International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

FWHM & HFR BASED AUTO FOCUSER MODULE FOR TELESCOPES

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FEATURED APPLICATION:

In this paper, the problem of focusing the telescope for deep sky observation has been solved. Based on image quality assessment, a fast and automated method based on Half Flux Radius and multiple output images were evaluated to find correct focus. The proposed method can be applied to any telescope which uses a rack and pinion method to focus on deep sky objects.

ABSTRACT: **Deep sky imaging and astrophotography involves taking photos of distant objects like nebulae, stars, comets, star clusters and galaxies which are spread over a few to tens of pixels in an image. It needs to be well in focus here's when we need a focusing module for the telescope. The basic requirements for a practical focusing system are speed, sharpness and robustness to noise. Accurate focusing is one of the most crucial steps necessary for astro photography and deep sky imaging. No matter how advanced the optical assembly is, it is bound to require some manual adjustments necessary for it's correct operations like collimation. But certain activities like focusing can be automated using computer vision and image analysis with use of robotics can make the process faster, easier, reliable and less time consuming. Where manual adjustments for correct focusing of a telescopes can take hours and various special equipments to overcome atmospheric aberrations, turbulences, wind conditions, pollution, etc, Full Width at Half Maximum (FWHM) and Half Flux Radius (HFR) based auto-focusing technique can reduce the complexity of the focusing process and can cut the cost of auto-focuser assembly to less than half. With implementation of this project we are aiming to make a motorized module for focusing telescope assembly and machine learning for its operation. The team also looks forward to working on every pixel data of the image so as to make the assembly best in accuracy and precision. This project is an improved version of previously built auto focuser modules in terms of accuracy, relevance and under considerations of various atmospheric phenomena which were omitted or were not taken into cogitation previously. This implementation can be used in various astronomical experiments and astrophotography both for professional and novice users. The method used in research can greatly diminish the time complexity of focusing a telescope from several hours to just some minutes.**

KEYWORDS:
Deep sky imaging, pixel, collimation, computer vision, Full Width at Half Maximum, Half Flux Radius, auto-focusing

I. INTRODUCTION

In the field of astrophotography pictures are clicked with extreme zoom and focus by an optical telescope. Star being a distant point source has extremely less overall brightness and energy therefore is difficult to focus on to get a crisp image. Various deep sky images you see on the internet are clicked by observatories and professional astrophotography instruments. But ametuer as well as professionals suffer from less accurate focusing of the instrument which in turn leads to blurry images. In this project we have worked on an auto-focusing mechanism which can be connected to a telescope to get a sharp focus on distant night sky objects. As focusing tools already present in the market require both time and effort and are usually costly and have no cross checking for perfect focus, we devised a way to study each image on the basis of pixel data in the star image and on the basis of energy/brightness of a pixel. This study uses predefined methods of Full Width at Half Maximum and Half

Flux Radius to calculate mean energy of pixels. With a certain number of iterations over an image of a fixed portion of night sky we can readily calculate the best position of eyepiece for optimal focus. The mechanism consists of a rack and pinion method which will rotate the focuser assembly of the telescope to either anticlockwise or clockwise direction over a number of iterations. The images clicked with each new calibration of focuser will be studied using computer vision and machine learning. After the process completes we will get the optimum position of the eyepiece for the best focus and also the image captured at accurate focal length. Whole assembly will be controlled by a low power **single-board computer** (**SBC**).

Number of stars considerably decreases when a night sky image is out of focus. In astrophotography little diversion from the actual focus can ruin the whole image and we are left with just faded blobs. Especially ameteur astro-photographers, the user has very little knowledge about the underlying calculations and methods to achieve a crisp deep sky image, hence an auto-focuser module will readily help them to a great extent.

II. LITERATURE REVIEW

Deep sky imaging is difficult for new enthusiasts who possess interests in the field of astronomy. Many factors come into play when a novice starts taking pictures of deep sky objects, these factors include collimation, atmospheric aberration, Anomalies present in the atmosphere etc which makes it difficult to get crisp in-focus images. Much research has been done in the similar field but lacks overall efficacy and accuracy.

Jaemo and Quiyang [1] have used region of interest based focusing methods and variance detection. Under terrestrial observation conditions this method can be effective, but in astronomical observation situations this method falls short in terms of accuracy. The reason being that terrestrial objects are near enough to cover a large amount of pixels but stars (if ignoring the atmospheric aberrations and other optical defects) cover at most one pixel due to the distance they are from us. This means the region of interest and variance method can only rely on the atmospheric aberrations and other optical defects that make the star's light spread out over an area. Furthermore, the tests they conducted were performed on terrestrial objects where the focusing factors and parameters are much different than astronomical bodies and deep sky objects.

Aniket, Vipul, Manish and Saishwari [2] came up with a brilliant idea of focusing using sharp edge detection using laplacian operators. While this method can be effectively used on astronomical bodies like the moon and some planets that can be easily resolved, it doesn't perform well enough when we apply this method to a deeper survey of the sky. Since the stars, as previously stated, actually cover only one pixel at most due to their distance from us, the shape that we see in images is the result of atmospheric aberrations and optical aberrations. Thus the light from the star spreads out over an area like a gradient. Edge detection on gradients can be a difficult task and most of the time isn't as accurate. The tests conducted were also on terrestrial objects and only those astronomical bodies that can be easily resolved by a camera sensor, like the moon. This method can be inefficient when applied to deep field observations.

Roy, Ratnakirti and Dey, Sumon [3] demonstrated the functioning of autofocus in digital cameras, but unfortunately the technology used is very much similar to variance detection method, and furthermore, since digital cameras use lenses that have very small focal lengths the level of accuracy and tolerance for error is much lower when compared to application in optical assembles with very long focal lengths.

Abu Olaim, Abdullah and Punnappurath, Abhijith and Micheal Brown [4] proposed an advanced autofocus system for smartphone cameras. Again due to the small focal lengths of smartphone cameras and the smaller pixel sizes, the level of accuracy isn't up to par for a system that requires micro level focus. Thus this concept did not prove useful for deep sky imaging and distant imaging application.

Wei Zhang and Wai-Kuen Cham [5] proposed a very advanced system that works on a focus map based on the edge blurriness, which is depicted explicitly by a parametric model. The only issue with this system is that it can only work on objects that cover a large amount of area on the image sensor and objects that have large surfaces that can be resolved easily, unlike stars that actually cover even less than one pixel and the extra area it covers is due to the atmospheric and optical defects.

Zhang and Cham [6] In this paper a postprocessing method to tackle the single image refocusing-and-defocusing problem is shown. The proposed method can accomplish the tasks of focus-map estimation and image refocusing and defocusing.

Lorenzo Zago [7] Seeing: The seeing caused by atmospheric turbulence through which some of the light arriving from a star is scattered by refractive inhomogeneities. As the light wave propagates through the atmosphere it experiences fluctuations in amplitude and phase. An image formed by focusing this wave exhibits fluctuations in intensity, sharpness and position which are commonly referred to as scintillation, image blurring and image motion.

Miyashita, Kazuhisa [8] Half Flux Diameter-Applicate to determination for faint star event. It is difficult to determine if a star appears or not in the faint star event, because, in the case of noisy video, the star often disappears into large noises. Half Flux Diameter function is useful for analysis in such cases.

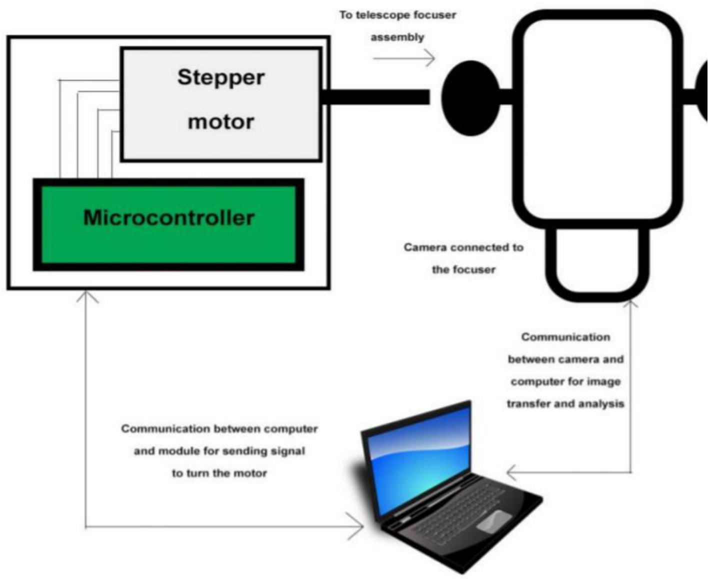
Tzyh-Chian, Yao-Chou, Hwai-Tsu [9] Revisiting Autofocus for Smartphone Cameras This paper demonstrates the use of fuzzy logic for focusing. The automatic focus is performed by evaluating the object distance and luminance. The object distance is measured by the beams of infrared light. The idea was good for objects at smaller distances like 10-20 meters as infrared rays tend to get absorbed by the surrounding environment which decreases the efficiency of the focus in the image.

IV. TECHNOLOGY USED

Robotics- Robotics is an interdisciplinary field that creates a bridge between computer science and engineering. It involves design, construction, operation and use of automated systems and can work as a substitute for humans and can replicate human actions over a number of iterations. Robotics can be used in various situations and also in dangerous environments like in the vicinity of radioactive materials, bomb detection, land mine detection and their deactivation, manufacturing processes or where humans cannot survive. Use of robotics is to attempt the replication of human behaviours like talking, walking, lifting, cognition and any other human activity. Today's robotics are inspired by nature and environment which can readily sense change in environment and can change their behaviour as required.

III. ARCHITECTURE

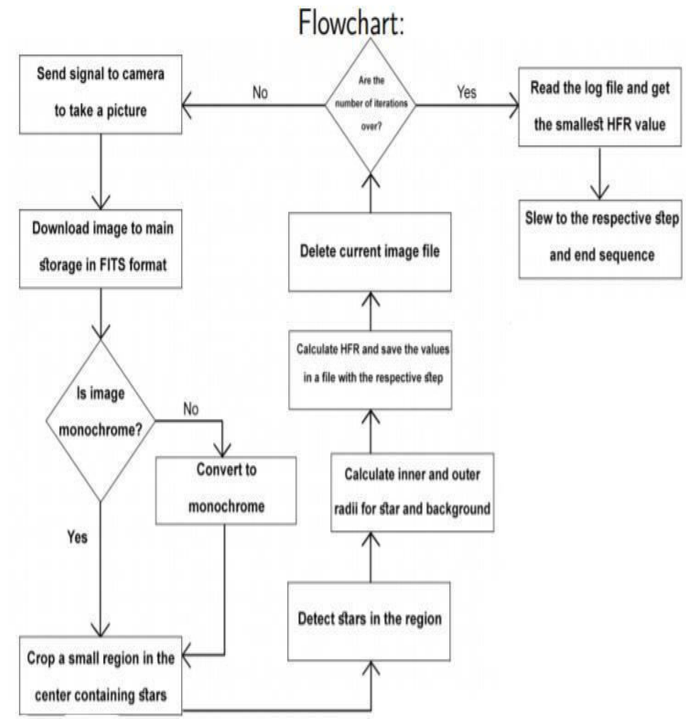
The first and foremost step in any project is to design a blueprint of a project. The diagram should contain all the actions being performed.



The experimental setup contains a telescope (Ritchey Chretien 6 inch) fitted with a Digital Single-Lens Reflex(DSLR) camera with sensor size of ⅓ inch, pixel size 3.75 micron, monochrome sensor. The whole assembly of the camera with the telescope is connected to a computer which records the images taken by the camera and logs them in a .fits file for further processing. Stepper motor (Nema 17 PG 14) is connected to the focuser of the eye piece and can be rotated either clockwise or anti-clockwise over equal number of iterations for both the directions. In each iteration a picture of the night sky is clicked for analysis.

Micro controller (Arduino Nano) connected with the stepper motor gives signals to the geared stepper motor to rotate in the desired direction and in turn rotate the fouser of the telescope. After each titration the clicked pictures are automatically uploaded in an algorithm which works to find out the least HFR value of the image. The image with least HFR values will be in best focus and the position of stepper motor fixed with focuser will give the best focus position of the eyepiece lens.

Data Flow Diagram for Auto- Focuser Module



V. HALF FLUX RADIUS

This is a measurement which is an improved version of Full Width at Half Maximum(FWHM)measurement invented by Larry Weber and Steve Brady for calculating half the total average energy of pixel in the star image.Mainly due to seeing, the star are not imaged as a dot but a spread out Gaussian Shape.

Def. The HFD is defined as the diameter of a circle that is centered on the unfocused star image in which half of the total star flux is inside the circle and half is outside.

The formula for calculating HFR is

$$\sum_{i=0}^{N} V_i \cdot (d_i - HFR) = 0 \Leftrightarrow HFR = \frac{\sum_{i=0}^{N} V_i \cdot d_i}{\sum_{i=0}^{N} V_i}$$

where V_i is the pixel value minus the mean background value, d_i is the distance from the centroid to each pixel, N is the number of pixels in the outer circle and HFR is the Half Flux Radius for which the sum becomes 0.

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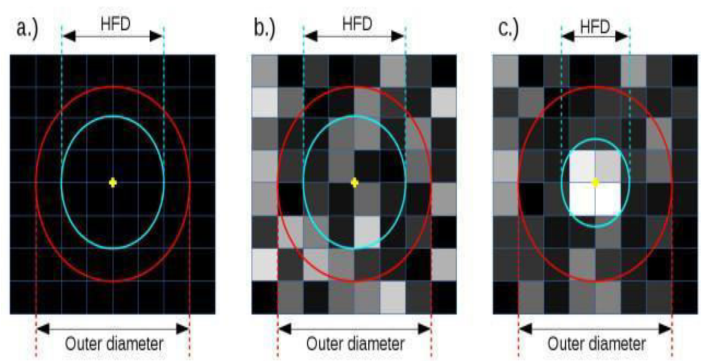
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

HFR is just the mean radius of all the images of stars present in the picture for which the sum becomes 0. The difference d(i)–HFR becomes negative for all the pixels which are inside the inner circle (di<HFR) and positive for all which are outside the inner circle (di>HFR). It is easy to calculate HFR after transposing the equation.



The HFD illustrated for different images. Left: black image, middle: noise, right: star in focus. In the first image there is no star in the image so there is no flux at all which means a totally black image so HFD don't actually exist. Similarly in the middle image there is too much noise and is distributed all over the image therefore HFD does not give any value. Whereas in the third image there is a focused star there is a focused star image therefore the HFD value decreased. HFD also gives acceptable values for stars which are far out of focus which makes it a more robust and stable FWHM method.

THE PROCESS

i. A command shall be sent to the camera to take an image. Firstly we will start with an image taken through the telescope being out of focus.

ii. The image will be in .fits file when downloaded, shall be run through a process of cropping the region of interest and detect if stars are present in the region and convert it into monochrome.

iii. Then a signal shall be sent to a stepper motor to turn in either clockwise or anti-clockwise direction.

iv. All the above steps are repeated for however many iterations the user wants in both clockwise and anti clockwise direction.

v. Once the iterations are over, the least value of HFR is extracted from the array of values and the image corresponding to this HFR is the image in best focus. The length of focal tube of the telescope achieved using the rotation of the stepper motor will be the best length of the focal tube for the telescope for these many iterations.

vi. If the image still seems out of focus then we will start again with a set number of iterations from the previous position where we got the least HFR value for the image.

MEASURING HFD

i. Subtract the mean brightness of the background from the image.

ii. Find the centroid of the star by simply calculating weighted average of each pixel present in a star’s image.

iii. Determine distance of each pixel from the centroid.

iv. Sort the pixel in order of increasing radius.

v. Generate an integral of the pixel flux along the diameter (= 2 X radius) dimension. This integral is shown on the user form as a small plot to the left of the Find and Focus buttons. This plots the diameter along the horizontal axis and the integrated flux along the vertical axis. The integral shows zero integrated flux at the zero diameter and it shows the full star flux at the largest diameter.

vi. Determine the Half Flux Diameter from this integral, which is simply the diameter where the integrated flux is half of the full star flux. This HFD point is marked on the flux integral plots with a vertical line.

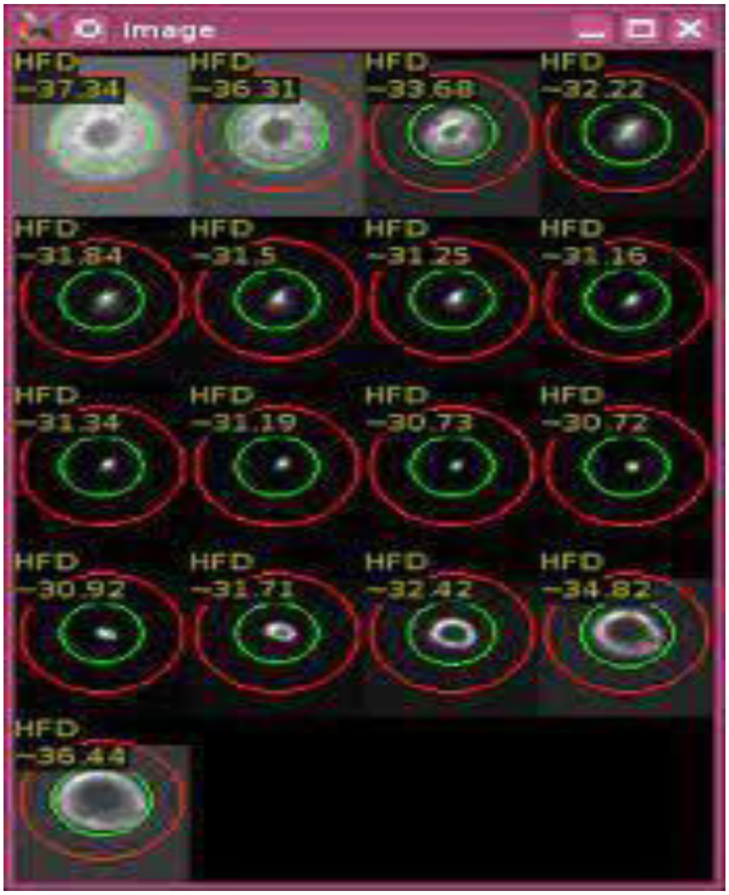
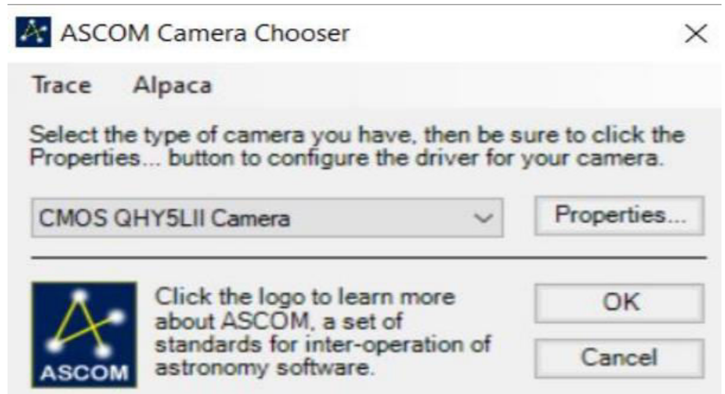


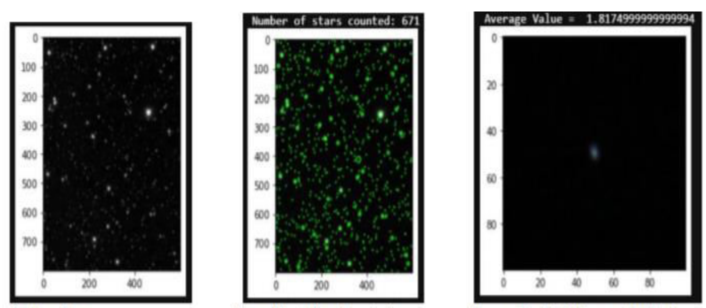
IMAGE PROCESSING

i. The execution phase begins with image signals being sent to the camera to capture images and save it in FITS format for lossless pixel interpretation. The following shows the interface for ASCOM compatible camera selection. This serves as an interface from camera to upload file directly on computer when clicked.



ii. After camera selection the sequence for autofocus begins. Images captured are downloaded and analysed and the required values are recorded.

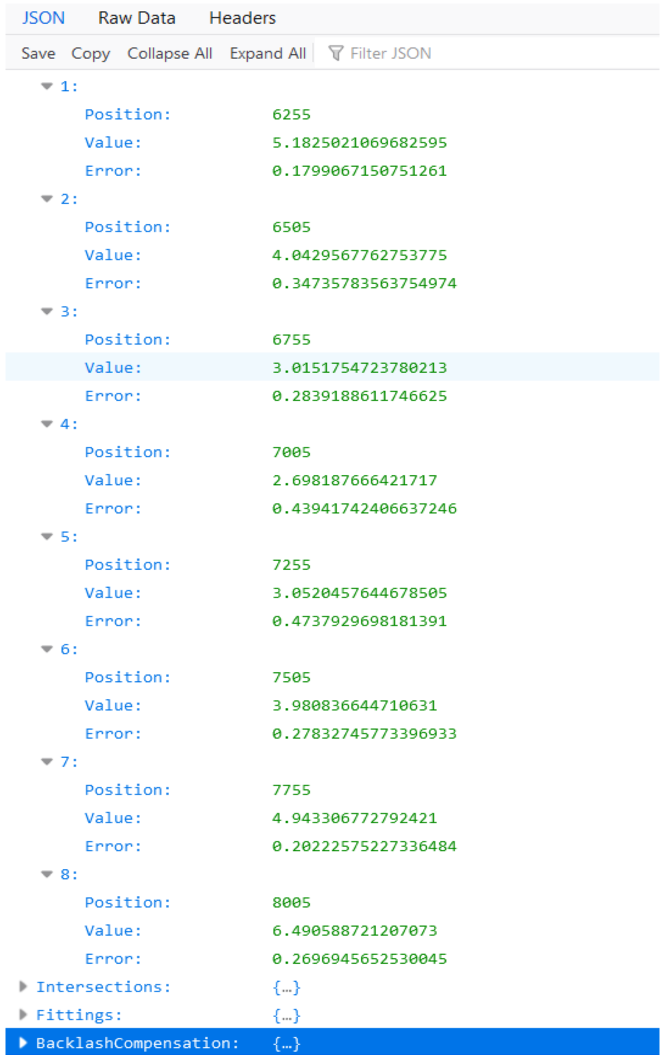
iii. Following shows the implementation of sequence of image analysis to be performed, here the image depicts the cropped image from a full length star image taken by telescope and stars are detected and marked with a green circle.



Captured image Stars detected and marked Average pixel brightness calculated

iv. After making all the stars in the image the average brightness of all the pixels in the image is calculated. This will serve as a benchmark to check if there is a star in the image or not. All the stars detected will have pixel brightness above this mean brightness value, for calculation of half flux diameter we subtract the mean background value of pixels from the image.

v.. Now we calculate HFD which is twice the HFR value and log it into a JSON file.



VI. CONCLUSION

The research and implementation of the telescope's auto-focuser module using FWHM and HFR for deep sky imaging with the support of robotics is successful. Cheap price, fast, easy to use even for a novice, reduced hassle of collimation and independent of atmospheric aberrations are the key advantages of the system. The setup works on pixel data of the image hence is accurate with high precision. Setup was tested under windy, summer and even winter environments to see different aspects of weather conditions on the experiment. The experiment proved successful in all types of weather conditions as long as the stars are visible clearly. The implementation of the concept on actual experiment proved accurate and reduced the time taken for focusing the telescope to less than 10 minutes. This methodology can be implemented easily using online tools and libraries already present online which makes the experiment open to any kind of users who possess interests in astronomy and astro-photography.

VII. FUTURE ENHANCEMENTS

In the course of time this setup can be made widely available for novice astronomers which also can be used by skilled professionals to resolve the time of setup for imaging deep sky objects. Being of low cost and readily available parts the setup can be sold commercially by a company, it will readily hit the astronomy market as the cost of this setup is cut to much less than half in comparison to the actual parts one needs to buy focusing modules for telescopes.

With the use of latest technology and 3D printed parts the setup can be made to look less bulky, use of rechargeable batteries or USB charging batteries can help powering the stepper motor with less frequent changing of batteries used in the setup. A mobile application can be built in place of API which can be used to run the setup, with increased functionality of Single Board Computers (Eg Arduino uno) more predefined functions can be added to the setup. With the use of Wi-Fi and bluetooth technology the setup can be used to remotely focus the telescope as required.

Hence, in the times to come this project can be polished and evolved further so that it is able to give more advanced results that are even more effective. This will also enable novice astronomers to work their skills in deep sky imaging and astrophotography.

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