The analysis of the 2019 annular solar eclipse with simple instruments for developing student worksheet

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Abstract. The annular solar eclipse occurred when the Earth-Moon-Sun position aligned in the same line where the angular diameter of the moon is smaller than the angular diameter of the sun due to the moon is on the farthest distance with respect to the earth. The event was observed on 26 December 2019 at Siak Regency, Province of Riau, Indonesia. Based on that event observation, the sun is gradually covered by the moon until the peak event where the sun is completely covered and showing “ring of fire”. All stages of eclipse are captured as images from DSLR camera that been attached into telescope with specific filter as well as illumination determination from observation location using lux meter during the event. This study explained how to get the information from solar eclipse images available by using image-processing software namely ImageJ so it can be used as a student worksheet. The plotting of both pixel area-time graph and illumination-time graph of this study shows a similar trend. Therefore, the data acquired in this study is obtained well so it can be used as a student worksheet in the Astronomical Position lecture based on the actual phenomenon with a simple instrument for observation.

1. Introduction
The annular solar eclipse might not be as popular as a total solar eclipse, but the uniqueness of this phenomenon is quite interesting for further study. A solar eclipse is one of the rare moments that useful for science learning [1], not only as general and popular knowledge but also to practice the ability to observe, analyze and conclude a phenomenon as expected from the Astronomical Position lecture. In order to fulfill that, a team of researchers at the Earth and Space Laboratory conducted the annular solar eclipse expedition to Sungai Apit, Siak Regency in Riau Province as seen in Figure 1 below. That location is one of the best locations to observe the totality of the eclipse event as shown in the red line that marked the totality event trajectory over that area.
The path of the earth's movement around the sun and the moon around the earth is not a perfect circle, but a rather ellipse-like orbit. This results in the closest and farthest positions relative to one of the focal points of the ellipse geometry where the larger center of mass is concentrated. In this case, the larger mass is the sun in the earth-sun orbit, and in another case such as moon-earth orbit, the earth is the larger mass. From that configuration with respect to the earth, the sun and the moon diameter could show a different size depending on its position relative to the earth. The diameter size of the celestial object is defined as the angular diameter (θ) \[2\], as shown in the equation below:

\[
θ = \frac{D}{R}
\]

Where D is the actual diameter of the object and R is the distance of the object from the earth. By naked-eye view, the moon and the sun are having quite similar in angular diameter size because on average, the moon's distance with respect to the earth is 400 times closer than the distance of the earth to the sun even though the sun's actual diameter is 400 times larger than the actual diameter of the moon. Thus, when the sun-moon-earth in the parallel configuration and the moon angular diameter is greater than or equal to the sun angular diameter, then the sun will be completely covered by the moon and the total solar eclipse event occurred.

With a lot of studies about eclipse already been conducted since a few decades ago makes a lot of data are also being collected. Most of them are dominated by eclipse imaging collected from various cameras. It is one of the precious assets for researchers because it contains a lot of information that can be extracted. The process to take an eclipse image is called the astrophotography technique [3]. The tools needed are quite simple these days which are, a DSLR camera, telescope set, and solar filter. A DSLR camera that being connected to a telescope could provide a sharp image of the event with a narrow field-of-view as well as zoom ability so the image will be only focused on the eclipse event. The image from the DSLR camera connected to the telescope is better due to the stability from a tripod and still could be enhanced by using a tracking rotor in the mounting system. By setting the combination of ISO and shutter speed of the camera from manual mode, the best image of the event will show up on the camera screen [4].

When the annular solar eclipse occurred, one of the variables that could be measure is the illuminance value change, which is how much the light comes to some unit of an area determined as Lux or Lumen/m², while the process is called illumination [5]. This process provides a measure of illumination such as perceived by the human eye in general. Commonly known as luminance levels, IESNA (Illuminating Engineers Society of North America). Therefore, this article will explain of how the process of collecting annular solar eclipse data with simple equipment then analyzed it with the theory of the occurrence of eclipses, image processing, and comparing the data variables obtained to get a conclusion. The results obtained are expected to be the material for making Student Worksheets based on natural phenomena [6,7].

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Figure 1. Observation location and eclipse contact time
2. Method
The instrument used in this study are 1. A telescope set consist about a DSLR Canon 200D, William Optic F=385 mm OTA, EQ-mounting, and a solar filter, 2. Luxmeter, 3. Laptop and 4. ImageJ Software. The method that being used in this study are an experiment with data collection flow as seen in Figure 2 below.

![Flowchart of the study](image)

**Figure 2.** Flowchart of the study

The steps taken are as follows, first assembling a telescope with DSLR and Lux meter set in an open area and on stable ground, both images of the sun are taken every 5 minutes from before to after the eclipse as well as the measurement of illuminance with a lux meter. can be processed with ImageJ software [8,9] to determine the area of the sun and moon so that it can be seen what percentage of the sun's surface is not covered by the moon called Obscuration and then plots the area with respect to time, the third plots the illuminance with respect to time, and the fourth analysis both graphs.

3. Result and Discussion
There are quite a lot of the sun images because every 5 minutes, 3-5 images are taken, then the photos will be grouped into 3 tables, namely table 1 before the eclipse to calculate the area, table 2 images at the peak of the sun to calculate the area of the moon, and table 3 images every 5 minutes to find out the plotting of changes in the area of the sun covered by time. The process of image data processing using ImageJ software (Figure 3).

To get the ratio of the angular diameters of the sun and the moon, we need to search for each area in the image of the sun and moon first. The area of the sun is obtained from the image of the sun before the eclipse with the orange colour of the sun from the ND5 filter used, while the area of the moon is obtained...
when the peak of the eclipse is when the lunar disk is inside the solar disk. We can also get the area of the sun and the moon from an average of 15 images that have been processed with ImageJ software, the results obtained are the Sun Area of 810548 pixels and the Moon Area of 758583 pixels, we can see in Table 1 and Table 2.

Based on Tan A and Marius S A A [10], we can calculate the angular diameter of the sun ($\theta_{Sun}$) and the angular diameter of the moon ($\theta_{Moon}$) at the time of the annular solar eclipse of 26 December 2019. On that date the moon was at a distance of 8 days after perigee which is about 388559 km while the earth was approaching the closest distance to the sun is at a distance of 147371753 km from the data with calculations in equation 1, the following results can be obtained below

$$\theta_{Sun} = \frac{D_S}{R_S} = \frac{1392.000}{147.371.753} = 0.009445 \text{ rad} = 0.542^0$$

$$\theta_{Moon} = \frac{D_M}{R_M} = \frac{3.475}{388.559} = 0.008913 \text{ rad} = 0.510^0$$

The comparison of the angular diameter of the Sun and the angular diameter is known as Obscuration ($Obs$) or the closure of the sun by the moon in parallel conditions is a feature of the eclipse process, with 100% obscuration meaning that the solar disk is completely covered by the moon which is called a total solar eclipse if the angular diameter of the moon is diameter the moon is smaller than the angular diameter of the sun, where the moon does not completely cover the sunset as the sun rings. Obscuration calculations based on direct measurements of solar image processing during eclipse ($Obs_{Image}$) and calculations based on theoretical data ($Obs_{Theoretical}$) are described as follows:

$$Obs_{Image} = \frac{\text{Area}_{Moon}}{\text{Area}_{Sun}} = \frac{758.583}{810.548} = 0.936 = 93.6\%$$

$$Obs_{Theoretical} = \frac{\theta_{Moon}}{\theta_{Sun}} = \frac{0.510}{0.542} = 0.941 = 94.1\%$$

From the results of calculations based on eclipse image processing, it is obtained that the value of $Obs_{Image} = 93.6\%$ and based on the theoretical data of $Obs_{Theoretical} = 94.1\%$, we can see that the values
of $\text{ObsImage}$ and $\text{ObsTheoretical}$ are relatively the same with a difference of 0.05%. In other words, the Observation event that occurred during the annular solar eclipse on 26 December 2019 is in line with the calculation theory, and vice versa in theory the Observation value can be proven directly by image processing, especially if you look at the results of detailed algorithm calculations from NASA as shown in Figure 1 the observation value, 94.11% is very close. So that the eclipse image obtained can be said as Good Exposure, because the resulting image is neither too dark nor too bright and Good Focus because the image is not blurry so that the circles of the sun and moon are very clearly distinguished.

Table 3 presents data on the solar area during the solar eclipse which was obtained from image data processing using ImageJ, the image processing is the image of the sun from before the eclipse to after the peak, from 9:30 WIB to 12:40 WIB with a span of every 5 minutes.

**Table 3. The Sun Area during the eclipse event**

| No | Time  | Area   | StdDev | No | Time  | Area   | StdDev |
|----|-------|--------|--------|----|-------|--------|--------|
| 1  | 9:30  | 819575 | 17.529 | 21 | 11:10 | 524478 | 11.215 |
| 2  | 9:35  | 813358 | 12.606 | 22 | 11:15 | 484205 | 9.306  |
| 3  | 9:40  | 816868 | 12.745 | 23 | 11:20 | 453480 | 12.891 |
| 4  | 9:45  | 810288 | 11.479 | 24 | 11:25 | 424387 | 7.837  |
| 5  | 9:50  | 810505 | 9.274  | 25 | 11:30 | 381589 | 11.03  |
| 6  | 9:55  | 810111 | 9.781  | 26 | 11:35 | 331994 | 11.992 |
| 7  | 10:00 | 810878 | 9.794  | 27 | 11:40 | 277957 | 13.021 |
| 8  | 10:05 | 810159 | 10.035 | 28 | 11:45 | 253078 | 14.124 |
| 9  | 10:10 | 811190 | 10.114 | 29 | 11:50 | 211703 | 26.63  |
| 10 | 10:15 | 810598 | 10.089 | 30 | 11:55 | 167097 | 10.609 |
| 11 | 10:20 | 809714 | 10.425 | 31 | 12:00 | 128087 | 12.756 |
| 12 | 10:25 | 801076 | 9.914  | 32 | 12:05 | 87795  | 12.64  |
| 13 | 10:30 | 773988 | 10.658 | 33 | 12:10 | 63937  | 22.951 |
| 14 | 10:35 | 749654 | 11.108 | 34 | 12:15 | 51905  |        |
| 15 | 10:40 | 725598 | 11.067 | 35 | 12:20 | 63231  | 20.887 |
| 16 | 10:45 | 695781 | 11.05  | 36 | 12:25 | 90354  | 13.733 |
| 17 | 10:50 | 660238 | 10.638 | 37 | 12:30 | 134608 | 13.677 |
| 18 | 10:55 | 630484 | 10.405 | 38 | 12:35 | 175096 | 12.122 |
| 19 | 11:00 | 596461 | 10.715 | 39 | 12:40 | 207625 | 19.311 |
| 20 | 11:05 | 561863 | 10.927 | 40 | 12:45 | 230166 | 11.325 |

By making a graph of Area with respect to Time as seen in Figure 4, there is a pattern of decreasing the area of the sun covered by the moon (blue line), at 9:30 WIB to 10:20 WIB The Sun's Pixel Area (Pixel) tends to be the same such as when starting at 10:25 WIB the solar pixel is visible and then it begins to decrease because it is covered by the moon area until the peak of the annular solar eclipse was seen at 12.15 WIB with an area value of 51.905 pixels, if the average solar area is 810.548 pixels, there has been a decrease in the number of pixels by 758.643 for 120 minutes. This means that the moon is moving past the sun at a speed of 6.322 pixels/minute. The process of decreasing Illuminance is clearly shown as well in Figure 4 (red line), which is 10:30 to 11:30, although it was stable for about 20 minutes then it decreased again until the Luxmeter showed 47 Lux at 12:15 WIB when it entered the peak of the annular solar eclipse. Referring to the illumination scale which is the reference for lighting conditions, the number 47 lux is in between 10 lux (twilight condition) and 100 lux (cloudy condition). Thus, it can be described as when the peak of an annular solar eclipse is like a few minutes before dusk or like cloudy clouds which covers the sky even though it is noon.
From combined plotting of the Sun Area-time graph and illuminance-time graph, it can be seen that a similar pattern matches, this shows that the data obtained from both solar and scientific images are very good. It can be understood that when the light source is reduced in number, the lighting conditions will be dimmer, this is what happens when a solar eclipse occurs where the sun is slowly covered by the moon so that the light flow received in an area slowly decreases. The amount of light that comes illuminating is correlated with the human perception of brightness, which is why the lighting conditions are dimmed and quantitatively recorded on the Luxmeter.

In Table 4, the results of the measurement of Illuminance using a Lux Meter are presented at the observation location with recording every 5 minutes. Since morning, the observation location has been covered with overcast clouds around the horizon, even though it has been drizzling for a short time. This causes the sun to be seen occasionally because when it is about 09:30 WIB, the sun is still below 45° or around the horizon, so it can be seen that there is a fluctuation in the illuminance value. The illuminance value gets bigger as the sun rises to the zenith in the sky from 09:50 WIB to 10:35 WIB, but after the lunar disk enters the disk at 10:23 WIB slowly and the larger the covered area of the moon then at 10:45 WIB Illuminance value is decreasing. In the range 12:15 WIB to 12:20 WIB is the peak moment of an annular solar eclipse where the lowest illuminant value is from the range of 47 - 54 Lux with the image of the sun at that time can be seen in Figure 5.

| No | Time   | Illuminance (Lux) | Remarks  |
|----|--------|-------------------|----------|
| 1  | 9:30   | 666               | Cloudy   |
| 2  | 9:35   | 820               | Clear    |
| 3  | 9:40   | 815               |          |
| 4  | 9:45   | 805               |          |

Figure 4. Area-time and Illuminance-time graph

Figure 5. Peak moment of the ring solar eclipse December 26, 2019

Table 4. Illuminance during eclipse

| No | Time   | Illuminance (Lux) | Remarks |
|----|--------|-------------------|---------|
| 21 | 11:10  | 800               |         |
| 22 | 11:15  | 723               |         |
| 23 | 11:20  | 680               |         |
| 24 | 11:25  | 599               |         |
4. Conclusion
The solar image data taken during the annular solar eclipse phenomenon on December 26, 2019 shows an observation value that is close to where the image processing results can be 93.6% and the theoretical calculation results are 94.1%. The graph of Illumination and Pixels against time shows a pattern, a decrease in value occurs at 10.30 WIB to 12.15 WIB the lunar disk slowly covers the sun disk leaving a thin circle that we see as a giant ring in the sky. The facts obtained from this research become a strong basis that the data obtained from the results of the Annular Solar Eclipse can be used as learning material in the form of Student Worksheet.

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