New solar elevation angle measuring instrument

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Abstract. This paper will introduce a new instrument to measure solar elevation angle. This instrument has advantages of simple structure, cheap price and convenient use, and can easily overcome the influence of ground inclination angle on the measurement, which other instruments measuring solar elevation angle fail to realize. It is portable, can quickly and accurately measure the solar elevation and can be used on uneven ground in the open. The theory of the instrument is simple. It is the application of the Newtonian mechanics, as well as geometry. This paper will introduce general structure and use method of the instrument, carry on brief principle analysis and use manual model of this instrument to measure solar elevation at different ground inclination angles within about one minute. And it is found that all the readings are basically the same. Finally, solar elevation of the afternoon is measured by the instrument model, and the sunset time is predicted. The prediction result is only 13 minutes later than theoretical time, which shows that the measurement is accurate.

1. Introduction
The application of solar elevation angle plays an important role in people's production and life. In the field of architecture, the design of sun visors needs to know the solar elevation angle [1]. In the electrical field, although there are power generation equipment that can automatically adjust direction of photovoltaic panels according to direction of solar light, the development maturity, operation experience scale and operation reliability of these equipment are not as good as fixed photovoltaic panels. Therefore, fixed photovoltaic panels still occupy an important position. And a fixed photovoltaic panel with artificial adjustment of inclination needs to use elevation angle data [2]. At the same time, distance design between photovoltaic panels needs to use elevation angle data, too [3]. Besides, if local latitude has been figured out by GPS and solar elevation angle has been known, sun declination angle can be calculated. And then we can calculate the time at this moment as well as sunshine hours, which plays an important role in agriculture, forestry, photovoltaic power generation and other fields [3]. The determination of atmospheric stability is based on ground wind speed and solar radiation level, and the solar radiation level needs to be determined by cloud amount and solar elevation angle [4]. The influence of cloudiness on snow albedo is related to the solar elevation angle [5]. In the field of teaching, it is difficult for beginners to understand the concept of solar elevation angle because it is abstract [6], so experimental instruments are needed for beginners to learn geography by measuring solar elevation angle...
If you want to get elevation data with an instrument, you may find yourself in trouble. At this stage, although solar elevation angle can be accurately measured by some means, the data can only be obtained by using complex equipment such as radar in places like observatories [7], which indicates
that its data can not meet individual needs. One of the reasons for this problem is that there is no better instrument for measuring. Referring to information existing [8-13], it is found that there have been several kinds of instruments with relatively simple structure to measure solar elevation angle. Although they have the ability to measure solar elevation angle, and one of them are even used as teaching tools, they all have a common problem: they must be used without inclination on the ground. Once the ground is tilted, its measurement will be troublesome, and the data from its measurement will even be problematic. The root cause is that the direction of their dials changes as the ground angle changes, and we can't guarantee that the ground is completely horizontal. This paper will introduce a kind of instrument that can measure solar elevation angle with instantaneous reading. What's more. Ground angle will not influence its measuring data. In addition, it has simple structure, convenient manufacture and low cost.

![Figure 1. The shape of the instrument.](image1)

![Figure 2. The connection between the bracket and the semicircular orbit.](image2)

![Figure 3. Internal structure of the cylinder.](image3)

![Figure 4. Calibration line(left). Instrument readings(right).](image4)

2. Instrument structure and using method

2.1. Structure of instrument

The shape of the instrument is shown by figure 1. Base and bracket are connected. The brackets are connected with a semicircle track. The connection is shown by figure 2. A ball bearing rail pulley slides on the semicircular track. The cylinder connected below the pulley is where the scale is located. Tube caps are on left and right sides of the cylinder, which control the center of gravity of the cylinder. There is a hole with a diameter of 0.8 mm in the center of the tube caps. A thin line goes through the holes. And there are heavy objects at both ends of the line. There is a scale as well as a leveling instrument in the cylinder, which is shown by figure 3. In addition, the instrument also has a stabilization device, which can make the cylinder stable in the case of wind, but this paper is not ready to introduce it.

2.2. Using method

① Before measuring, move the position of the tube caps so that the leveler's bubble is roughly centered.
② Place the instrument on the ground, let the specific shadow of the edge of the cylinder coincide with
a calibration line inside the cylinder. The line on the left in figure 4 is the calibration line. ③When the instrument is stable, read directly, as shown in the right side of figure 4.

![Figure 5. Picture of reading principle.](image)

![Figure 6. Solar zenith angle(°) varying with time.](image)

3. Reading principle
Reading principle is shown by figure 5. The earth's center is O. Axis of the cylinder is a point P. So the cross section of the cylinder is a circle. And OP is roughly the direction of gravity. The $\theta$ in figure 5 is zenith angle--complementary angle of elevation angle. Note that the OP and the circle intersects at H point. Put a scale inside the cylinder. The H (line) is “zero scale line”. When the sun rays is perpendicular to the axis of the cylinder, the "reading" of the P’s projection line on the inner side of the cylinder is the degree $\theta$. Therefore requirements are: ①The zero scale line (H) should be on the plane represented by the OP and should be perpendicular to the gravity line. ②The sun ray should be perpendicular to the axis of the cylinder.

For the first requirement, we can let the leveler’s bubble centered to ensure that the zero scale line and gravity line are perpendicular, which is shown by figure 3. As long as the center of gravity of the cylinder is directly below the pulley, the bubble will automatically be in the center when the device is stable. For the second requirement, a calibration line is drawn directly below the cylinder edge. It can be guaranteed that the sun ray is perpendicular to the axis of the cylinder when we let the shadow of specific edge of the cylinder coincide with the calibration line inside the cylinder, which is shown by figure 4. These two requirements guarantee that the direction of scale not to be affected by ground inclination.

4. Instrument performance testing and analysis
A model of the instrument has been made by hand. And it is worth to mention that the scale of this model shows zenith angel considering reading habits. Measuring zenith angle is equivalent to measuring elevation angle because they are complementary angles.

| Group | ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ |
|-------|---|---|---|---|---|---|---|---|
| Reading(°) | 32.4 | 32.4 | 32.5 | 32.4 | 32.5 | 32.5 | 32.5 | 32.6 |

*The eight groups represent that the same object was placed on eight different positions of the instrument. ①~⑧ indicates the time sequence of the eight experiments.

4.1. Instrument performance testing
First, the same object was placed on each of the eight positions of the instrument base to tilt it and eight readings were got.

Second, on the afternoon of March 9, 2021, the model of the instrument was used to measure the solar zenith angle. Some points can not be measured because the day was cloudy. After fitting the variation curve of the angle with quadratic function, sunset time of that day was predicted.
Table 2. Data of zenith angle on March 9th.

| Time   | 14:05 | 14:10 | 14:16 | 14:20 | 14:25 | 14:30 | 14:35 | 14:40 | 14:45 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Reading(°) | 43.1  | 43.9  | 44.8  | 45.1  | 46.1  | 47.0  | 48.0  | 48.9  | 49.9  |

| Time   | 14:50 | 14:55 | 15:00 | 15:05 | 15:10 | 15:15 | 15:20 | 15:25 | 15:30 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Reading(°) | 50.8  | 51.4  | 52.6  | 53.7  | 54.2  | 55.8  | 56.5  | 57.5  | 58.4  |

| Time   | 15:35 | 15:42 | 15:50 | 16:03 | 16:08 | 16:13 | 16:18 | 16:22 | 16:26 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Reading(°) | 59.5  | 61.0  | 62.3  | 64.4  | 65.6  | 66.6  | 67.2  | 68.0  | 69.1  |

4.2. Results and analysis
For the first test, from the experimental results shown by table 1, values of the eight sets of data are very close. This can prove that the instrument's readings are not affected by ground inclination. And it shows that solar zenith (elevation) angle measured can be accurate enough as long as the scale of the instrument is accurate.

For the second test, results are shown by figure 6 and table 2. It is predicted that the sunset (90° of the angle) is at 18:15. By consulting relevant information, official announcement time of the sunset on that day is at 18:02. Some factors can exert impact on the result. For example, our minimum time unit is minutes. And from the data it can be found that the sun moves at an average speed of 0.18°/min. And 15:00~15:05 can be 15:00:00~15:05:59 or 15:00:59~15:05:00, which indicates that the data may have an error of 0.36°. This is one of the major sources of measurement error. In addition, because the sun is blocked by buildings and clouds after 16:26, the data can not be obtained since then. And from the data obtained, it can be seen that variation of zenith angle should be accelerated thereafter, so this can lead to the “lag sunset”. Despite the influence factors mentioned above, the error of sunset that we predicted is as small as 13 minutes. For the measurement in this afternoon, the result can prove that the instrument can measure solar zenith (elevation) angle accurate enough.

5. Discussion and conclusion
This instrument can overcome the influence of ground inclination on readings, which is the key factor to accurate measurement. There are other factors that may exert influence on the accuracy of the instrument. For instance, position of the calibration line and the leveler may be deviated because the instrument model is made by hand. But from actual operation, when the specific projection deviates slightly from calibration line and the bubble of the leveler deviates slightly from the center position, there is almost no visible difference in the reading of the instrument. Additionally, the craftsmanship of the model will affect the accuracy of the measurement. And when a particular device is used to make this instrument, this will not be a problem. From both theory and practice, it can be proved that this instrument can measure solar elevation angle accurate enough. Also, it can be used on outdoor uneven ground. It is cheap, easy to operate and easy to read. It is solid and portable because it has simple structure and can be removed and installed freely. It allows anyone to measure accurately at any time in any areas, which indicates that it can meet people's personalized needs for data. So if it is used in education, production and life, it may bring convenience to people.

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