Research on Laser Distance Measurement Technology for Remaining Volume of Large Open-pit Material Yard

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Abstract. In view of the problems of low volume calculation accuracy, long data acquisition period, and inability to uniformly measure and calculate the storage yard type when measuring the storage of large yards using volume and density conversion, a high-speed laser scanner, distance sensor, angle sensor, and pitch sensor are proposed. Integrated technology, quickly obtain the three-dimensional coordinate data of the yard, and derive a unified three-dimensional coordinate solution algorithm, establish a three-dimensional coordinate system of the yard space to solve the three-dimensional coordinates of the yard, and accurately calculate the storage volume of the yard. At the same time, the system construction architecture, composition, data processing methods and issues to be considered are proposed. This method effectively solves the problems faced by the existing measurements in large yards, and improves the measurement efficiency, accuracy and safety. Under the test conditions, the absolute accuracy reaches 0.4%. Several project examples show that the method is simple, efficient and accurate. The ordinary measurement time of a 200m stockyard does not exceed 20min, and the repeated measurement error of the measurement volume is less than 0.7%. It has good application prospects and popularization value.

1. Introduction

In the contemporary society where the industry is developing rapidly, the application range and usage of powder are very huge. As an important basic material for economic development, from the perspective of scientific and technological development, there will be no other materials to replace its role in the next many years. Powder as an important raw material for economic construction has been widely used in many fields, such as buildings, highways, bridges, underground passages, ports and so on. In addition, some powders with special functions also have a special status in national defines, science and technology, and special projects. Powder is the basic production material for national construction, and its demand is large. The raw material cost of powder material accounts for more than 70% of the total cost. In order to reduce the cost of powder materials, it is necessary to accurately...
measure the volume and quantity of raw materials. Because the volume of the warehouse is huge, and the volume of raw materials in the warehouse is constantly changing, it causes many difficulties for manual measurement and is difficult to estimate properly. It is estimated that the long-term input and output of the powder plant will cause great inconvenience than the planning, and sometimes will cause great losses to the enterprise. However, at present, most enterprises still have not used accurate measurement technology to measure the surplus of raw materials in the warehouse. Accurate measurement of large material stacking positions has the characteristics of irregular stacking and scattered distribution, which is a technical problem that has been difficult to overcome for many years. Taking the powder factory as an example, the most prominent problem is the problem of material storage measurement. Doing a good job in storage management is one of the important tasks of the powder factory operation and management. The technology of measuring the stacking position of powder has been difficult to achieve the degree of automatic monitoring. In most powder factories, the stacking measurement is still mainly carried out by manual methods. For example, methods such as weighing and manual regulation require a rough estimate, which consumes a lot of manpower and material resources, and the measurement accuracy is not high. In addition, raw materials and raw material warehouses are relatively closed, which makes it more difficult for humans to make relatively accurate measurements. They can only be extended vertically by simple ropes. After touching the materials, they are estimated according to the empirical shape. This method to a large extent, it affects the normal production evaluation of enterprises. In response to these problems, people have put forward many solutions, such as CCD plane vision, sound wave ranging, three-dimensional laser, etc., and played a certain role. In order to reduce the amount of capital invested in stacking position measurement as much as possible, this paper uses a two-dimensional laser point-by-point scanning method to carry out high-precision measurement. It conducts detailed and in-depth research from both theoretical and practical aspects and designs a solution [1].

2. Measuring principle

2.1. The basic principle of interference length measurement

The basic optical path of laser interferometry is a Michelson interferometer (as shown in Figure 1), which uses interference fringes to reflect the measured information. The interference fringe is a trajectory formed by two points with the same optical path difference on the receiving surface. The laser beam emitted by the laser reaches the translative mirror P and is divided into two beams. When the optical paths of the two beams differ by an even multiple of the laser half-wavelength, they strengthen each other to form bright streaks; At odd multiples of the wavelength, they cancel each other to form dark stripes. The optical path difference between the two beams can be expressed as

\[ \Delta = \sum_{j=1}^{N} n_i l_i - \sum_{j=1}^{N} n_l l_j \]  

(1)

Where \( n_i, n_l \) is the refractive index of the two optical paths of the interferometer; \( l_i, l_j \) is the geometric distance of the two optical paths of the interferometer. The measured object is connected to one of the optical paths, so that the mirror M2 moves in the direction of the light beam 2. For every half-wavelength movement, the optical path of the light beam 2 changes by one wavelength, so the interference fringes produce a periodic bright, Dark changes. The measured length can be obtained by measuring the change of the interference fringe [2].
The relationship between the measured length $L$ and the number of interference fringe changes $N$ and the wavelength $\lambda$ of the light source used by the interferometer is

$$L = N \frac{\lambda}{2}$$

Equation (2) is the basic measurement equation for laser interferometry. Starting from the measurement equation, the basic error analysis of the laser interferometry system can be performed

$$\frac{\Delta L}{L} = \frac{\Delta N}{N} + \frac{\Delta \lambda}{\lambda}$$

Where $\delta L, \delta N, \delta \lambda$ is the measured length, the interference fringe change count and the relative error of the wavelength. This shows that the relative error of the measured length consists of two parts, one is the relative error of the interference fringe count, and the other is the relative error of the wavelength, that is, the frequency. The former is the design problem of the interferometric length measurement system, not the content of this book. The latter is not only related to the laser frequency stabilization technology mentioned above, but also related to environmental control, that is, the control of temperature, humidity, and air pressure. Therefore, the measurement error of the laser interferometric length measurement system must be analysed according to specific conditions [3].

There are also several possible options for the overall layout of the laser interferometer optical path. In the design of the laser interferometer optical path, the principle of common path is generally followed, that is, the measuring beam and the reference beam should try to follow the same path as much as possible to avoid the measurement error caused by the inconsistency of the environmental conditions such as the atmosphere on the two optical paths. A typical optical path layout has a common optical path layout using corner cube prism reflectors, as shown in FIG. 2. The pyramid prism in Fig. 2a can separate the incident light and the reflected light by a certain distance in space. This optical path can prevent the reflected light beam from returning to the laser, so as to avoid the instability of the laser output frequency and amplitude caused by the returned light beam. Pyramid prisms have anti-yaw and pitch performance, which can eliminate errors caused by the deflection of the measuring mirror. However, this type of paired cube prism requires paired processing, and the

![Figure 1. Schematic diagram of the laser interferometer](image-url)
processing accuracy is high, so a cube prism can also be used as a movable mirror (Figure 2b). A plane mirror can also be used as a fixed mirror in the reference optical path. Using a corner cube prism as a movable reflector can also use several other light paths. As shown in Figure 2c, the dual-beam interferometer is also an ideal optical path layout, which is basically not affected by the extra degrees of freedom of the lens holder, and the optical path doubles. Other optical path layouts include overall layout, optical frequency doubling layout, and structural layout with zero optical path difference, each with its own characteristics and uses [4].

Figure 2. Typical light path layout has the common light path layout using corner cube prism reflectors

In the optical path of the dual-frequency laser interferometer, a magnetic field is applied to the He-Ne laser in the axial direction. Due to the Zeeman effect, the laser light is split into left-handed polarized light \( f_1 \) and right-handed polarized light \( f_2 \) with a certain frequency difference. After passing through the 1/4 wave plate, \( f_1 \) and \( f_2 \) become linear polarized light \( v_1, v_2 \) which is perpendicular to each other, and are split into two beams by the beam splitter \( B_1 \), one of which is reflected to the main section and the polarization direction of the two linear polarized light perpendicular to each other is 45°. The analyser \( P_1 \) generates beat signal. The photodetector \( D_1 \) does not respond to the sum frequency signal of twice the optical frequency, but receives only the reference difference frequency signal with the frequency \( \Delta \nu \). After another beam of light propagates forward through the beam splitter \( B_2 \) and enters the polarization beam splitter prism \( B_2 \), whose polarization direction is perpendicular to the paper, \( v_3 \) whose polarization direction is inside the paper is completely transmitted. Then it is reflected back through the reference arm mirror \( M_1 \) and the measurement arm mirror \( M_2 \) to combine, and through the analyser \( P_2 \) similar to the analyser \( P_1 \), the beat signal generated is received by the photodetector \( D_2 \). Since the measuring mirror \( M_2 \) moves at a speed \( V \), the Doppler effect of light causes a Doppler shift \( \Delta \nu_0 \) of the frequency of the light returned by \( M_2 \), and the frequency of the received measurement signal is \( \Delta \nu \pm \Delta \nu_0 \). The Doppler frequency shift \( \Delta \nu_0 \) is obtained by synchronously subtracting the measurement signal and the reference signal, and the Doppler frequency shift is integrated with the measurement time, that is, the displacement of the measuring mirror can be measured by cumulative counting. The Doppler shift caused by measuring the movement of the mirror can be expressed as

\[
\Delta \nu_0 = \frac{2V}{c} \nu = \frac{2V}{\lambda}
\]

Where \( c \) is the speed of light and \( \lambda \) is the wavelength of light. If the time used for measurement is \( t \), the displacement \( L \) of the measuring mirror can be calculated by the following formula
\[ L = \int_0^\infty v dt = \int_0^\infty \frac{\lambda}{2} \Delta V dt = \frac{\lambda}{2} \int_0^\infty \Delta v dt = \frac{\lambda}{2} N \]  

Where N is the cumulative pulse number recorded. The measured signal of the dual-frequency laser interferometer is added to the carrier frequency as a frequency modulation, which should generally be less than one-third of the carrier frequency, so the corresponding Doppler frequency shift cannot exceed \(0.5\,MHz\), and the maximum allowable measurement speed for \(\frac{s}{mm}\) is \(150\,mm/s\). In this way, the operating frequency of the processing circuit can be set between \(1.0 - 2.0\,MHz\), so as to filter out all the noise less than \(1.0\,MHz\).

Figure 3. Optical path diagram of dual-frequency laser interferometer

2.2. Laser reflection diffraction measurement method

Reflection diffraction is measured using the edge of the measured object and the slit formed by the mirror. The optical path difference of the k-th dark fringe at point P should meet

\[ 2b \sin \theta - 2b \sin(\theta - \varphi) = k\lambda \]  

In the formula, \(\theta\) is the angle between the incident parallel laser beam and the reflector, and \(\varphi\) is the diffraction angle, which is the angle between the intersection of the slit and the mirror and the connection between point P and the reflected light that meets the law of reflection. Under the geometric relationship of the figure, the slit width can be expressed as

\[ b = kL\lambda / \left[ 2x_k \left( \cos \theta + \frac{x_k}{2L} \sin \theta \right) \right] \]  

Equation (7) shows that the measurement sensitivity has doubled due to reflection. Reflection diffraction technology is mainly used for surface quality assessment, linearity measurement, gap measurement, etc. This method is easy to realize detection automation, and its detection sensitivity can reach \(2.5-0.025\,\mu m\) [5].

2.3. Laser phase ranging

Phase ranging is to measure the propagation time by indirectly measuring the phase difference \(q\) between the continuous modulated laser and the distance \(d\) to be measured. The optical path of the laser phase range finder shown in FIG. 4 is similar to that of a pulse laser range finder, except that the light source does not use a pulse laser, but uses a laser whose intensity is modulated. It can be a
semiconductor laser or other continuous-emitting lasers. In this way, the modulation phase of the continuous modulated light wave changes continuously during the propagation process, and the phase changes every time the propagation is equal to the modulation wavelength. Therefore \(2\pi\), the relationship between the distance \(d\), the round-trip phase difference \(\phi\) of the light wave and the modulation wavelength \(\lambda\) is

\[
d = \frac{\lambda \phi}{2 \pi}
\]

(8)

Figure 4. Principle block diagram of laser rangefinder

3. Construction of laser ranging material volume measurement model

The primary problem of multi-sensor integrated yard measurement is to establish a measurement space reference and a multi-sensor time reference, so that multi-sensor data can be efficiently and reliably fused in a unified time and space. Taking the stacker-reclaimer as an example, the Z-value measuring sensor is installed at the front end of the boom, the distance sensor is installed at the front of the walking wheel, and the angle sensor is installed at the centre of rotation. First, establish the yard measurement plane coordinate system XOY, the plane coordinate system is established according to the yard envelope rectangle of the measurement site, and secondly establish the yard Z axis coordinate, the value is measured by the high-speed laser scanner combined with the pitch angle sensor angle, stack reclaim The length of the machine arm is converted. The working mode of the laser scanner is fixed to start from one side (such as from left to right), cover a certain angular range (such as 0 ~ 180 °), scan point by point at a certain angular interval (such as 0.5 °), each scan The period is a measurement section, and the measurement result is the actual distance from the scanner to the measured point. The distance and angle sensor returns the pulse value in the form of pulse, and the actual distance and boom angle are calculated through calibration conversion. By continuously acquiring the yard scanning cross-sections at fixed distance intervals and collecting the three-dimensional coordinate data of the entire yard, it provides support for establishing a three-dimensional model of the yard. The sensor time reference is realized by the acquisition control device. The acquisition control device sends acquisition instructions to each sensor and marks the data with time labels to achieve time synchronization of the collected data. The system scanner uses SICK's LD-LRS3100, and the angle and distance sensors use SICK's E6B2. -C type encoder, the controller is independently researched and developed, and the data and control process are carried out through 5G wireless network [6].
3.1. Yard model
According to the sensor installation position and data usage, combined with the yard coordinate system, the parameters to be considered for the long yard model are the angle between the carrier boom and the carrier walking track, the angle between the laser scanner and the ground and the boom, the boom Angle to horizontal plane and angle between scanning section and track. For a circular yard, the stacker-reclaimer rotates around the centre of rotation, and there is no need to obtain distance data. Only the angle between the laser scanner and the horizontal plane, the angle between the scanning section and the scanner itself, etc. are considered [7].

3.2. Stacking experiment
During the experiment, the stockyard 1 selected 11 reference measurement points and the stockyard 2 selected 3 measurement points.

| Latitude and longitude | Heading angle / (°) | Elevation / m | Vertical inclination / (°) | Lateral inclination / (°) |
|------------------------|--------------------|---------------|--------------------------|-------------------------|
| 1 102.21233351, 38.4950217 | 292.664 | 1554.85 | -1.011 | -1.135 |
| 2 102.21111533, 38.4590525 | 292.562 | 1554.87 | -1.097 | -1.172 |
| 3 102.2120717, 38.4493741 | 272.592 | 1554.84 | -1.376 | -1.028 |
| 4 102.210109, 38.49500001 | 294.621 | 1554.94 | -1.143 | -1.599 |
| 5 102.21046083, 38.4951667 | 296.547 | 1554.84 | -1.071 | -1.173 |
| 6 102.20995551, 38.4954801 | 292.822 | 1554.75 | -1.046 | -1.286 |
| 7 102.20947767, 38.4956561 | 297.132 | 1554.73 | -1.024 | -1.088 |
| 8 102.20973733, 38.4959517 | 114.888 | 1555.05 | 1.032 | -1.631 |
| 9 102.21114551, 38.49553883 | 115.585 | 1555.13 | 1.746 | -2.214 |
| 1 102.220109233, 38.4959533 | 108.317 | 1554.99 | -1.303 | -3.731 |
| 0 102.21105117, 38.4957483 | 295.372 | 1555.06 | -1.314 | -2.241 |

The accuracy of the measurement results is affected by two aspects, one is the measurement error caused by the accuracy of the RTK or continuous operation satellite positioning service integrated system, and the other is the error generated by the algorithm itself. The accuracy of the current RTK is in the order of centimetres, and the accuracy of the scanner is in the order of millimetres, so the error caused by the first aspect can be ignored. According to the results of the previous research, three consecutive measurements were carried out under different included angles and the experiment was performed on the absolute increment test. The calculation results show that the three-dimensional graphics are basically consistent. The single point repetition rate is the average of each measurement result divided by the average value and the standard unit 1, and the average is taken. For example, the calculation result of the point 1 repetition rate is 0.85%. On average, it does not exceed 0.9%. The error is divided by the average value of each result and then averaged. For example, the error calculation result of point 1 is 0.0046, and the other points except point 11 are all less than 0.4%. 

Table 1. Specific parameters are shown in below
Table 2. Specific measurement results are shown in

| Point | Single point of volume 1 / m³ | Single point of volume 2 / m³ | Single point of volume 3 / m³ | Repeatability single point |
|-------|-----------------------------|-----------------------------|-----------------------------|---------------------------|
| 1     | 1992.8                      | 2026.5                      | 2035.9                      | 0.008455                  |
| 2     | 5845.7                      | 5880.8                      | 5894.6                      | 0.003178                  |
| 3     | 3654.8                      | 3602.8                      | 3633.5                      | 0.005062                  |
| 4     | 7977.8                      | 7964.1                      | 7813.9                      | 0.008814                  |
| 5     | 8610.7                      | 8787.5                      | 8613.2                      | 0.008998                  |
| 6     | 8227.5                      | 8293                        | 8159.7                      | 0.005432                  |
| 7     | 4622.1                      | 4690.9                      | 4693.5                      | 0.006673                  |
| 8     | 4188                        | 4165.2                      | 4207.1                      | 0.003434                  |
| 9     | 4597.6                      | 4633.4                      | 4662.6                      | 0.004836                  |
| 10    | 4129.9                      | 4098.3                      | 4176.4                      | 0.006696                  |
| 11    | 4412.1                      | 4422.3                      | 4320.2                      | 0.009831                  |

4. Conclusion
The use of high-speed laser scanners combined with distance and angle sensor integration technology can realize non-contact measurement and solve the problems of large artificial influence, long period and low accuracy in traditional measurement. Practical measurement results show that this method is a good non-contact method for measuring the volume of large open yard stockpile, which can be promoted in mineral enterprises and has good application prospects. However, this article does not make good use of the repeated measurement data of the intersection area of two single-point measurements. That is, for the data in the same area, only the data in a single point measurement shall prevail, and the other data are directly discarded. Efficient and reliable data fusion method, make full use of duplicate data, remove glitches and jitter, and improve the accuracy of measurement calculation.

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