Research on Cloud-Base Height Detection Method Based on Infrared Technology

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Abstract. Cloud-height measurements are important for understanding the physical conditions of the atmosphere and forecasting the future weather. From the perspective of measuring the height of clouds, this article uses infrared cameras equipped with fisheye lenses to capture different cloud images at different positions. Through the image, the pitch angle of the cloud is obtained to calculate the cloud height. Compared with the traditional laser cloud measurement method, this method has the advantage of measuring all-day cloud height at one time and is convenient and quick to measure. As the need to take pictures in different locations, it is particularly suitable for cloud height measurement on ships. Using the navigation characteristics of ships, only one infrared camera is required to achieve multi-position measurement.

1. Introduction
The cloud is a phenomenon [1] caused by the condensation or desublimation of the atmosphere in the atmosphere. It is a collection of water droplets, gas, or ice crystal colloids that stay in the atmosphere and is the tangible result of the huge water cycle on Earth. Clouds have a non-negligible impact on aviation. Aircraft takeoffs and landings must consider the level of cloud distribution, thickness, cloud base height, and cloud clearance within the flight area [2], [3]. In addition, in artificial rainfall and artificial defoliation tests, the method adopted should be determined according to the nature of the cloud. Therefore, the rapid and effective observation of the cloud will help us understand the physical conditions of the atmosphere and predict the weather in the future. At present, there are many methods for estimating cloud height, such as estimated measurement method, cloud screen cloud measurement method, air ball detection method, rotating beam cloud-gauge method, micro-pulse laser radar method, and semiconductor laser cloud-gauge [4]. The method of estimation is entirely artificially estimated by technical personnel of the station. This method has a large number of uncertainties, so the accuracy is not high; Cloud screen lights [5] measure the height of the cloud through a goniometer by irradiating the light beam at the bottom of the cloud. However, when the cloud layer is high, it is difficult for the light beam to form a light spot on the cloud layer and the cloud height measurement cannot be completed. Air balloons are not suitable for use in high winds and inclement weather. There are also great limitations. The rotating beam Ceilometer measures the cloud height by recording the time difference between the beam emission time and the photocell to receive signal, however, in rainy weather, raindrops will have a certain refraction of the light beam, which will cause the instrument to produce a greater error. Ceilometers have higher requirements for meteorological conditions when
measuring cloud height. When using a laser to measure cloud height, when the laser encounters a thin cloud, it may directly penetrate the cloud, resulting in inaccurate measurements [6]. The semiconductor laser Ceilometer adopts DSP technology and unique lens design. It can also realize real-time on-line continuous monitoring, which plays an important role in studying the law of cloud changes and can provide vertical visibility, cloudiness, boundary layer, etc. A variety of atmospheric information has become one of the focuses of cloud detection. Various countries have spent a lot of manpower and material resources on this method for research [7].

For all-day cloud measurement technology, Huo Juan et al [8] used cameras to achieve all-weather cloud measurements, but visibility seriously affects measurement accuracy. Jia et al. extracted cloud heights and moving speeds from satellite images of different angles [9]. They used the principle of infrared imaging to achieve the measurement of all-day cloud elements. This article innovatively applies this principle to cloud-height measurements to obtain infrared images of clouds at night. Secondly, using cloud base azimuth, elevation angle and horizontal distance between two measurements to calculate cloud height [10]. In this paper, we designed a cloud measurement instrument to obtain the height of the cloud base, and compared the data obtained with the laser cloud measurement instrument to verify the feasibility.

At present, accurate measurement of cloud height often uses laser measurement methods or dual-station digital camera measurement methods [11], in which the former is active detection and the latter is passive detection, which is passive measurement [12]. The active measurement of defects is that they can only measure the cloud height at one point at a time. In addition, when the scattering of laser light is not obvious at the bottom of the cloud, the measurement error is relatively large, and the price of the cloud-height cloud-meter is expensive. The method of measuring cloud height in this paper makes up for the insufficiency of the laser measurement method.

2. Measurement Principle
First of all, this paper uses the infrared band imaging camera to detect and obtain the sky-height image of the whole day. Secondly, the fisheye lens is added to the camera. Through the principle of fisheye lens imaging, the transformation from traditional two-dimensional detection to three-dimensional detection can be realized [13]. The height of the cloud base can be calculated from the obtained images, the measured azimuth and elevation angles of the cloud base, and the distance between the two measurement points.

2.1. Ranging Principle
Assuming that the height of the cloud base is measured, the clouds in the sky are still (The speed of the cloud is much slower than the movement of the ship and the measurement can be completed within a few minutes, so this assumption is reasonable under normal circumstances). When the ship is at point A, firstly adjust the tripod horizontally and point the camera vertically at the sky, take the first photo and take a second photo when the ship moves about 100 meters. Write down the horizontal distance L of AB, and measure the target azimuth β and pitch angle ε by image analysis. Record the bottom of the target cloud as P and the point of projection on the AB water level as point P’. Observed by the image photographed at the point A, Observation target P azimuth β₁, pitch angle ε₁, referred to in point B of the lens of the observation target P photographed image azimuth β₂, elevation angle ε₂ as shown in Figure 1.
Figure 1. Ranging principle schematic.

The angle of $\beta_1$ or $\beta_2$ and the horizontal distance $L$ between A and B can be calculated in the triangle $ABP'$, using the sine theorem to obtain $AP'$:

$$AP' = \frac{AB \cdot \sin \beta_2}{\sin(\pi - \beta_1 - \beta_2)}$$

Derived by the above formula, the correct azimuth angles $\beta_1$ and $\beta_2$ of the camera observation target $P$ are calculated. The pitch angles $\varepsilon_1$ and $\varepsilon_2$ are the key points of this method. The following are the specific derivation of the azimuth and pitch angles. The camera used in this experiment has a size of 2592*1728 pixels, and the size of CMOS chips is 22.3*14.9mm. There are:

The pixel ratio in the X axis direction is: $R_X = \frac{22.3}{2592}$, the pixel ratio in the Y axis direction is: $R_Y = \frac{14.9}{1728}$. Assuming that the position of the target in the image is $(X_P, Y_P)$, the coordinates of the center point $(X_0, Y_0)$ have azimuth:

$$\beta = \frac{(X_P - X_O) \cdot R_X}{f}$$

Pitch angle:

$$\varepsilon = \sqrt{(X_P - X_O)^2 + (Y_P - Y_O)^2}$$

The height of the cloud top can be obtained by matching the pitch angle of point $P$ obtained in equation 3 above.

3. Experimental Process and Results

In this paper, the measurement of the height of the known building height and laser cloud measuring instrument is mainly used to verify the feasibility of the method.

1. The feasibility and accuracy of the experimental method are verified using a target of known height (highest point height of the comprehensive laboratory building). A, B at 50 meters away from the two points of the shooting, shooting results are shown in Figure 2, calculated results are shown in Table 1:
The average of the six sets of data is 28.1 meters, which is close to the actual value of 30 meters. There is a certain error, but this method is feasible.

2. The height of the cloud base obtained from the experiment was compared with the data measured by the laser cloud meter to verify the accuracy of the method. At the two points A and B, the sky was photographed, and then the same cloud was found in the two figures to calculate the height of the cloud base. In the image taken at point A, cloud M and cloud N are recorded as $M_1$ and $N_1$, respectively, and cloud M and cloud N are recorded as $M_2$ and $N_2$ in the image taken at point B respectively. The experimental results are shown in Figure 3. The calculation results are shown in Table 2:
Table 2. Cloud height calculation results.

| Observation point | target | x     | y     | β₁   | ε₁   | β₂   | ε₂   | Cloud base height |
|------------------|--------|-------|-------|------|------|------|------|-------------------|
| A                | M₁     | 1669  | 813   | 7.79 | 66.80| 49.64| 48.82| 1255              |
| B                | M₂     | 1729  | 1373  |      |      |      |      |                   |
| A                | N₁     | 2033  | 997   | 21.05| 49.54| 11.72| 64.53| 1212              |
| B                | N₂     | 1925  | 1607  |      |      |      |      |                   |

The heights of the clouds M and N measured with the laser cloud meter were 1268 meters and 1233 meters, which were close to the results obtained by the test method, but there were also errors.

4. Conclusion
This article uses an infrared camera with a fish-eye lens to measure the height of the cloud at the end of the day. It can also measure the height of the cloud throughout the day. The feasibility of the experimental method is demonstrated by two methods. There are some errors in the experimental results. After analyzing the whole process of the experiment, we found that the distance between the measuring points is inaccurate and the camera shooting angle is not vertical, which caused these experimental errors. The experimental device used in this article is simple and convenient to use and it is suitable for rapid measurement of the height of the cloud at the ship, and plays an important role in the combat performance of combat and weaponry.

5. References
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