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ASTRONOMICAL ANGLE MEASUREMENT WITH THE USE OF NEWTONIAN TELESCOPE AND DSLR CAMERA

Stud. SÁRA HANNA BERGER; Supervisor: ROLAND BANC
Institutional affiliation: Óbuda University Alba Regia Technical Faculty;
Székesfehérvár Teleki Blanka Gimnázium, Hungary

***ABSTRACT**: Our task is to measure angles for astronomical purposes using a Newtonian telescope and a DSLR camera. The paper includes overview of the construction and imaging of astronomical telescopes, instruments and DSLR cameras.*
The aim is to go beyond numerical estimations to the determination of real values by measurements. From these measurements various conclusions can be drawn: the variation in the apparent size of the Moon due to its motion in an elliptical orbit, which can be used to infer the eccentricity of the orbit, the ratio of the distance of the perigee and apogee from the focal point, and the determination of the celestial velocity of the Moon, compared with its calculated value.
***Keywords:** Astronomy; angle measurement; telescope; DSLR camera;*

1. The operating principle of a DSLR camera

A DSLR camera is a combination of a single-lens reflex camera and a digital image sensor. In a DSLR (Digital Single Lens Reflex) camera, light is transmitted through the lens and through an aperture of a given size to a flip-up flat mirror. From here, the light rays are transmitted to the pentaprism or penta-mirror, and the image can then be viewed in the viewfinder by the photographer (fig .1).

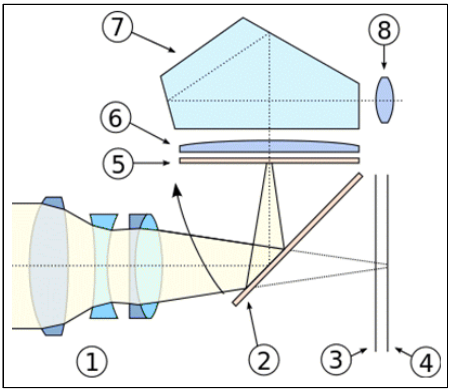

Fig.1. The setup and imaging of a DSLR camera

Now the photograph is taken, the flat mirror (which is positioned at 45°), is snapped open, so the light will be transmitted to the image sensor, which is then transferred to the memory card via various additional devices. Shooting with DSLR camera has several drawbacks. At the moment of taking a picture, you may feel a slight shake after the mirror is snapped. During this time the sharpness of the photo may change and lose quality. However, we must also mention the distortion that occurs after the photograph has been taken. Often, we want to project non-even surfaces onto a flat surface with our camera. This is when we can observe that the same distances are the same in the centre, but they become denser at the edges of the photo.

2. Overview on telescopes

Telescopes are distinguished by their optics and their mechanics. By Newtonian telescopes we mean the optics. It was invented by Sir Isaac Newton to solve the problem of chromatic aberration (a colour aberration that occurs when different lenses or prisms refract different wavelengths of light differently).

Newtonian telescopes use mirrors for imaging. At the end of the telescope there is a main mirror, which is a concave mirror, so that the light rays coming through the aperture are collected at a single point. In front of the focal point is an auxiliary mirror tilted at 45°, which is a flat mirror. This transmits the light to the eyepiece in out camera's sensor (fig. 2).

Substituting the data gives an approximate value: α .0,5072°

4. Measurement

Our study was carried out in an appropriately selected field. It was necessary to have a sufficient distance (i.e., it was possible to take pictures from up to 1km), a level road surface, and to be free of trees and dense vegetation.

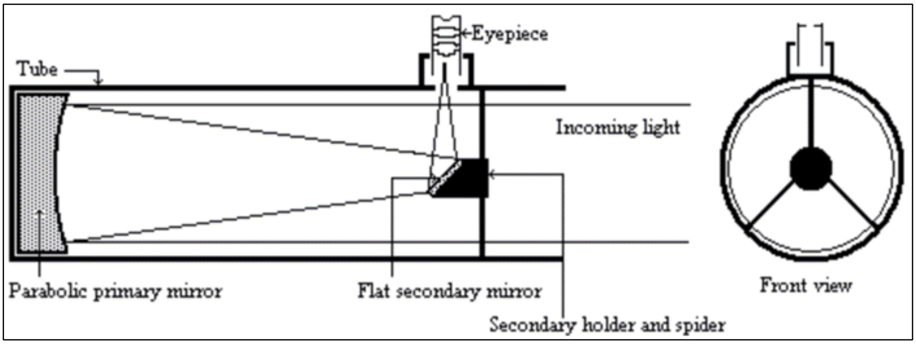

Fig. 2. The setup and imaging of a Newtonian telescope

3. The apparent diameter of the Moon

The apparent diameter of the Moon can be calculated by estimation, but only an approximate value is obtained. In this case, we use only data from external sources. The reason for the approximate value is that we take the average distance of the Moon, but its apparent diameter is different in the perigee (this is the closest point to the Earth of the Moon's elliptical orbit) and the apogee (this is the furthest point from the Earth of the Moon's orbit).

The following equation can be written to estimate the apparent diameter of the Moon:

$$\alpha = \tan^{-1}\left(2 \cdot \frac{rM}{dEM}\right)$$

rM=radius of the Moon
dEM=distance between the Moon and Earth

Two people were needed to carry out the measurement. One person walked the required distance with the required instrument (fig. 3), in our case a broomstick held up at right angles to the observer, and the other person took the recordings on the spot.

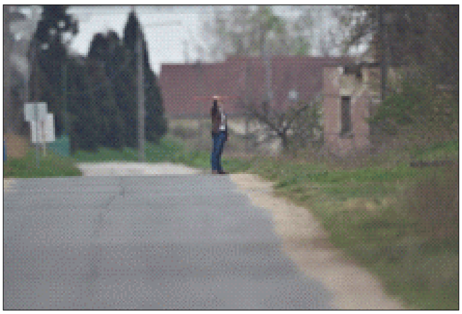

Fig. 3. Recording the measurement

Before the survey, the necessary equipment was assembled (fig. 4). Once the telescope was in position, the camera was mounted on it.

Fig. 4. Assembling the telescope

After preparation, the measurement itself began. The aim is to obtain a reference value for the apparent angle of a rod horizontal to the ground and perpendicular to the direction of observation which can be used to infer the apparent diameter of the Moon. In each case, the person holding the straight rod recorded their position while taking the photographs so that our distance from the person taking the measurements can be calculated from GPS.

Then the images were matched according to the distance from the person measuring and the photographs. So we determined which measurement belonged to which fixed coordinate (fig. 5).

Later, it can be observed from the data that as the distance increases, the size of the straight rod in pixels decreases proportionally, as does the value of its apparent angle, which can be determined by distance measurement using the software “Google Maps”, the value od the apparent angle can be calculated using the cosine theorem, the Pythagorean theorem (for larger distances only a small deviation is observed), the arc segment, or by using the equilateral triangle. The result of the measurements are the same for the two separate lunar images, since one is a multiple of the other with a constant value.

One we knew the apparent angle of the straight rod and the corresponding pixel value, and we calculated the apparent diameter of the celestial body in pixels in the image of the Moon (fig. 6), we could return the value of its apparent angle in degrees by using proportionality. The apparent diameter is obtained from the follofing equation:

$$Apparent\ diameter\ of\ Moon\ [Aa] = \frac{Rod\ [Aa] * Apparent\ diameter\ of\ Moon\ [pixel]}{Rod\ [pixel]}$$

Apparent angle = Aa

Fig. 5.Telescopic measurement: positions of the telescope placed during the measurement and of the measuring rod set up during taking each photograph

4. Results

The measurement data are shown in the following table. For these measurements, our image of the Moon has a resolution of 6000*4000 pixels and a diameter in pixels of 2240.31 pixels.

To compare our results, we chose the pixel/degree value. The latter is calculated as the length in pixels of the straight rod and its apparent angle (tab.1).

photo. The Moon does not exactly orbit the Earth in a perfect circular way but follows an elliptical path. Thus, the apparent diameters at the perigee (Earth's proximal point) and apogee (Earth's distant point) do not match. Data from the same measurements were used with a photograph taken at a different time. The resolution of the image is not the same, but it is possible to calculate how many pixels on the "X" and "Y" axes of a 4496*3000 resolution image correspond to the same pixel on the 6000*4000 resolution

Table 1 Results of the measurements

	Distance (meter)	Rod's length (pixel)	Rod (pixel/°)	Apparent diameter of Moon (°)
1.measurement	473	659,367	4536,11	0,4939
2.measurement	541,43	575,462	4531,63	0,4944
3.measurement	727,81	418,029	4425,07	0,5063
4.measurement	825,28	367,164	4407,14	0,5083
5.measurement	945,98	312,46	4299,04	0,5211
6.measurement	1008	291	4266,28	0,5251
7.measurement	1230	236,647	4233,93	0,5291

Fig. 7. First picture of the Moon

The graph shows that as the distance increases, the pixel/degree value for the straight bar decreases. In our graph, we plot only the pixel/degree values associated with the first photo, since their values are a constant multiple of the results of the second image. In the same way, using the Pythagorean theorem, the length of a straight bar in pixels can be calculated. In this case, the diameter of the Moon in pixels is calculated from the original unconverted scale image, which is 1800 pixels (tab.2).

Table 2. Table of the results II.

	Distance [metre]	Rod's length [pixel]	Rod [pixel/ °]	Apparent diameter of Moon [°]
1.measurement	473	494,0856	3399	0,5295
2.measurement	541,43	431,22	3396	0,5300
3.measurement	727,81	313,248	3316	0,5428
4.measurement	825,28	275,133	3302	0,5450
5.measurement	945,98	234,1426	3222	0,5587
6.measurement	1008	218,1774	3199	0,5627
7.measurement	1230	176,9411	3165	0,5686

Fig. 9. Second picture of the Moon

Conclusion from measurement

Compare:

The measurements show that the average apparent diameter of the Moon is larger in the second image than in the first. This leads to the conclusion that they were at different points in their elliptical orbits at the time the two images were taken. While the average is lower for the first image than for the second, the Moon was closer to the perigee in the second image and further away in the first image.

Ratio between apogee and perigee:

We can calculate the ration of the apparent diameter of the Moon in Apogee to that in Perigee from data obtained from external sources. In both cases, the Earth-Moon distance is considered.

In Apogee: $4.05696 \cdot 10^{8}$ *metres*

In Perigee: $3.631 \cdot 10^{8}$ *metres*

Based on this, the ratio between Apogee – Perigee is 1:11675

From the results, we can infer the eccentricity of the Moon's orbit, which is the elongation of the elliptical orbit. Based on previous calculations, the ration of apparent diameters obtained from measurements can be determined to infer eccentricity. This has been done in the previous subchapter, and the ratio is 1:1.11675. The following equations can be written for the perigee and apogee distances:

$$Rp = (1 - e) \cdot$$

Ra = (1+e) @

From the latter equation, we can express a (semi-major axis):

a = (Ra + Rp) / 2

We can express e (eccentricity) also:

e = 1 - Rp/a

e = Ra/a - 1

By summing the previous equations and substituting the semi-major axis, we obtain the value of the eccentricity in parametric terms:

e = (Ra - Rp)/(Ra + Rp)

The apogee distance can be called "r" and the ratio can be used to express the perigee distance, which is *r @1/1.11675)*

As a result, we get:

$$e = \frac{r - \frac{1}{1{,}11675}}{r + \frac{1}{1{,}11675}} = \frac{r}{r} \cdot \left(\frac{1 - \frac{1}{1{,}11675}}{1 + \frac{1}{1{,}11675}} \right) =$$

$$= 1 \cdot \left(\frac{1 - \frac{1}{1{,}11675}}{1 + \frac{1}{1{,}11675}} \right) = 0{,}055156$$

The angle between the two sides of a photo:

Either by other measurements, or by inference from the above, the angular distance between the two edges of the photograph can be determined.

To carry out our task, we need to find a suitable site where we can take the measurement with our instruments, telescope and camera. Once the equipment is assembled, two sticks are fixed so that they are visible on both edges of the photograph. Once this has been done, the angle can be calculated by measuring the distance and calculating the cosine. This will give us the angle between the two edges of the image taken by our camera or telescope. We know that the resolution of our photographs is 6000*4000 pixels, so we know how many degrees 6000 pixels equals. However, it is not easy to do the former, because for Newtonian telescopes, there is a minimum distance value from which a sharp image can be obtained due to the layout. This value can be up to 30-40 metres, if not more. Therefore, from the data of our measurements, if it is known that X pixels in the image are equal to Y angles, then the 6000 pixels between the two edges of the image will correspond to what angular value. Based on our measurements, this value is approximately 1.32145°

5. Measuring the apparent diameter of the Moon based on the distance of stars

The angular measurement can also be performed based on the distance between two stars, the angular distance of which can be determined using the appropriate software. One such application is "Stellarium". In this software, the value is given in degrees, angular minutes, angular seconds, which are converted to be given only as a log.

The distance between the two stars in the photograph can be calculated in pixels using the same method as in the precious measurements, using the program "Microsoft Paint". From the data, the apparent diameter of the Moon can be inferred by proportionality.

Conclusion

As a result, we have found a way to measure the distance of astronomical objects in angular terms. To demonstrate this, we chose the Moon, whose apparent diameter was measured. We obtained successful results, but it is noticeable from the measurement results that the results show an increasing trend as the distance is increased. One of the sure reasons for this is the inadequate focusing and the fact that distortions were not considered and not investigated.

Possible solutions to avoid these errors include choosing the sharpest possible focus when taking the measurement and having the person holding the straight rod in the center of the picture. As a result, it is easier to determine the coordinates of the two end points of the straight rod in the picture using a program called Microsoft Paint.

If I were to take the measurement again, I would make sure that I recorded the data as accurately as possible, took the precise pictures and investigated what was causing the upward trend in the measurement results.

References

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