Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

EXPLORING THE COSMOS: A WEB-BASED APPLICATION FOR POLLUTION, CONSTELLATION AND MOON PHASE RECOGNITION

Mihai MAFTEI, Iuliana MARIN

National University of Science and Technology Politehnica Bucharest,
313 Splaiul Independentei, District 6, Bucharest, Romania

Corresponding author email: marin.iulliana25@gmail.com

Abstract

Throughout human history, the fascination with celestial objects and the night sky has persisted. This article introduces a web-based application designed to assist users in identifying constellations, light pollution that obscures stars in the night sky, along with moon phases in astronomical photographs. The application utilizes image processing techniques and template matching to achieve this recognition, enabling users to explore the cosmos independently. The article outlines the methodology, including the creation of constellation templates and the process of image normalization and matching. It also discusses the mathematical calculations involved in star recognition and moon phase determination. The application's user-friendly interface and feedback from users are presented, indicating a positive response. The article concludes by highlighting the potential for further development, including the conversion of the application into a mobile version and the addition of features such as air pollutants indices, a moon phase calendar, and zodiacal data. The application is poised to be a valuable tool for astronomy enthusiasts, navigators, and those interested in exploring the mysteries of the night sky.

Key words*: constellations, image processing, moon phase, stars, template matching.*

INTRODUCTION

Since the dawn of humanity until these days, the idea of evolution has been understood. People always searched for methods that would make their lives easier and learn as much as they could in the shortest amount of time. Modernity, technology, and tools make life easier wherever we turn, but when we turn off the switch and the power go out, we become aware of the mysteries of the sky, a blue map covered with shining dots that stand in for the past, present and future.

Known as stars, they are essential elements of the cosmos that can be connected and represent constellations, often used by navigators for guidance or even for mythical storytelling. Even so, only a skilled and experienced stargazer with sufficient background knowledge will be able to identify constellations.

Numerous guidebooks, websites, and cell phone apps have been developed to assist non-professionals in locating the constellations (Contreras-Koterbay & Mirocha, 2016; Gomez & Fitzgerald, 2017; McKee et al., 2022; Molnar & Kiss, 2023). Even though these options appear to be useful, they can only make suggestions and cannot take environmental factors into account. However, the question remains how a human can look up at the sky and identify the stars and constellations by himself. Everything may now be streamlined and made feasible thanks to technological advancements (Modeling, Systems Engineering, and Project Management for Astronomy III | Request PDF, n.d.), and the only things that are required are a clear desire to study and hard work. Searching for an answer to this question and thinking about the preceding catch-up regarding the process of cosmic reaching (Hall, 2022), the current research wanted to create something that will assist people who share interest in cosmic exploration. The present paper is about a constellation recognition application which will allow the user to scan the sky and identify unfamiliar celestial objects. The application includes features such as constellation recognition, by using a pattern matching algorithm, but also a moon phase detector, using its circularity. The important steps in this process, that will be discussed in the next chapters, are similar applications, along with the creation of the template coordinates file, the processing of the test images and the detection algorithm for both constellation and moon phase recognition. The last chapter outlines the conclusions and future work.

MATERIALS AND METHODS

An early scientific tool for keeping time and performing observations was the astrolabe (Raposo, 2022). This instrument was a popular astronomical equipment in the Middle Ages, and it is one of the first instruments used for sky searching. The astrolabe has origins in antiquity, but it was widespread in the 17th century, being used for astronomical observations, such as determining the height or distance from the zenith of the sun, moon, planets, or stars, but also the heights of mountains and towers, as well as the depths of wells. But it was more important when the astrolabe was used as an additional computational tool, meaning that the locations of the sun and other bright stars in relation to the meridian and the horizon, as well as the astronomer's geographic latitude and true north orientation, were all possible by using this equipment (Edney, 2023).

Another tool used in astronomy, the sextant, was made by John Bird in the 18th century (Kelly & Gráda, 2022). A sextant is a device used to calculate an object's height above the horizon. The angle and time of measurement can be used to create a location line on a nautical or aeronautical chart, in that way a sextant is often used to find one's latitude by observing the sun and moon. It can also be used to determine the angle between any two objects when held horizontally, such as stars or even planets.

From Galileo until now, the telescope has played and continues to play an important part in our understanding of the cosmos, and its continuing growth and refinement will no doubt lead to many new discoveries and insights into the future (Zubairy, n.d.). A telescope is an optical equipment used to examine distant celestial objects such as stars, planets, and galaxies. It collects and focuses light from these objects, which is then amplified and brought into focus to generate a picture.

The use of optical instruments such as telescopes, cameras, and image processing techniques to automatically identify and locate stars and constellations in the night sky is referred to as optical star and constellation recognition (Rettberg, n.d.). This method is frequently employed in astronomical research, surveying, and navigation.

One common method of optical star recognition is to use a star catalog as a reference, which contains the positions and brightness of known stars (Savanevych et al., 2023). The positions and brightness of the stars in the image are identified and measured after images of the night sky are compared to the catalog.

In the field of artificial intelligence known as computer vision, it is possible for machines to gather useful data starting with digital photos, movies, and other visual inputs, and then act or offer ideas in response to that data (Utama et al., 2023). Computer vision requires a large amount of data since it performs data analysis repeatedly until it begins to distinguish distinctions and ultimately images. In the current research are involved computer vision methods like thresholding, contour detection, and star extraction from astronomical photos. This procedure includes several phases, including picture preparation, segmentation, feature extraction, and classification.

When referring to constellation searching, a solution to this problem could be using Deep Learning (Khajuria et al., n.d.). This represents a machine learning approach that trains computers to do what people do naturally: learn. Deep Learning is an area of artificial intelligence that focuses on creating large neural network models that can make accurate data-driven decisions, its technologies, such as speech recognition and facial detection on digital cameras, being available on all current smart phones. This machine learning type is a search method aimed at selecting the optimal function from a collection of functions to explain the connections between characteristics in a dataset (Mehta et al., 2022).

A common deep learning model for image analysis tasks like object identification and recognition is the convolutional neural network (CNN) (Zhao et al., 2022; Lubura et al., 2022). In a CNN, each neuron only analyzes data in its receptive field, like the neurons from a biological vision system that respond to inputs only in the constrained region of the visual field. Simpler patterns, such lines, or curves, are identified first in the layers, then more distinct patterns, like objects (Kyselica et al., 2022). Consequently, CNN could be a solution for constellation detection. Automatic learning and extracting relevant features from images are an example of how in the context of constellations searching, CNN learns to identify key patterns and structures that correspond to different stars connections (Song et al., 2023). Translation invariance or robustness to noise and variability are other examples of features that could help in night sky searching (Ramos-Alcaraz et al., 2023).

Another solution for constellation detection is called template matching. While template matching is sometimes seen as a very basic, restricted approach to the most fascinating issues in computer vision, it does touch on many old and new techniques in the field (Jordan et al., n.d.). In this technique, templates are built to reflect the intended pattern or object and they encapsulate the fundamental properties and qualities of the item to be detected (Doukari et al., 2022). The template is then moved over different sections of the input picture. The similarity measure, matching score, thresholding, and localization are computed next, followed by iterative search, because the template matching procedure may entail numerous iterations.

Image processing is critical in template matching because it provides the required techniques and procedures to improve the input pictures, extract significant characteristics, and efficiently complete the matching process. Important factors such as preprocessing, feature extraction, feature representation, template creation, matching algorithm, and post-processing must be highlighted since in the current research all of them are used to get the desired outcome.

RESULTS AND DISCUSSIONS

The proposed solution for gaining the constellation detector involves template matching, technique in which are built templates that reflect the intended pattern or object, and they encapsulate the fundamental properties and qualities of the topic to be detected. The template is then moved over different sections of the input picture. The similarity measure, matching score, thresholding, and localization are next computed, followed by iterative search, because the template matching procedure may entail numerous iterations.

Another method that was involved was image processing, a technique that represents the manipulation and analysis of digital pictures using algorithms and procedures with the objective of increasing their visual quality, extracting relevant information, or changing them into new forms.

Image processing in template matching provides the required techniques and procedures to improve the input pictures, extract significant characteristics, and efficiently complete the matching process. Factors such as preprocessing, feature extraction, feature representation, template creation, matching algorithm, and post- processing are highlighted since all of them are identified to get the desired outcome. As mentioned, there are a few steps of the process that need to be developed before, to make sure that the application will work as planned.

Templates

The production of the used template establishes the initial section of the program. The AstronomyOnline website graphics of all 88 constellations were used to map out the complete celestial sphere in alphabetical order and according to International Astronomical Union (IAU) rules (Observation - 88 Constellations, n.d.).

After obtaining the constellation photos (Figure 1), they were preprocessed using the Python programming language to obtain the coordinates of the stars in each of them. Therefore, an iteration of each file in the template directory was performed to extract the required characteristics.

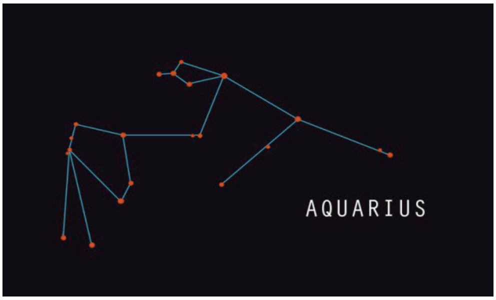

Figure 1. Example of Downloaded Template

Distances and normalization

The constellations in images are represented using the red color to depict the stars and with blue to determine the connections between them. Thus, after reading the images with the function 'cv2.imread()', the red and blue color channels are obtained using the 'get.red()' and 'get.blue()' methods. The results are illustrated in Figures 2 and 3.

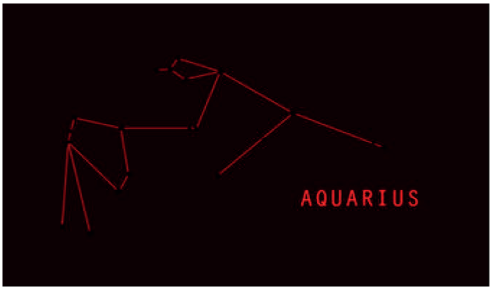

Figure 2. Application of the Red Channel

Figure 3. Application of the Blue Channel

The 'binarise_image()' method was used to threshold the red and blue channels, with any extraneous items being deleted once the binary pictures of stars and lines are converted to grayscale. The use of the 'cv2.bitwise_not()' function to invert the stars binary picture for boosting star areas is followed by edge detection using the 'cv2.Canny()' function.

The Hough line transformation was applied to detect and extract lines from a binary picture. The contours on the edge picture are filtered to remove noise once they have been detected, as in Figures 4 and 5.

To extract the normalized coordinates of stars and lines from contours and drawn lines, the iterate function is used. In the iterate function, it is gone through all the contours of the stars and the centroid for each one of them is calculated, so that it is obtained the brightness (size) of every dot.

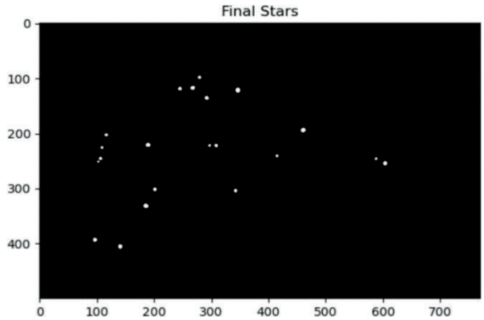

Figure 4. The Found Stars

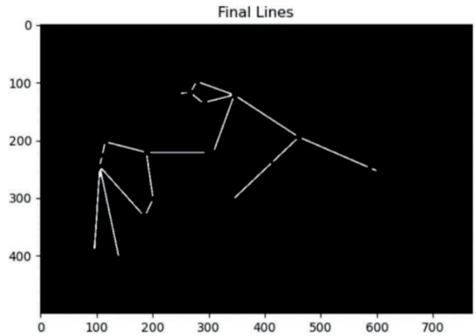

Figure 5. The Found Connections between Stars

The list of coordinates of every point is sorted in descending order, such that there are obtained the first two brightest stars. After getting the first two biggest stars, there can be passed through all the stars and calculate the normalized coordinates bycalling the 'get_normalised_coordinates()' function. This takes the x and y coordinates of the stars and lines, then shifts them with respect to the brightest star, before replacing it in the origin of the coordinate system. It is calculated the distance and angle between the first and second brightest stars and then the distance between all the stars is normalized, as well as the coordinates for points and lines are updated.

The extracted coordinates, as well as the number of contours and normalized lines, are saved in the 'templates_coordinates' dictionary, and then a visualization of the normalized stars and lines is created using the 'matplotlib.pyplot' library and the output is saved as an image (Figure 6), in which there can be seen the first two brightest stars, such that the user can clearly see the connections and how the constellation was found.

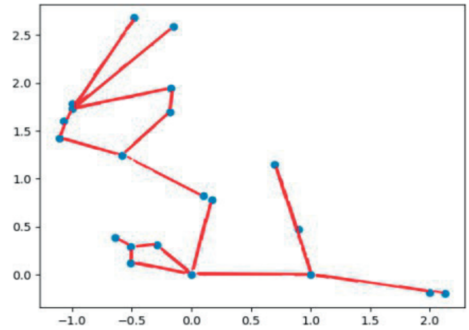

Figure 6. Normalized template example

Following the processing of all template pictures, the 'template_coordinates' dictionary is serialized and stored as a binary file using the 'pickle.dump()' method, so that it may be used in testing to validate the matching with additional photos.

Template matching
After the dictionary with the coordinates of the template for all constellations is triggered, new images of the night sky can be examined to see if there are any similar scenarios.
When a new image is uploaded by the user, the path to it is sent to the 'test_normaliser' function. Then it does the same processing operations that were outlined in the template file creation process, such as normalization and extraction of the coordinates of the stars discovered in the image, which are saved and returned as a list.
The 'simillarity_error' function calculated the similarity error between the normalized coordinates of the test picture and the template image to ensure that there was discovered the perfect match of the stars pattern. The function analyzes the distances between comparable star coordinates and calculates the error depending on the threshold, then returns the count of matched stars and the error value. The constellation with the greatest score is then chosen as the anticipated label. The user may observe the visualization of the matching stars since it is crated and saved in a local directory.

Moon phase
The moon, the nearest big celestial body, and the only natural satellite of planet Earth, has been recognized since prehistoric times and is the second-brightest object in the sky after the Sun. The Moon's nature and genesis have been the subject of centuries of observation and scientific research. Early investigations into the Moon's motion and position enabled tide prediction and sparked the creation of calendars.
The major benefit of researching the history of astronomy is that ancient people observed the same patterns in the sky as today, unlike the study of most historical events, which are singular occurrences. The most significant advances in comprehending Moon phases and eclipses were placed in the explanations provided by Aristotle in his well-known work "On the Heavens" in the fourth century BC is the result of his research in the cities of Babylonia and ancient Greece (Belmonte & Lull, 2023).
Although these discoveries were made very early, they were fought for, and they provide guidance on how to effectively arrange activities for pupils. Aside from a constellation recognition form, the user may scan the moon in a separate form to determine its phase (Figure 7) and the number of days till a new or full moon.

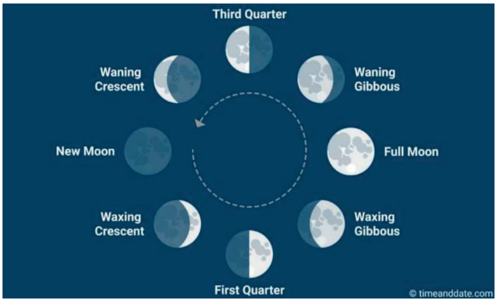

Figure 7. Cycle of the Moon (Phases of the Moon, n.d.)

The idea is like the stars pattern in that when the user enters a photo of the moon, the algorithm analyzes it and looks for the largest item in the image. After locating it, the image is binarized, and the algorithm calculates the circularity of the object, allowing us to determine the stage of the moon phase. After the moon's circularity is determined, there is identified which side is present, left or right, or if the moon is at its fullest. The object's y minimum and maximum points were computed as a solution to this problem. Next, there was drawn a line between these two points and counted the pixels on the line's left and right sides that make up the contoured object. In this method, the circularity is on the left side if there were discovered more pixels there; else, the right side is similarly affected. The moon phase in the image is determined based on these characteristics.

Mathematics behind the overall computation

Some important equations in astronomy, particularly in the field of star recognition and normalization, are used to calculate the distance between two points and the angle between three stars (Mathematical Handbook for Scientists and Engineers: Definitions, Theorems ... - Granino A. Korn, Theresa M. Korn - Google Books, n.d.). These computations aid in the identification and normalization of star locations in the night sky.

Distance between two points (used to determine the distance between two stars)

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

where:

- (x_1, y_1) and (x_2, y_2) are two coordinate points.

The angle is formed by three points (used to determine the angle of rotation of three stars)

$$angle = \arccos\left(\frac{c^2+b^2-a}{2cb}\right) \quad (2)$$

where:

- a, b and c represent the distances between three points. In this example, there was calculated the angle in point A.

The circularity formula (used to determine the circularity of the moon contour)

$$circularity = 4 * \Pi * (A / P^2) \quad (3)$$

where:

- P represents the perimeter of the contour;
- A represents the area of the same contour.

Interface

The application of the current paper was built for anyone who wishes to learn about the constellations visible in the night sky (Figure 8). Users may upload photos or photographs taken by themselves and then see what the software detects and shows as a result. The application may be a valuable learning tool for instructors, professors, and students, as it can motivate them to be outgoing and understand how the connections between stars are discovered on their own.

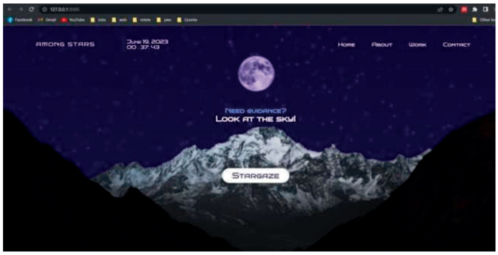

Figure 8. The interface available for the user

The interface is represented by a web application that contains some information about constellations, some appealing visuals, and, most importantly, a slide containing two forms that allow the user to upload the desired picture (Figure 9), scan it with the help of the program behind the application, and view the results. The two forms rely on a backend application that processes and tests the uploaded picture to produce the desired outcome.

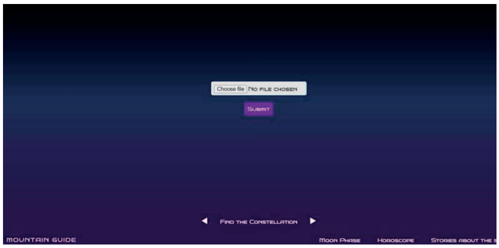

Figure 9. upload of the wanted file to be analyzed

In the current chapter it is explained how the application was tested, how it works, what should be uploaded, and what the outputs are. The feedback that was received while giving the application to various users to test it and see how they reacted is also included. Furthermore, there are presented the conditions in which the application may, or may not, work and the details about light pollution.

Testing and results

As previously mentioned, the program operates as follows: the application is launched, running the main.py file, and accessing the address printed in the console, the program is available to the user. In the graphical user interface, the tester may examine the interface's visuals and read some information about the sky, while as the user scrolls down, he will be able to see two

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

forms: one for constellation recognition and one for moon phase recognition.
If the user selects to upload and inspect an image in the constellation form, the application will display the provided image, the stars of the identified constellation in a coordinate system so the user can see how they were found (Figure 10), and finally a picture of the template used.

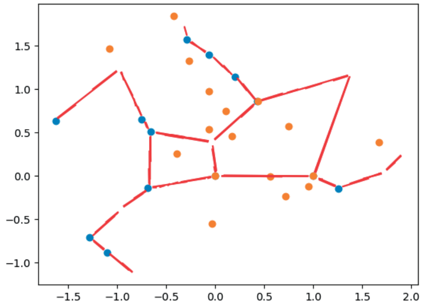

Figure 10. Example of predicted image of a constellation

The coordinate system image will show the first two brightest stars in the locations (0.0) and (1.0), as well as the lines connecting the stars that make up the constellation. Aside from these images, there will be some information about the discovered constellation (Figure 11).

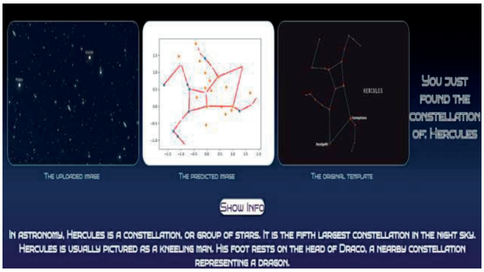

Figure 11. Output of the constellation detection form

The same approach applies to recognizing moon phases. The user submits a picture of the moon, presses the button, and then a picture of the moon, contoured with a red line and having crossed a blue line between the y min and y max of the contour (Figure 12; that will be used for calculating the number of the pixels), will be displayed, along with a picture representing the phases of the moon, to help the user understand the concept.
In addition to constellation recognition, the user will receive information about the current moon phase, as well as the anticipated time until the next new/full moon phase, as illustrated in Figure 13.

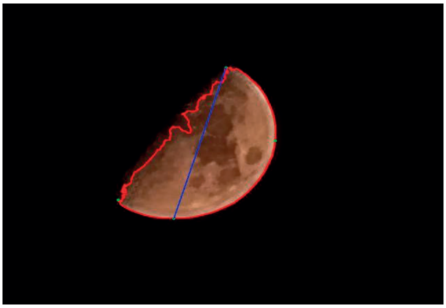

Figure 12. Example of detection image for the Moon

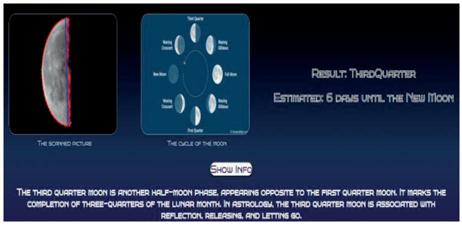

Figure 13. Output of the Moon Phase recognition form

In what concerns the feedback for the application, 20 individuals answered a survey. When asked if they were pleasantly surprised by the application's interface, most users (55% replied yes), with three not so delighted with the offered visual effects, indicating that they can be improved in the future updates. When looking for constellations, most users (40%) like the high accuracy feature of the results, while 20% prefer the application to be user pleasant, therefore it must include interactive elements that capture the user's attention. A free tool is more of an approved application for users, as 17.8% consider that a costly one is unappealing. Another characteristic is that the employed tool should not have any advertisements, as this will prevent the user from being upset and bored by the annoying commercials. Therefore, the overall opinion regarding the proposed software solution was positive.

Light pollution
There is a lot of pollution, and as a result, the stars are not as visible, the major reason being that there are a lot of different illumination sources that fill the night sky with artificial light. Light pollution is the intentional change of

outdoor light levels from those that occur naturally, or, due to excessive artificial light. Light pollution, like noise pollution, is a type of waste energy that can have negative consequences and impair environmental quality. Furthermore, because light (delivered as electromagnetic waves) is normally created by electricity, which is typically generated by the burning of fossil fuels, a link between light pollution and air pollution (from fossil-fuelled power plant emissions) may be established.

This kind of pollution has a negative impact on professional and amateur astronomers, as well as casual night sky viewers since it diminishes the visibility of stars and other celestial objects. The decrease in night sky visibility is caused by skyglow, which is upward-directed light emitted by poorly built or aimed lighting and security floodlights. This squandered light is dispersed and reflected by solid or liquid particles in the atmosphere before returning to people's eyes from the ground, obliterating their view of the night sky. This is a concern not just for astronomers and those who simply wish to gaze at the stars because the glare from streetlamps, business security lights and signage, or even a neighbor's bright and misdirected yard illumination can cause pain and distraction, lowering many people's quality of life (Figure 14) (Light Pollution | Definition, Causes, & Facts | Britannica, n.d.).

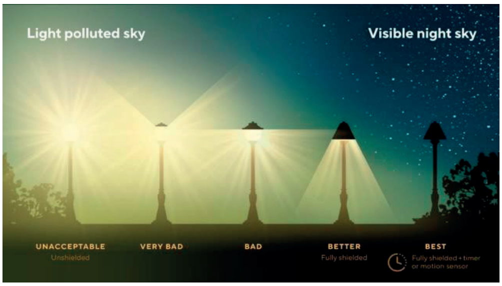

Figure 14. Process of light pollution

Light pollution is also harmful to birds and other creatures. Many migrating birds, for example, fly at night, when the light from the stars and Moon aids in navigation. The glare of artificial light causes these birds to get disoriented when they fly over urban and suburban regions (Light Pollution | Definition, Causes, & Facts | Britannica, n.d.). There is multiple advice for how to reduce light pollution, from turning off the lights when not in use, to pointing our lights towards the ground when going out and even unplugging from devices as the sun sets (10 Simple Ways to Reduce Light Pollution | Visit Durango, CO | Official Tourism Site, n.d.). In Figure 15 provided by (Light Pollution Map, n.d.), can be observed the locations where the light pollution is at its highest values (Barentine, 2019).

Figure 15. Map of light pollution

There are areas where light pollution exists but is not recorded or even known. The current program was improved so that it can compare photos of the same point in the sky taken at different times of the night or of the year. External data from specialized sources can be integrated into the program to provide information on light pollution in various regions. This data can be used in tandem with photographs to provide a more complete picture of light pollution levels. Light sensors in mobile devices are taken into consideration if users use their phones to capture photos. The sensors directly measure the level of ambient light when the photo is captured and how blurred is the taken photo (Mander et al., 2023).

Image processing techniques are used to determine the level of light pollution in the night sky, for example contrast stretching or histogram equalization to enhance the features in the image and convert the image to a suitable color space, such as LAB (CIELAB) or HSV (Hue, Saturation, Value).

Another solution that could work is the luminance calculation by converting the image to grayscale to simplify processing and then calculate the luminance of each pixel. This can be done using different methods, such as a weighted sum of RBG (Red, Green, Blue) channels, which we are already familiar with. In Figures 16 and 17, can be observed a case of light pollution, the picture being taken in different moments, but in the same place, this highlighting that the problem is real.

Figure 16. Light polluted night sky

Figure 17. Clear night sky

CONCLUSIONS

The proposed program is a web-based application for constellation and moon phase recognition. After technical improvements, image processing techniques may now be used to locate and identify constellations in astronomical photographs automatically. Therefore, even without Internet connectivity, the proposed program can automatically recognize constellations in photos.

The application has the potential to become an even more powerful tool for studying the stars, discovering the universe, and even calculating the level of light pollution with ongoing development and upgrades. Aside from stargazing and pollution detection, the application can also serve as an educational guide, explaining in detail the algorithm of constellation detection and teaching students every step of the way.

As future work, the software solution will be converted into a mobile application for users to be able to utilize it for real-time sky scanning. In this manner, users can immediately scan the celestial objects or point the phone's camera at the sky and capture a photo.

To make the program more appealing to users and maintain their attention, the user interface will be improved to be friendlier and include additional functions like a moon phase calendar, user-specific zodiacal data, and information on how planetary alignments affect people's behavior.

Finally, the application has the potential to be a valuable tool for stargazers, navigators, volunteers who want to support the fight against light pollution, and anyone else interested in the night sky. Its success is due to the combination of superior technology, precision, and user-friendliness.

REFERENCES

Barentine, J.C. (2019). Methods for Assessment and Monitoring of Light Pollution around Ecologically Sensitive Sites. *Journal of Imaging 2019, 5*(5), 54.

Belmonte, J.A., & Lull, J. (2023). *Mapping the Stars: The Skies of Ancient Egypt*. 193–306.

Contreras-Koterbay, S., & Mirocha, L. (2016). The New Aesthetic and Art: Constellations of the Postdigital. *The New Aesthetic and Art: Constellations of the Postdigital*.

Doukari, O., Greenwood, D., Rogage, K., & Kassem, M. (2022). Object-Centred Automated Compliance Checking: A Novel, Bottom-Up Approach. *Journal of Information Technology in Construction (ITcon)*, *27*, 336.

Edney, M.H. (2023). Latitude, Longitude, and Geospatial Technologies to 1884. *The Routledge Handbook of Geospatial Technologies and Society*, 7–22.

Gomez, E.L., & Fitzgerald, M.T. (2017). Robotic Telescopes in Education. *Astronomical Review*, *13*(1), 28–68.

Hall, E.D. (2022). Cosmic Explorer: A Next- Generation Ground-Based Gravitational-Wave Observatory. *Galaxies, 10*(4), 90.

Jordan, J., Posada, D., Zuehlke, D., Radulovic, A., Malik, A., & Henderson, T. (n.d.). *(Preprint) AAS 22-775 Satellite Detection in Unresolved Space Imagery for Space Domain Awareness using Neural Networks*, from https://www.researchgate.net/publication/362252394_Satellite_Detection_in_Unresolved_Space_Imagery_for_Space_Domain_Awareness_Using_Neural_Networks

Kelly, M., & Gráda, C. (2022). Connecting the Scientific and Industrial Revolutions: The Role of Practical Mathematics. *The Journal of Economic History*, *82*(3), 841–873.

Khajuria, T., Tulver, K., Luik, T., & Aru, J. (n.d.). *Constellations: A Novel Dataset for Studying Iterative Inference in Humans and AI.*

Kyselica, D., Jurkasová, L., Ďurikovič, R., & Šilha, J. (2022). Astronomical Objects Classification by Convolutional Neural Network Algorithms Layers.

Proceedings of the International Conference on New Trends in Signal Processing, NTSP.

Light pollution | Definition, Causes, & Facts | Britannica. (n.d.). Retrieved 30 November 2023, from https://www.britannica.com/science/light- pollution.

Light pollution map. (n.d.). Retrieved 30 November 2023, from https://www.lightpollutionmap.info/#zoom=5.21&lat=45.1575&lon=23.0716&state=eyJiYXNlbWFwIjoiTGF5ZXJCaW5nUm9hZCIsIm92ZXJsYXkiOiJ3YV8yMDE1Iiwib3ZlcmxheWNvbG9yIjpmYWxzZSwib3ZlcmxheW9wYWNpdHkiOjYwLCJmZWF0dXJlc29wYWNpdHkiOjg1fQ==

Lubura, J., Pezo, L., Sandu, M.A., Voronova, V., Donsì, F., Šic Žlabur, J., Ribić, B., Peter, A., Šurić, J., Brandić, I., et al. (2022). Food Recognition and Food Waste Estimation Using Convolutional Neural Network. *Electronics, 11*(22), 3746. https://doi.org/10.3390/electronics11223746

Mander, S., Alam, F., Lovreglio, R., & Ooi, M. (2023). How to Measure Light Pollution—A Systematic Review of Methods and Applications. *Sustainable Cities and Society*, *92*, 104465.

Mathematical Handbook for Scientists and Engineers: Definitions, Theorems – Granino, A. Korn, Theresa M. Korn - Google Books. (n.d.). Retrieved 30 November 2023, from https://books.google.ro/books/about/Mathematical_Handbook_for_Scientists_and.html?id=A 4XCAgAAQBAJ&redir_esc=y

McKee, P., Kowalski, J., & Christian, J.A. (2022). Navigation and star identification for an interstellar mission. *Acta Astronautica*, *192*, 390–401.

Mehta, T., Bhuta, N., & Shinde, S. (2022). Experimental Analysis of Stellar Classification by using Different Machine Learning Algorithms. *2022 International Conference on Industry 4. Technology (I4Tech)*.

Modeling, Systems Engineering, and Project Management for Astronomy III | Request PDF. (n.d.). Retrieved 30 November 2023, from https://www.researchgate.net/publication/234224661_Modeling_Systems_Engineering_and_ Project_Management_for_Astronomy_III

Molnar, Z., & Kiss, D. (2023). Constellation Recognition on Digital Images. *SACI 2023 - IEEE 17th International Symposium on Applied Computational Intelligence and Informatics, Proceedings*, 443–447.

Observation - 88 Constellations. (n.d.). Retrieved 10 November 2023, from https://astronomyonline.org/Observation/Cons tellations.asp.

Phases of the Moon. (n.d.). Retrieved 30 November 2023, from https://www.timeanddate.com/astronomy/moon/phases.html

Ramos-Alcaraz, G.E., Alonso-Arévalo, M.A., & Nuñez-Alfonso, J.M. (2023). Star-Identification System Based on Polygon Recognition. *Aerospace 2023, 10*(9), 748.

Raposo, P.M.P. (2022). The Astrolabe: From "Mathematical Jewel" to Cultural Connector. *Migrants Shaping Europe, Past and Present*, 19–40.

Rettberg, J.W. (n.d.). *Machine Vision: How Algorithms are Changing the Way we see the World*. Retrieved 10 November 2023, from https://www.wiley.com/en-cn/Machine+Vision%3A+How+Algorithms+are+Changing+the+Way+We+See+the+World- p-9781509545247

Savanevych, V., Khlamov, S., Briukhovetskyi, O., Trunova, T., & Tabakova, I. (2023). Mathematical Methods for an Accurate Navigation of the Robotic Telescopes. *Mathematics 2023, 11*(10), 2246.

Song, S., Sun, H., & Xu, W. (2023). Modulation Recognition with Enhanced Constellation Based on Convolutional Neural Network. *IEEE Vehicular Technology Conference*, *2023-June*.

Utama, J.A., Zuhudi, A.R., Prasetyo, Y., Rachman, A., Sugeng Riadi, A.R., Nandi, & Riza, L.S. (2023). Young Lunar Crescent Detection Based on Video Data with Computer Vision Techniques. *Astronomy and Computing*, *44*.

Zhao, Z., Wei, J., & Jiang, B. (2022). Automated Stellar Spectra Classification with Ensemble Convolutional Neural Network. *Advances in Astronomy*, *2022*.

Zubairy, M. S. (n.d.). *A Mysterious Universe: Quantum Mechanics, Relativity, and Cosmology for Everyone*. Retrieved 30 November 2023, from https://books.google.com/books/about/A_Mysterious_Universe.html?id=0IbgzwEACAAJ

10 Simple Ways to Reduce Light Pollution | Visit Durango, CO | Official Tourism Site. (n.d.). Retrieved 30 November 2023, from https://www.durango.org/blog/post/ways- reduce-light-pollution/