International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 03, March-2019

Autofocus Mechanism for Telescope

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Abstract- **Focusing is a vital parameter in image recording. Autofocusing is a process of getting a sharp image projection on the camera sensor by using closed loop system. The basic requirements for a practical autofocusing system are speed, sharpness and robustness to noise. This paper presents autofocusing algorithm in spatial domain specifically applicable for high magnification imaging. We have used Laplacian operator to detect sharp edges in the selected region of interest for focusing and rotate the rack and pinion focusing mechanism by stepper motor to get sharp image projection on camera sensor. This method has been tested on several images and scenarios.**

Keywords - Autofocus; telescope; laplacian; image processing, spatial domain.

I. INTRODUCTION

In the field of astrophotography digital images are captured with extreme zoom by an optical telescope. Because of extreme zoom and larger focal ratios of the telescope an overall brightness is low in the image. Hence it is difficult to adjust the focus for getting the sharp image. In the observatories and professional astronomy research institutes the images are captured with an advanced instruments. But in an amateur astrophotography, people usually suffer from focus problem and as a result they get blurred images.

In this project we have worked on an auto-focusing mechanism which can be connected to a telescope to get the sharp focus on camera sensor. As manual focus control provided by telescope manufacturer is no longer sufficient for imaging. The mechanism consists rack and pinion telescope focuser which has driven by a stepper motor. The camera is attached to an eyepiece and the whole assembly is going to be controlled by a low power single board computer.

Number of stars visible in an image are drastically reduced when a captured image is not sharply focused as far as astrophotography is concerned. Specially in amateur asteroid hunting, searching is only possible when the image is very sharply focused. Hence an auto-focusing mechanism will help an amateur astro-photographers and asteroid hunters to the great extend.

II. LITERATURE REVIEW

Autofocus technique is mainly divided into two types, one is active autofocus and another is passive autofocus. In the active autofocus method, a distance measuring device that may be either an ultrasonic sound wave or infrared reflection based. The sensor measures the distance between the camera and the object and by measuring the distance the algorithm decides the lens position at which we will get a focused image on the camera sensor.[4]

Another type of autofocus is passive autofocus. Passive autofocus is mainly divided into two types. Phase detection and contrast detection. In phase detection autofocus incoming light ray is split into two rays. The phase detection hardware has two different tiny image recorders along with their micro lenses. When the image gets perfectly focused on the sensor, two image recorders in the hardware get identical images. In contrast detection autofocus technique, pixel by pixel contrast is measured of successive images and maximum contrast frame get found by the algorithm. The maximum contrast frame is a sharply focused image.[1,3]

In higher magnification imaging, the gradient-based sharpness measure has excellent focusing capability than algorithms such as correlation based measure, statistics based measure, Transform based measure and edge-based measure. Gray level difference in neighboring pixels represents sharpness of an image. Either Tenengrad measure with the horizontal and vertical gradients using Sobel operator or Laplacian filter is a great choice for the gradient-based measure.[5,2]

Table 1. Comparison of various sharpness detection methods[5]

Sharpness measure	Advantages	Disadvantages
Gradient based	Applicable to high magnification images Quick response	Large portion of saturation region
Statistics based	-	Low accuracy and noise response
Correlation based	Quick response Applicable to high magnification images Response slope is adjustable	Slightly increased computations
Transform based	Applicable to high magnification images	Slightly increased computations
Edge based	-	Computational complexity, Separation of strong edges, Not applicable to high magnification images

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Courtesy - Yi Yao, Besma Abidi, Narjes Doggaz, and Mongi Abid.*"Evaluation of Sharpness Measures and Search Algorithms for the Auto-Focusing of High Magnification Images"*

III. PROPOSED METHODOLOGY

We are going to implement auto-focusing mechanism on self assembled 15x50 telescope which has the Celestron optics. It has a precise rack and pinion focuser which will be driven by a stepper motor. An open source single board computer *Raspberry Pi* will be the heart of a system. Raspberry Pi will capture the image through a telescope and an algorithm in the form of python script will detect sharpness of the image. Raspberry Pi has got GPIOs so the image processing result will be reflected on GPIOs as a stepper motor rotation signal[6]. This is all about hardware and real world implementation.

In image sharpness measurement, we are going to implement gradient based measurement scheme. In an image, gray level differences among neighboring pixels provide a reasonable representation of an image's sharpness. To get the focus coordinates, a LCD display will be interfaced with hardware and that will be continuously projecting current camera data. The user has to give focus coordinates either by finger touch or by console click event.

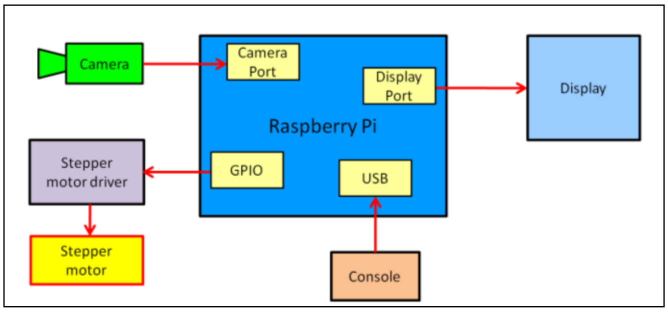

Fig 1. Block Diagram of the system

IV. PROPOSED ALGORITHM

In this algorithm successive variance comparison is used to get a sharp image automatically. First, the image is recorded by the camera and the user is been asked to give a region of interest for focusing. And on the defined region of interest further processing is done. The detailed sequence of the algorithm is given below.

1. Project the live streaming from the telescope camera on the user screen. Ask the user to give focus coordinates by the provided console and select the region of interest which is to be considered for further mathematical operations to measure the sharpness of it.
2. When the user gives focus coordinates, it is necessary to park the focuser to its reference point, as a rack and pinion mechanism has two ends. When the focuser gets parked reference point to set to zero by a limit switch.
3. Now, the focuser is at the reference position, hence moving it to predefined direction will vary the distance between two lenses of the telescope and hence sharpness of the image will change.
4. As the sharpness goes on increasing, at some point of the focuser movement variance will reach its maximum value and again start decreasing toward zero. This is quite similar to hill climb algorithm.
5. The values of the variance of every image are stored in the array. Every time the maximum value of variance from the array is calculated. When the recent value reaches less than 20% of the maximum value from the array it is concluded that the hill descending is happening.
6. At this point in the variance value, the motor direction is changed to reverse which, as a result, move the rack and pinion focuser in the opposite direction and sharpness of the image starts to increase
7. In this last step of the algorithm, every recent value is compared with the maximum variance value from the defined array. and when the recent value reaches 95% of the maximum value. the motor is stopped. So the resultant image is sharply focused image.
8. It has been found that due to telescope vibrations a slight shake due to inaccuracies in the mount, some variance values have an abrupt deviation in successive readings. Average of successive five values have been taken in order to suppress those abrupt deviations. Hence the graph of focus position vs variance become more accurate and smooth.

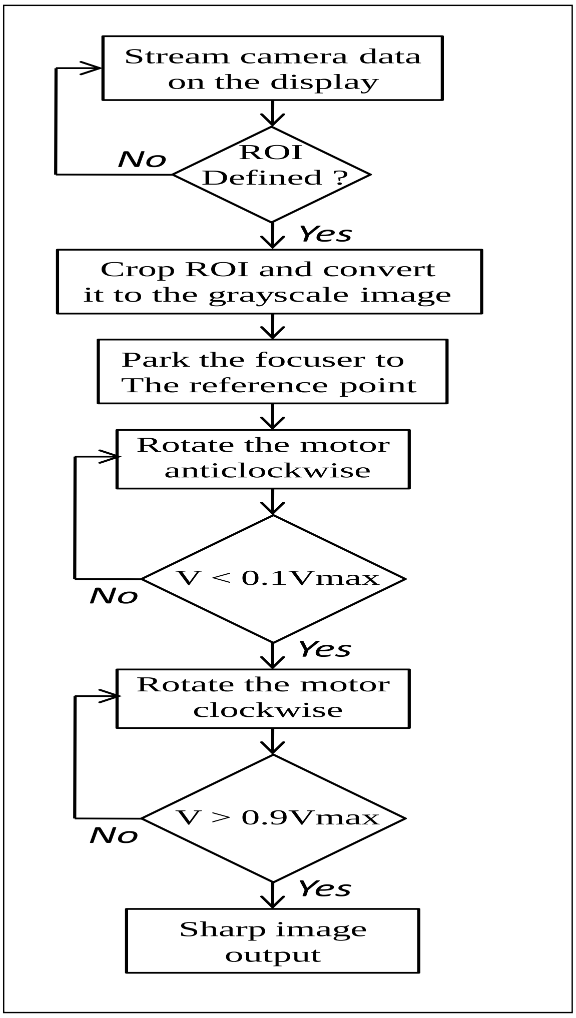

Fig 2. Flow chart

International Journal of Engineering Research & Technology (IJERT)
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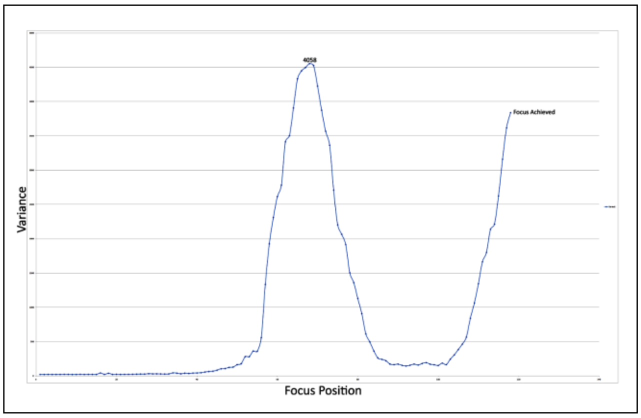


Fig 3. Focus position vs. Variance without averaging.

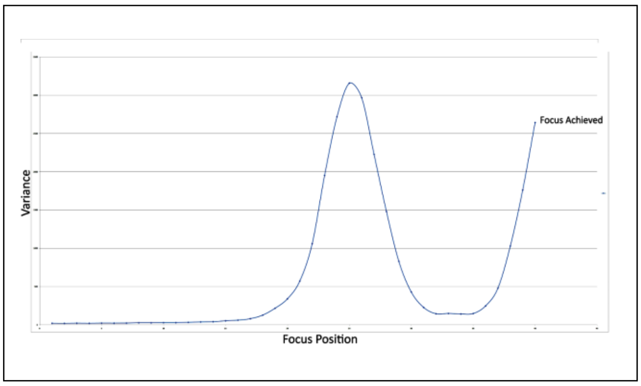


Fig 4. Focus position vs. Variance with averaging.

V. STATISTICAL PARAMETERS

1. Laplaican operator

$$L(x,y) = \frac{\partial^2 I}{\partial^2 x^2} + \frac{\partial^2 I}{\partial^2 y^2}$$

Where,

$L(x,y)$ is a output image
$I(x,y)$ is a pixel intensity value

2. Variance

$$\sigma^2 = \frac{\Sigma(x-\mu)^2}{N}$$

Where,

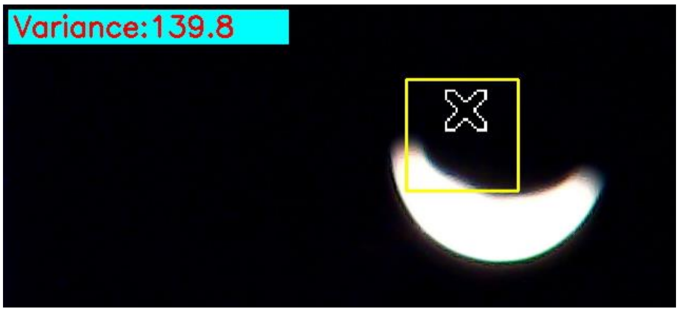
σ^2 is variance
χ is the value of an initial data point.
μ is the mean of data point
N is the total number of data points

3. Averaging of variance

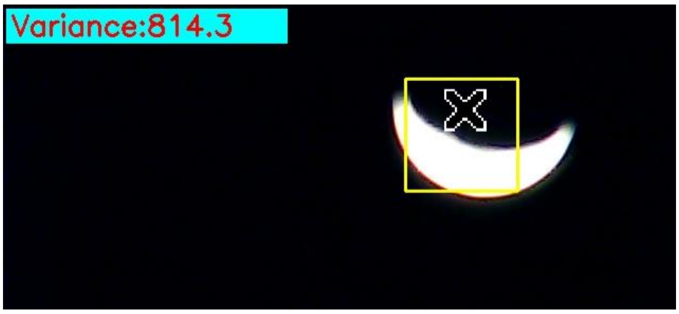
$$\bar{V} = \frac{1}{n}\sum_{i=0}^{n} xi$$

Where xi is a variance of latest frame

VI. EXPERIMENTAL RESULT

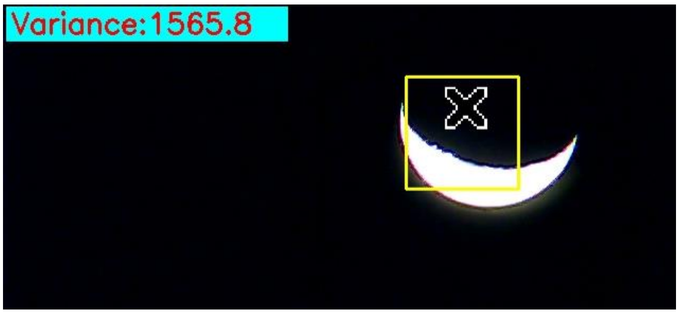


(a) Variance 139.8



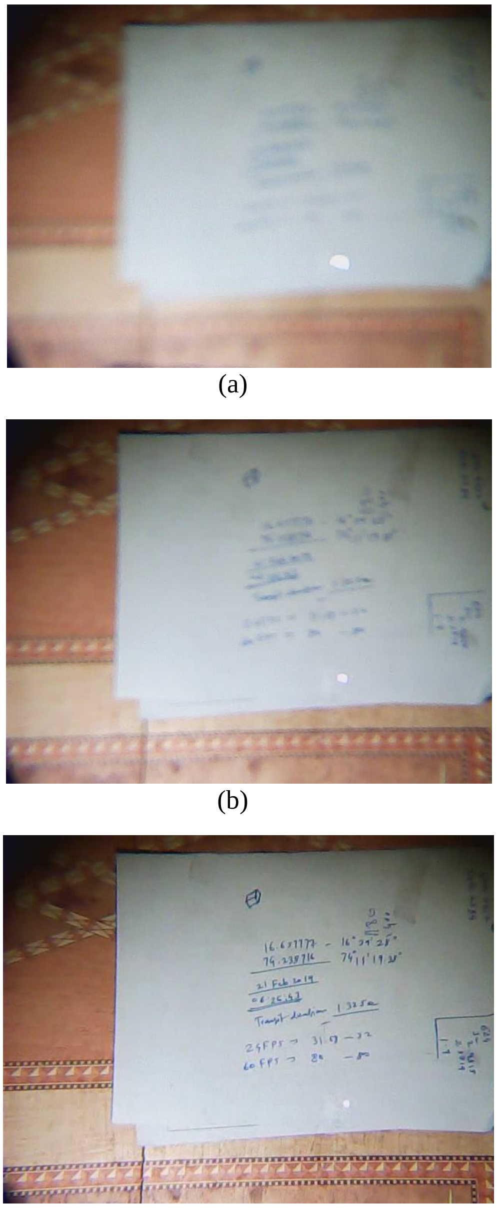
(b) Variance 814.3

(c) Variance 1292.1



(d) Variance 1565.8

Fig 5. Focusing algorithm working. From defocused image (a) to sharp image (d). Image captured by Telescope at 15x magnification and USB web camera.



(a) (b) (c)

Fig 6. Low light performance of proposed algorithm.
(a) Defocused (b) Partially focused (c) Focused

Table 2. Real time data of variance, motor direction and focus status with respect to iteration steps.

Step number	Motor direction	Variance of ROI	Focus status
1	Anticlockwise	32.62928	Defocus
2	Anticlockwise	38.18802	Defocus
3	Anticlockwise	41.80423	Defocus
4	Anticlockwise	52.72631	Defocus
5	Anticlockwise	61.19632	Defocus
6	Anticlockwise	80.38739	Defocus
7	Anticlockwise	126.9063	Defocus
8	Anticlockwise	216.4991	Defocus
9	Anticlockwise	339.7576	Defocus
10	Anticlockwise	572.5896	Defocus
11	Anticlockwise	1059.164	Moderate focus
12	Anticlockwise	1950.688	Moderate focus
13	Anticlockwise	2716.945	Perfect focus
14	Anticlockwise	3157.174	Perfect focus
15	Anticlockwise	2966.333	Perfect focus
16	Anticlockwise	2225.528	Moderate focus
17	Anticlockwise	1479.209	Moderate focus
18	Anticlockwise	828.8435	Defocus
19	Anticlockwise	429.8095	Defocus
20	Anticlockwise	227.6932	Defocus
21	Anticlockwise	144.8395	Defocus
22	Anticlockwise	148.7029	Defocus
23	Anticlockwise	141.8684	Defocus
24	Clockwise	147.5137	Defocus
25	Clockwise	247.0296	Defocus
26	Clockwise	480.1231	Defocus
27	Clockwise	1029.202	Moderate focus
28	Clockwise	1761.385	Moderate focus
29	Clockwise	2642.486	Perfect focus
30	Stopped	2935.268	Perfect focus

VII. CONCLUSION

A novel approach to the telescope autofocusing by using gradient-based sharpness measure and hill climb search algorithm is presented. The algorithm is experimentally tested on both celestial and terrestrial objects. In gradient-based measure, a large area of focus vs. variance plot goes in the saturation region. The accuracy of focus by the proposed algorithm is found to be 95%. The accuracy gets increased with a reduction in algorithm malfunctioning chance when variance averaging method was used. To improve the accuracy we can combine multiple sharpness detection algorithms as mentioned in this paper.

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