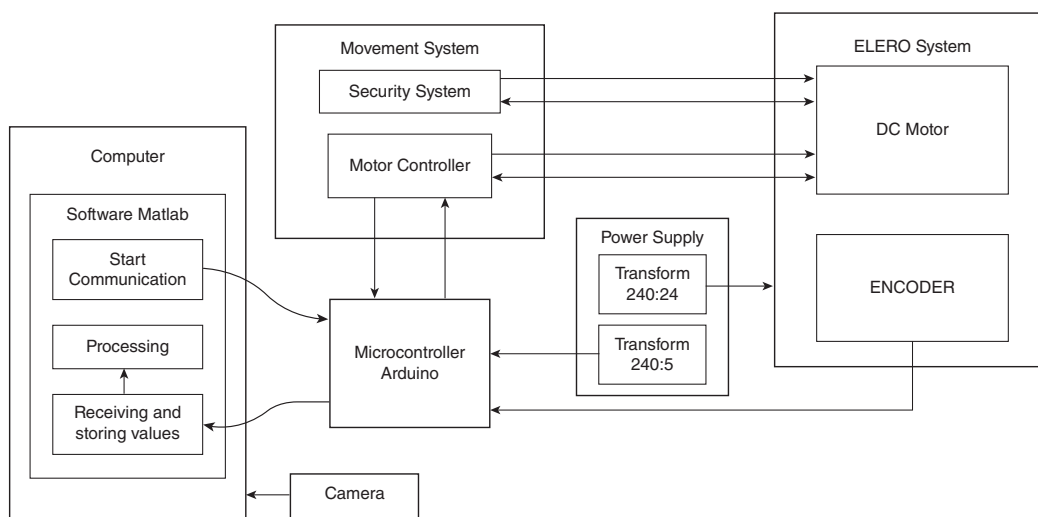
### Data Acquisition

The data acquisition depends on a system that integrates two blocks, the camera position control and the computer data reception, blocks have to interact in order to make a communication where data are sent without lose information. The camera positioning requires a control that allows the camera displacement in the elevation axis. A microcontroller lets the control which is responsible for receiving signals from the optical Encoder that sends an initial and final signal to know the displaced distance of the motor. Control must perform an automatic scrolling while the camera is capturing each image. The second block involves the software where a program has the five algorithms that processing the image in a Matlab script. Script receives data, save it in a structure called Scanned which contain image format (X, Y, channel, N), where X and Y are the frame size, channel represent red, green or blue channel in the image and N is number of the frame within the set of images, GRACE is depicted in figure 3 that shows the structure of GRACE second version. Also, the focus measure that give each of the five algorithm is stored in a structure called Focus, where the values of each frame are placed in different columns by each of the channels, i.e, a measure of each channel's focus.



**Figure 3.** GRACE second version that has the next parts as shows in the figure where 1) it is the microscope located in the camera axis, 2) light source, 3) XYZ mechatronic system and 4) the visual mechanism which is under construction.

Both blocks integrate the circuit (hardware) that execute the movement and the program (software) that save the structures with the image and the focus measure. Besides, blocks communication is bidirectional since blocks must communicate so much to go capturing images with the camera as well as the program goes sending the amount of accounts that the motor should be moved.



**Figure 4.** Data acquisition system showing two blocks, the computer data reception in the left and camera position circuit at the right.



The acquisition begins with the connection of the microcontroller with the others electronic parts, entails the respective hardware configurations between the DC motor, the Encoder, the motion system and the Arduino connection, not the computer, as shown in figure 4. The last step consists of the called *AutofocusGrace* function in which the algorithm has received the video variables, the serial communication is available with the circuit to move along the axis and acquiring an image set that is captured on certain number of pre-established steps are starting to set. In addition, the five algorithms execution is happening while good position is calculated with the algorithms results.

## Image Processing

The image processing is described by means of the five autofocus algorithms that have been used to obtain a focus measure (FM which has a lumen value as SI derived unit) and indicated a sharpness determined by mathematics which calculate for three channels in each of the algorithms. The higher the focus measure (FM) the sharper the image because of that it is thought to use such measurement in order to normalize (as a standardization) data obtained by each algorithm and channel to perform comparisons. The algorithms explanation has been an important contribution to the development of the goniometric device because the algorithms were only implemented experimentally but did not have a basis for which it was given to the task of searching several studies to compile the information that summarizes the most relevant of each algorithm.

The sharpness measure underpins and validates the Energy of Gradient, the Energy of Laplacian, the Gaussian Derivation, the Tenengrad, and the Vollaths Correlation algorithms. They must give a metric of sharpness. All the methods implement the idea of searching focus measure quality which help to represent to high frequency content in the image, in most of the cases.

## Energy of Gradient

The gradient energy is a method that achieves a measure of focus by analyzing all the pixels of the X and Y axis of a frame or image to be analyzed [9]. The gradient provides a vector which points in the direction of the greatest change relation of the two-dimensional function [10]. In general, the principle of the Energy of Gradient is a differentiation-based focus function. It is to consider the existence of an edge if there is a discontinuity in the image intensity function. [11] It means that a maximum is obtained in the derivative that is applied when searching for the intensity values of the image.

## Energy of Laplacian Autofocus Algorithm

The Laplacian is a method to measure the amount of edge present in image, using the second derivative for image sharpening. Technique consists of establishing a discrete formulation of the second order derivative and then constructing a filter mask based on that formulation [12]. Laplacian is a derivative operator which is used to highlight intensity discontinuities in an image and neglects regions with low intensity levels, leads to generate clear images. The method uses the square of the results of the convolution of the image with the mask of the filter mentioned above, a data media is obtained and also the focus measure to analyze the sharpness of the image.

## Gaussian Derivation Autofocus Algorithm

It is a focus method that results from combining a smoothing and a gradient to measure the energy contained in the image [11]. The level of smoothing is used for the medium of Gaussian Derivation application, while the gradient is provided by the mask that is chosen according to the desired purpose. Gaussian Derivation method gives a response to the best focus position when finding a local maximum [13], in this way it can be said that it is a complex method that works for the search of the sharpness of the image when implementing Gaussian filters in which the results with scalar value indicates the focus measure that has been achieved.

## Tenengrad Autofocus Algorithm

It is a technique that analyzes the nature of the edge based on the differentiation of the image, algorithm performed by Tenenbaum formulas [14]. It is an edge detector for autofocus when there is a distortion (blurring) between dark and clear boundaries in the images. Because PSF (Point Spread Function which is a response to the impulse) is distributed at each pixel intensity, we take into account the differentiation of the image to find out the measure of focus.

## Vollaths Correlation Autofocus Algorithm

Vollaths Correlation method looks for the similarity between a central pixel and a predefined zone (surroundings), it is an image relation with itself, and this is spatial filtering processing when using the autocorrelation operation. Autocorrelation is based on Chapter 4. Methods and Materials 40 cross-correlation, which means that it looks for the correspondence of a selected area in the image with respect to another image (or with the same image) to determine its displacement [15]. Vollath proposes a method that is based on experimental determinations using several criteria and properties until finding the criterion that satisfies the search for the value of the focus measure [16].

## Data Extraction

Once the process has finished acquiring the necessary data set by the algorithm designed, the information must be manipulated to give interpretation and give an explanation. For this purpose, the data has been classified into several types of graphs, tables and tables representing the data. The graphs show the data of the focus measures for each algorithm and channel and tables have been designed to show images according to the algorithms of edges detection to highlight the best results.

## Simulation Results

The result related to the solution design is going to be showed and discussed in this section. An aspect to emphasize is that the image capturing has been carried out with several species of flies. However, the last tests have been realized with *Sarcophaga* sp, *Scathophaga stercoraria* sp and the third fly is believed to be most likely *Calliphora* since the fly has not being as closely examined as the other two.



## Setting camera results

The camera configuration has got a desired image format when the camera was aligned with the insect eye which always tries to place in the center of the image to appreciate the compound eye, as figure 5.a, a zoom is applied to analyze the eye facet in Matlab, shown in figure 5.b.

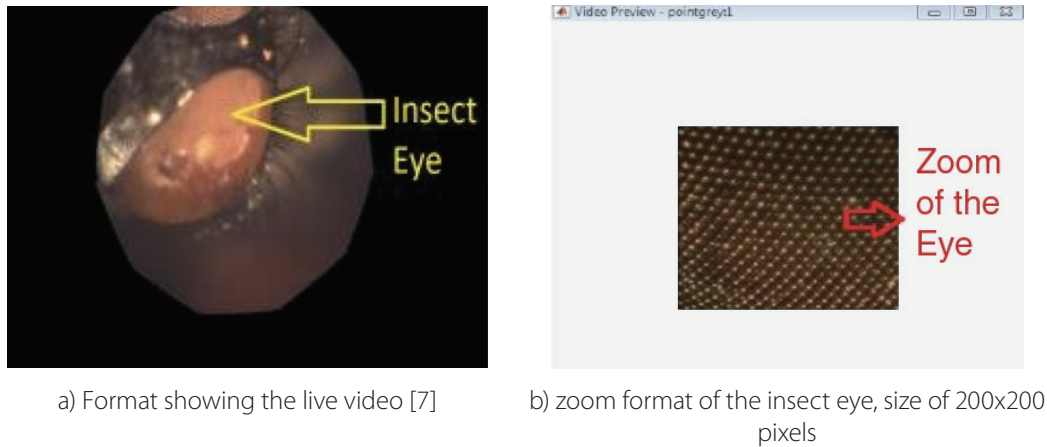


Figure 5. Desired region size where the insect is placed to be analyzed

The video transmission had several problems for not having a continuous streaming, so it has been solved by incorporating in the camera initialization script a section where it includes the interruptions. The video streaming which is obtained is 19 frames per second (FPS) on average and through a command is generated in the command line of Matlab results an appropriate and continuous transmission. Another problem was that image involved all the environment around the insect eye, it has been solved by means of an algorithm implemented by laboratory partner [17] who solved the problem choosing an interest point within the image where it is visualized what is wanted.

## Data acquisition Results

The camera position and the algorithm implemented in Matlab script achieved a continuous video streaming where communication transmit and received signal without loss. An important aspect is set serial parameters like a baud rate of 9600 signal unit per second, data bit representing data size that is 8 and time out in the communication is 60 seconds. During transmission the distances in sending which is interpreted in Arduino microcontroller to perform the displacement which is automatically as well as capturing a certain amount of images and process them with the autofocus techniques.

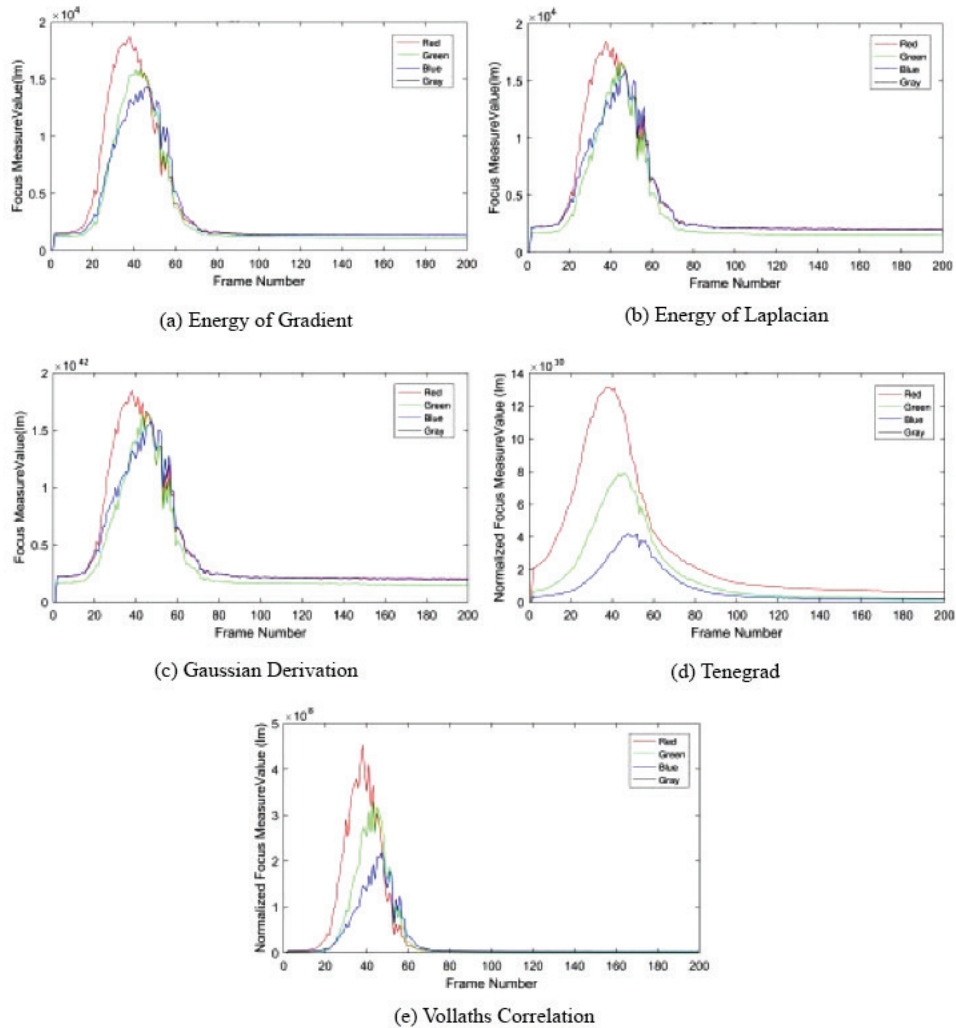
The *AutoFocusGrace* has been created to fulfill the synchronization process, function consists of making a camera shift to capture several photographs, analyzing with the five autofocus techniques and finishing return the camera when function had the best approach using techniques, position and focus measure were found in a structure called *Focus* where saved all positions and focus measure (FM) values evaluated in the three channels. The return of the camera has been implemented with a servo control base on image that is known as *AutofocusSlopes* function which complies to stop the camera displacement until an image satisfies the focus conditions. Focus condition takes a group of 5 FM that compute the slope which evaluate if value is positive

and less than the previously calculated slope and highest focus value is reached is when the displacement stop, that was one of the better improvement in autofocus algorithm.

This implementation is image control because the calculation of the focus measures (FM) performed by the autofocus techniques is defined where the best sharpness proceeding to manage to stop the camera movement. To finish, it can be noticed the integration of hardware and the software has been vital to achieve the camera position control (hardware) sent from all the Matlab script (software) to satisfy data acquisition.

### Autofocus algorithm results

After executing autofocus algorithms, the resulting graphs have been designed to show a graphics where contains 200 frames (images) and the focus measure results are evaluated in the five autofocus algorithms and each technique in the red, green and blue channels.



**Figure 6.** Focus Measure values graphics represented in red, green and blue channels for the five autofocus techniques with *Sarcophaga sp* when scanning.

Figure 6 may be noted that most of the curves present noise along its stroke because there are external conditions that affect acquire data as they are noise and vibrations of where the goniometer is. That disturbances are less present in the Tenengrad technique as the graphics denote and several tests have been performed where it has always been consistent that noise and vibrations were quite eliminated with Tenengrad technique. To clarify the same result was reached in the three fly species, but for purposes of this article *Sarcophaga* analysis is the one that will be explained. Such a technique involves the convolution of the image with a Sobel filter [19] within their calculations which are quite appropriate for the FM values. The Gaussian Derivation presented the biggest problem with noise and vibrations, followed by Energy of Laplacian and Vollath's Correlation.

As for the channels, it is distinguished that the red channel is the fastest one to reach a maximum value in comparison with the other channels. The red channel presented magnitudes of the focus measurements values greater than in the cases of green and blue channels. Moreover, the red channel has a major difference in the Tenengrad technique, more than in the rest of the autofocus techniques.

**Table 2.** Summary of the maximum FM values obtained by each algorithm for autofocusing with *Sarcophaga* sp.

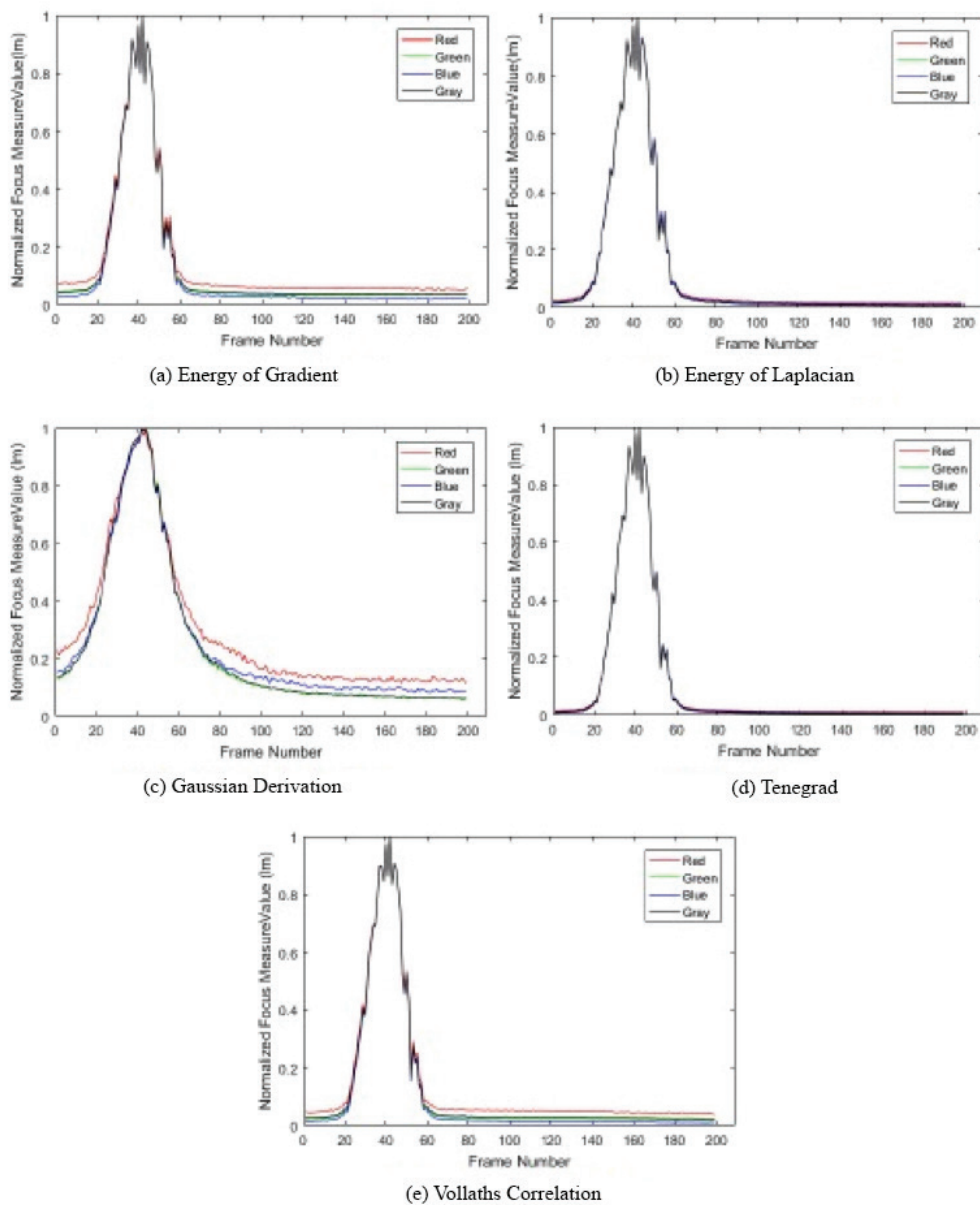
Technique	Red Channel		Green Channel		Blue Channel	
	Maximun FM value	Position	Maximun FM value	Position	Maximun FM value	Position
Energy of Gradient	$1.87 \times 10^8$	37	$1.58 \times 10^8$	40	$1.43 \times 10^7$	46
Energy of Laplacian	$1.85 \times 10^8$	37	$1.65 \times 10^8$	44	$1.59 \times 10^8$	46
Gaussian Derivation	$1.32 \times 10^{42}$	37	$7.90 \times 10^{41}$	45	$4.20 \times 10^{41}$	47
Tenengrad Vollaths	$4.53 \times 10^{10}$	37	$3.27 \times 10^{10}$	42	$2.18 \times 10^9$	46
Correlation	$6.11 \times 10^8$	37	$4.55 \times 10^8$	42	$2.94 \times 10^8$	46

In table 2, it can be appreciated that order of the values of FM are quite different, techniques of Energy of Gradiente, Energy of Laplacian and Vollath's Correlation remain in the order of the power to the eight, the Gaussian Derivation technique works in the order of the power of 42 while Tenengrad has exponential values in the order of 10, these results are generated by the mathematics that each carries.

The magnitudes of the values in the red channel are greater than in the green and blue channel, due to the photoreceptor pigments of insect *ommatidia* it captures the red spectrum better than the other channels.

## Normalized algorithms

To ratify which of the five techniques have better result and be able to make a comparison, focus values have been normalized which consists of taking the highest focus measure (FM) obtained and divide it with the other FM values to have results based on a maximum value of one.



**Figure 7.** Focus Measure Normalized values graphics represented in red, green and blue channels for the five autofocus techniques with *Sarcophaga sp.*

Normalized graphs (figure7) show that the channels overlap in their curves as result that graphs are similar behavior due to they are based on one but the disturbances are kept. It can be observed that the maximum values are always reached in the range from 20 to 40 frames in *Scathophaga stercoraria sp* and 30 to 50 in *Sarcophaga sp* fly and 16 to 25 in *calliphora sp* fly. Moreover, the normalization has helped to visualize that the difference between the unfocused and focused values has on average a gradient of 0.72 for *Sarcophaga*, 0.63 for *Scathophaga* and 0.73 for *Calliphora*.

Having learned that the autofocus techniques that had the best results have been Tenegrad and the Energy of Gradient, Tenegrad in the red channel has chosen to perform the camera positioning, it means, the AutoSlopes function it is possible to position the camera in a place where it had a good focus of the image and better observe the compound eye of the insect.

## Data Extraction Results

Since it was noticed that the techniques try to detect edges themselves, the off-line tests from autofocus algorithms have been used as an experimental criterion for implementing three types of edge detectors to ensure the analysis with the algorithms is validated with the best sharpness image.

Three types of edge detector are generic implementation in Matlab script adapted to the purpose. The first test converts the image to binary image, technique based on threshold chosen as  $T = 0.2$  which was the measure found after several tests. The second consisted in applying a Sobel filter setting its thresholds as  $T = 0:2; 0:4$  or  $0:6$  and Canny filter [14] setting its threshold of  $T = 0:4$  to the images that are based on searching the gradient of the image intensity in order to detect their edges that make up the image. Finally, the third test performed not only edge detector also improve disturbances such as noise and low contrast (conditions called poor) in the captured image has been created by some authors who sought to improve edge [18].

## Discussion

The autofocus algorithm has been proven to obtain sharp images during scanning insect compound eye through a block-segmented autofocus algorithm (figure 1) and it has an adequate operation of image captures with the GRACE second version device.

The live video (figure 7) is being carried out without stopping or the image has frozen, the video streaming is about 19 FPS. When executing the macroalgorithm to find the best approach with a continuous video this helps to capture suitable images in a  $200 \times 200$  size as the camera moves around the eye. The serial communication between the Arduino, the camera and the software in Matlab has been successful interaction between themselves, the serial synchronization parameters have to be the same when configured to ensure communication.

The values of the displacement counts to move the DC motor through the serial communication, has been achieved by the interruptions, it means, the system attended to the motion request as soon as the signals were generated, if issue is coming the message goes out several times to achieve the communication, and if it is not achieved the system stops and the program must be re-initialized.

The count values of the camera displacement have an error (like a delay) value of the three magnitudes. It has been accepted since the moment the camera stops in the calculated position, at the well-focused image. Error is related to DC motor that contains an Encoder which barely receiving the internal stop signal continue sending a bit later (3 more values) until motor voltage is zero.

The *AutoFocusGrace* function has adequately performance for the calculation of focus measure in the five autofocus techniques. The *AutoSlopes* function has been implemented to position the camera through image processing, it is an image-based control where it has been conceived make use of the best autofocus technique in only one of its channels.

The technique chosen was *Tenengrad* in the red channel the data set was divided into groups of five with which the slope was calculated. The slope method has been able to find a place by identifying abrupt changes and together the established condition achieved the behavior to stop camera movement. Despite this, Positioning had several problems, since the non-linearity of the system which affect the function but it is still functional because the movement is continuous.

The implementation of the *Focus* structure to store the focus measure and *Scanned* to store the captured images has had an important utility because it is required to have the complete data per channel for each focus technique to perform tests outside the execution of the algorithm.

The autofocus algorithms validations have been carried out by the execution of the corresponding mathematics of Energy of Gradient, Energy of Laplacian, Gaussian derivation, Tenengrad and Vollath's Correlation, techniques base on the search edge detection and focus measure (FM).

Focus measures give an average of the intensity of the image pixels to know the extent of their quality. The channel analysis helped to know that the red channel generates higher and faster values than other channels, regardless of the type of  $y$  that has been used. The Tenengrad chosen shown resistance to noise and vibration disturbances and indicate a great contrast between what is focus and out of focus for which an average gradient of 0.72 was obtained for Sarcophaga, 0.63 Scathophaga stercoraria and 0.73 for Calliphora.

Edge detection techniques have been used to find composite eye edges where threshold values were selected by experimental criteria until the desired shape has been detected and have been used to ensure the best product image where the camera stopped.

The autofocus algorithm implementation has produced a satisfactory result for the GRACE second version device which was the best technique and channel as well as to use that information to make a new way to control the camera positioning.

## Conclusions and Outlook

The implementation of the autofocus algorithm has been achieved through the structuring in five modules to divide the procedures and have an appropriate response by relating a control circuit (hardware) to the software programs, that implementation is called image-bases control. The algorithm by modules achieved an organized methodology to position the camera as well as to unify in a single execution the analysis of the five techniques in its three channels at the same time to be stored in a data structure. By mean of AutoSlopes function, which grouping five focus measure and retrieve a slope, was possible stopping the algorithm and the camera position when finding images with high magnitudes of FM through a group of five focus measure.

The search for the mathematics of each of the five algorithms have validated them because they are algorithms that make calculations based on the detection of edges that helped to define compound eyes as well as retrieve the focus measure gave in lumen unit that means an average of the intensity of the pixels to look for the sharpness of the images. With the execution of the algorithms, it has been possible to find out with the three flies' species that Tenengrad is the technique with quick results and precise time to find sharpest images and added to the functional prototype to GRACE second version. In addition, it included the communication without loss of data and capture uninterrupted images when making movement.

### Recommendations (Outlook)

The positioning control can receive modifications like include conditions of friction and gravity to counteract some difficulties when moving the position of the camera up or down. To capture images, a good lighting system is recommended, as well as to perform the eye scanning on a surface where aspects such as noise or vibrations are not perceived. For users, it is recommended to do a graphic interface where the user chose the techniques, the movement and next to that include the visualization of the live images that are currently seen. The electronic circuit has to integrate their all in a PCB, currently each integrated component are separately and connected by means of cables.



## References

- [1] D G Stavenga. Pseud opupils of compound eyes. In Handbook of Sensory Physiology, volume VII/6A, chapter seven, pages 357{439. Groningen, 1979. ISBN 3-540-08837-7; 0-387-08837-7.
- [2] Universidad de Costa Rica. Visin de los insectos. Museo de Insectos, 2009. URL <http://www.ciproc.ucr.ac.cr/index.php/es/areas/museo-de-insectos>
- [3] Michael F Land and Dan-Eric Nilsson. Animal eyes. Oxford Animal Biology Series, 2(1):221, 2002. doi: 10.1093/acprof:oso/9780199581139.001.0001.
- [4] Tamara R Spanier. The Design and Implementation of the Full Actuation for the Five DOF 3D Robotic Scanner. (July), 2015.
- [5] Doekele G Stavenga. Reections on colourful ommatidia of butterfly eyes. The Journal of experimental biology, 205(Pt 8):1077{1085, 2002. ISSN 0022-0949.
- [6] Vargas-Delgado. An Image Stitching Algorithm for Compound Vision Research. 2016.
- [7] G J Doornbos. Design and implementation of an autofocusing algorithm for a 3D robotic scanner IEM Bachelor thesis. (June), 2015.
- [8] Angulo García, Angulo. Sitemas Digitales y tecnologia de computadores. 2007. URL <https://books.google.nl/books?id=i8eX0aMzmzcC&lpg=PA147&dq=que%20es%20cmos&hl=es &pg=PR2#v=onepage&q=que%20es%20cmos&f=false>
- [9] Rafael C Gonzalez and Richard E Woods. Digital Image Processing (3rd Edition). 2007. ISBN 013168728X. URL <https://www.amazon.com/-/es/Rafael-C-Gonzalez/dp/013168728X>
- [10] Arturo de la Escalera Hueso. Vision por computador:fundamentos y metodos. Pages 1{63, 2001. doi: 10.1007/s00359-016-1119-7.
- [11] Diego Gonzalez-Aguilera, Javier Gomez-Lahoz, and Pablo Rodr guez-Gonz\_alvez. An automatic approach for radial lens distortion correction from a single image. IEEE Sensors journal, 11(4):956{965, 2011.
- [12] Rafael C Gonzalez and Richard E Woods. Digital Image Processing (3rd Edition). 2007. ISBN 013168728X. URL <https://www.amazon.com/-/es/Rafael-C-Gonzalez/dp/013168728X>
- [13] J M Geusebroek, F Cornelissen, aWSmeulders, and H Geerts. Robust autofocusing in microscopy. Cytometry, 39(1):1{9, 2000. ISSN 0196-4763. doi: 10.1002/(SICI) 1097-0320(20000101)39:1h1::AID- CYTO2i3.0.CO;2-J.
- [14] Accommodation in Computer Vision. Accommodation in computer vision. 1970.
- [15] Bernd Jahne. Digital Image Processing (3rd Edition). 1995. ISBN 013168728X
- [16] Dieter Vollath. Automatic focusing by correlative methods. Journal of Microscopy, 147(3):279{288, 1987. ISSN 00222720. doi: 10.1111/j.1365-2818.1987.tb02839.x. URL <http://doi.wiley.com/10.1111/j.1365-2818.1987.tb02839.x>
- [17] Ketan Kumar Sahu. Automated image feature identification for motorised mapping of insect eyes. In University of Groningen, 2017.
- [18] Aleman-Flores Santana-Cedres Trujillo-Pino, Krissian. Accurate subpixel edge location based on partial area e\_ect. (October), 2012
- [19] Diego Gonzalez-Aguilera, Javier Gomez-Lahoz, and Pablo Rodr guez-Gonz\_alvez. An automatic approach for radial lens distortion correction from a single image. IEEE Sensors journal, 11(4):956{965, 2011.