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APPLICATION OF MEASUREMENT ROBOTS BASED ON DEEP LEARNING IN BUILDING TILT STABILITY MONITORING

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Abstract. In order to better understand the application of measuring robots in monitoring the stability of building inclination, this paper proposes a deep learning based algorithm for analyzing the trend of building inclination using measuring robots. The author first proposes a method of using measuring robots to monitor the tilting stability of buildings. Based on the principle of laser ranging, construct a robot structure and laser ranging model to achieve information exchange between different units. Secondly, based on simulation analysis, the position relationship between the laser and the building was marked with triangular coordinates, and the inclination of the building was marked with robot benchmarks. The simulation process was designed. By using the forward crossing method to evaluate the accuracy of tilt monitoring and comprehensively monitoring the three-dimensional angle of free station setting, the problem of low monitoring accuracy in traditional methods has been effectively solved. Finally, the experimental results show that using this method, the accuracy of building tilt monitoring can reach 99%, which is 7% higher than traditional measurement methods. Due to the low efficiency, high cost, and low accuracy of traditional manual monitoring work, it can no longer meet the requirements of modern engineering measurement. Therefore, high-precision measurement robots are used for tilt stability monitoring. Compared with traditional monitoring, high-precision measurement robots can achieve high-precision, high-efficiency, and low-cost monitoring with faster speed, higher efficiency, and strong automation capabilities.

Key words: Measuring robots, building tilting, stability monitoring

1. Introduction. Monitoring the tilt stability of buildings is a highly technical task that requires regular, timed, and quantitative observation of buildings. By monitoring buildings, timely detection of displacement changes in buildings can be carried out in order to take effective measures. In recent years, with the increasing scale and quantity of construction projects, slope stability monitoring has gradually become an important task in engineering surveying. Due to the low efficiency, high cost, and low accuracy of traditional manual monitoring work, it can no longer meet the requirements of modern engineering measurement. Therefore, high-precision measurement robots are used for tilt stability monitoring. Compared with manual monitoring, high-precision measurement robots can achieve high-precision, high-efficiency, and low-cost monitoring with faster speed, higher efficiency, and strong automation capabilities. The design of a measurement robot includes a motor, controller, and angle measurement system. Measurement robots can be fixed on a planar coordinate measuring machine through a machine or robotic arm installed on the ground, and then control the motion of the robot's four robotic arms on the ground to measure according to the predetermined route and orientation. Adopting a dual turntable system for fast conversion. At the same time, the measurement robot uses Total station and electronic angle measuring system to realize three-dimensional tilt measurement of buildings. The Total station can directly obtain the three-dimensional coordinates and direction information of the measured object, and the angle measuring system can collect the two-dimensional coordinates of the measured object, and then convert them into three-dimensional coordinates. Install sensors on buildings to monitor them in real-time. Sensors can be installed at different locations in buildings, and data collection and analysis can be carried out through a data acquisition software system to achieve dynamic monitoring of buildings. The terminal consists of a data acquisition module, wireless communication module, power switch module, and SD card. It can communicate wirelessly with measurement robots to achieve data collection and transmission. The terminal also has an RS485 interface, which can be connected to an industrial computer to achieve remote control of

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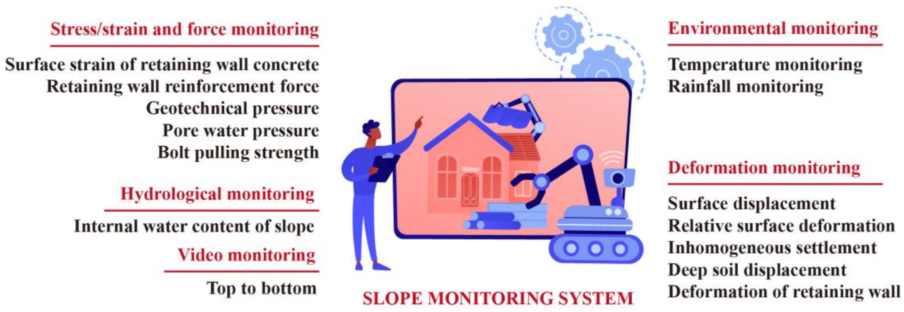

Fig. 1.1: Robot monitoring of building tilt stability

the measurement robot. At the same time, the terminal also has the characteristics of low power consumption, strong anti-interference ability, and long service life. This terminal sets up a wireless communication link between the measuring robot and the building to collect the inclination value of the building. At the same time, two data acquisition devices are also set up, one for collecting the coordinates of control points and reference points, and the other for measuring communication between robots and buildings [1,2] (Figure 1.1).

2. Literature Review. With the development of economy and society, the height and number of buildings are gradually increasing, the construction process of new buildings will inevitably cause changes in the stability of existing high-rise buildings, therefore, it is necessary to conduct Deformation monitoring on existing high-rise buildings around the site. The tilt of buildings will pose a threat to people's life safety. Therefore, the tilt stability monitoring of Tower block is also one of the main contents of Deformation monitoring. When monitoring the tilt stability of buildings, the measurement robot should be combined with the structure and surrounding environment of the building to avoid defects such as cracks and holes in the building walls. If there are cracks, holes, and other defects on the walls of a building, traditional repair methods should be used to repair them to ensure the safety of the building. If high-precision repair methods are used to repair it, it can shorten the repair time. Especially in recent years, with the development of high-tech technologies such as sensor technology, image processing technology, and communication technology, the performance of measurement robots has become increasingly high. In addition, with the continuous development of computer equipment such as electronics and computers, measurement robots have gradually shifted from traditional measurement to intelligent measurement.

Scholars have conducted some research on this issue. Giacoppo, G. A. proposed a method for measuring the inclination of buildings in mining subsidence areas based on point cloud feature line extraction, which can measure and analyze the subsidence trajectory through point cloud features. Although this method has certain applicability in tilt measurement of settlement buildings, laser point clouds are easily affected by ground obstacles and have low accuracy in tilt measurement of urban buildings [3]. Tian, Y. M. proposed a study on the dynamic deformation laws and internal forces of ground and buildings based on numerical analysis of Metro Line 3. By constructing a numerical analysis model, the impact of ground motion on buildings is studied, deformation data is collected, and inclination degree is measured. This method achieved the estimation of inclination measurement values for transportation buildings through model numerical analysis, but did not conduct building simulation analysis, and the reliability of the measurement results needs to be verified [4]. Zhou, T. proposed the application of inclination sensor in precision detection of parallel robots. This method utilizes inclination sensor to collect monitoring data and transmit it to the parallel robot system for measurement. The above three methods rely on traditional mechanical probes for measurement. Although the mechanical probe type measuring instrument is simple to use, its range of use is limited due to limitations caused by working principles, and human factors can cause large errors, which can easily lead to low accuracy of tilt monitoring [5]. In summary, the author proposes a method for monitoring the tilt stability of buildings using measuring robots, which can obtain various spatial dimensions of the building from all directions and achieve monitoring without contact, effectively improving measurement accuracy.

3. Research methods.

3.1. Monitoring of inclination stability of measuring robots.

3.1.1. Tilt stability monitoring process. The detailed process for monitoring tilt stability is as follows:

1. Monitoring points should be set up on the platform as needed, and control points should be placed in high-rise buildings. The selection of points should be firm and not affected by mining.
2. The auxiliary observation mark of the measuring robot is set at the stable position of the building, and a cloud platform point distribution map with equal inclination is drawn based on the obtained monitoring data [6,7].
3. In the adjustment calculation of monitoring data, the Centroid coordinates of the detection layer of the building are calculated based on the measured data; According to the accuracy requirements of servo Total station, the mean square error value of horizontal observation m0=± 0.5 is selected.
4. Benchmarks and observation points should be set up for monitoring the inclination of buildings through coordinate positioning.
5. For the same building tilt observation object, it is necessary to set two or more reference points at different positions within the observation range of the measuring robot.

In order to ensure the accuracy and stability of building tilt monitoring, it is necessary to select stable and long-term monitoring positions for stability inspection.

3.2. Simulation of robot benchmark labeling building inclination. Because the end effector of the measuring robot is a laser sensor, the laser sensor is connected to the robotic arm through 01, and the robotic arm of the measuring robot is simplified into a planar robotic arm model. The description of the position and posture of the laser sensor using coordinate annotation is more intuitive [8].

Let X be the laser sensor, therefore, the robot base coordinate system is Equation 3.1.

$$\begin{cases} x_e = l_1 cos\theta_1 + l_3 cos(\theta_1+\theta_2)\phi + l_4 cos(\theta_1+\theta_2+\theta_4) \\ y_e = l_1 sin\theta_1 + l_3 sin(\theta_1+\theta_2)\phi + l_4 sin(\theta_1+\theta_2+\theta_4) \end{cases} \tag{3.1}$$

The Kinematics parameters obtained by simulation are basically in line with the actual situation, which can be used to describe them and verify the theoretical feasibility of the proposed method. According to the tilt simulation process (as shown in Figure 3.1), complete the tilt simulation research of the robot benchmark labeling building.

3.3. Accuracy Appraisal of Building Tilt Monitoring. The servo Total station with high precision and strong automatic tracking ability is selected, and the front crossing mode is adopted to realize the three-dimensional accurate observation of building inclination observation. This method can effectively weaken the influence of the error of conventional observation methods on the observation accuracy. The calculation formula for inclination error (2) is:

$$i = \frac{\sqrt{(x_1-x_2)^2-(y_1-y_2)^2}}{|z_1 z_2|} < 0.05 \tag{3.2}$$

In Equation 3.2, x1, y1, and z1 respectively represent the coordinate errors of the upper half of the horizontal axis of the coordinate system; X2, y2, and z2 respectively represent the coordinate errors in the lower half of the horizontal axis of the coordinate system. Select the set of data with the highest error in the coordinate system to evaluate the accuracy of building tilt monitoring. If the monitoring error is less than 0.05, it indicates that the monitoring results of this method are relatively accurate .

3.4. Precision Analysis of Monitoring Schemes.

3.4.1. 3D free station adjustment calculation model. Before conducting long-term monitoring, analyze the accuracy of this plan based on three types of observation values and monitoring methods. When conducting accuracy analysis based on the instrument accuracy and observation method used, the mean square error in horizontal direction observation is my, $= \pm 0.5$",, and the mean square error in horizontal distance observation is $ms = \pm 0.5mm$, with a vertical right angle observation error of $mg = \pm 0.7$"$[9, 10]$.

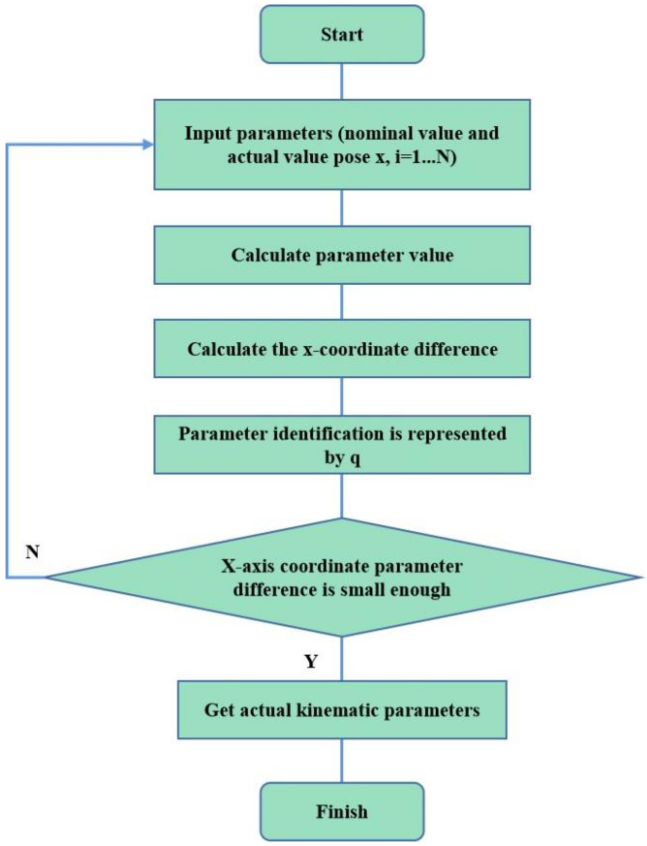

Fig. 3.1: Tilt Simulation Process

According to the principle of indirect adjustment, list the error equations for the three measurements in this scheme.

1. The error equation is shown in Equation 3.3

$$V = B\delta_x + L \tag{3.3}$$

   In the equation:
   V - Correction matrix of observation values;
   B - coefficient matrix of observation error equation;
   gx - unknown number correction matrix;
   L-constant matrix of observation error equation.
2. The coefficient matrix formula of the normal Equation 3.4

$$N = B^T PB \tag{3.4}$$

3. Expected results of errors.
   By writing VB program code to solve the coefficient matrix of the unknown number matrix, the expected error value is finally obtained. The expected error results are shown in Table 3.1.
   From the expected results in Table 3.1, it can be seen that if the mean of two independent observations is taken as the final observation result, the measurement accuracy of the monitoring project will meet the requirement of $\leqslant$ 1mm.
4. Actual measurement and data analysis

Table 3.1: Expected Results of Errors

Monitoring point number	Mean square error in X coordinate	Y coordinate mean square error	Mean square error of a point	Mean square error of elevation
S1	±0.07	±0.08	±0.08	±0.05
S2	±0.07	±0.07	±0.09	±0.06
1	±0.19	±0.39	±0.43	±0.16
2	±0.19	±0.39	±0.42	±0.21
3	±0.23	±0.23	±0.47	±0.15
4	±0.34	±0.21	±0.45	±0.14

Table 3.2: Results of Measured Data

1	X(m)	Y(m)	H(m)	type
2	936.25	963.45	148.36	undetermined
3	936.12	954.12	148312	undetermined
4	985.12	960.12	148.32	undetermined
S1	947.21	945.13	110.25	undetermined
S2	856.21	935.74	110.74	fixed

When observing on the actual site, the position of the measuring station remains fixed. Leica TM30 surveying robot is used to set up on S1 and s2 stations respectively for observation. Each station automatically observes 3 sets of measurements, and simultaneously observes the horizontal angle, distance and vertical angle. After collecting data from monitoring points, perform 3D adjustment model calculations, and perform overall rigorous adjustment calculations on all observation data [11,12]. The measured data is shown in Table 3.2.

3.5. Main parameters of measuring robots. The main parameters of the measuring robot include: Total station coordinate system, angle measuring accuracy, distance measuring accuracy and angle measuring speed. The coordinate system of Total station includes three coordinate systems, namely X, Y and Z direction coordinate systems, namely ground coordinate system, distance coordinate system and angle coordinate system. The distance measurement accuracy of Total station is 1 mm, and the angle measurement accuracy is 0.02°; The ranging speed is 6-10m/s. Angle measurement accuracy refers to the ratio of the difference between the angles of Total station in two observation directions and the difference between the angles of these two observation directions, expressed in%. In practical applications, in order to ensure the accuracy of measurement, direct reading method and indirect reading method are generally used to calculate the coordinates of the measuring station. The direct reading method refers to directly reading out the coordinates of the measuring station; The indirect reading method refers to obtaining the coordinates of a given point by substituting the station coordinates into the known point coordinates, provided that the station coordinates are already known [13,14].

In the actual survey, the angle measurement accuracy needs to be corrected due to the deviation of Total station observation value. Generally, the error of station coordinates can be divided into two situations: One is the systematic error of station coordinates, which can be corrected by setting reference points; The other type is the system error of angle measurement accuracy, which mainly comes from the system error generated by the measuring robot itself, its size is related to the coordinate system error and angle measurement accuracy of the measuring station. In order to ensure the accuracy and reliability of measurement robots, the angle measurement accuracy is generally controlled within 1°. For high-precision monitoring projects, additional compensation is required.

3.5.1. Measurement method.

1. Turn on the power of the automated measurement robot and adjust the working temperature of the laser ranging sensor to $-20°C \sim +40°C$.

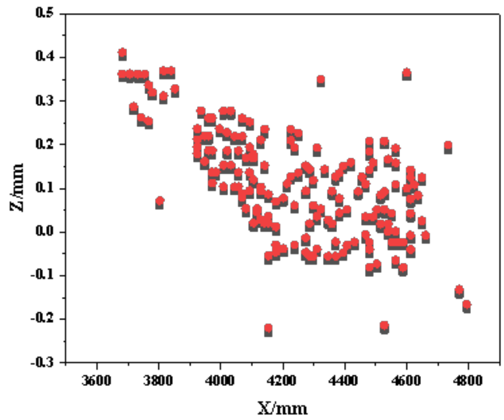

Fig. 4.1: 3D Display Results of Actual Building Inclination

2. Use a handheld computer to read the coordinates of the reference point, then place the measuring robot on the reference point and start the automatic tracking system.
3. Calculate the tilt angle and relative position of the building based on the sensor data on the measuring robot and the laser ranging sensor data.
4. Based on the laser ranging sensor data on the measuring robot and the coordinates of the measuring station, calculate the building tilt angle and relative position, and then compare the calculated building tilt angle and relative position with the reference point to calculate the error of the building tilt angle [15].

4. Experiments.

4.1. Experimental Environment. Taking a building as an example, through the method of establishing a model, the scanning angle between the coordinates of the measuring points and the light surface of each Launch pad is measured to obtain the required angle, so as to determine the relationship between the distance measurement problem functions of high-rise buildings; Utilize a large amount of random data to statistically analyze the coordinates of the measured point, and then use a three-dimensional discrete point cloud to represent the coordinates of the measured point. Through the Monte Carlo simulation of 3000 samples, the point cloud distribution is obtained, which is similar to the ellipsoidal distribution. The use of measuring robots for rapid monitoring of the inclination of buildings and the analysis of the accuracy of monitoring results using three-dimensional measurement methods have led to conclusions of universal significance.

4.2. Experimental process. The distance between the measurement target and the dual emission station will have a certain impact on the measurement results. Several monitoring points are selected within the range of 1100mm to 6000mm, with each selected point spaced at 110mm intervals, and experiments are conducted in sequence. Draw a 3D cloud spatial point map of the actual building inclination, a 3D display cloud spatial point map of building inclination under monitoring by measuring robots, and a 3D display cloud spatial electrical state of building inclination under traditional mechanical probe measurement. Compare the inclination and draw an experimental conclusion [16].

4.3. Experimental results. If the error distribution is introduced into the sensor, the direction of laser ranging can be changed. Therefore, the point cloud obtained by Monte Carlo method takes the laser ranging error into consideration, and the distribution accuracy of the point cloud obtained by laser ranging method is very high. The three-dimensional display of the actual building inclination is shown in Figure 4.1.

Using the point cloud data in Figure 4.1 as supporting data, traditional mechanical probe measurement

Table 4.1: Comparison of Monitoring Accuracy between Two Methods

	Number of monitored dimensional groups (piece)	Actual total number of groups	Detection accuracy%
Traditional mechanical probe measurement	2765	2800	92
Measurement robot mechanical probe measurement	2985	2800	99

and measurement robot monitoring methods were used to compare and analyze the monitoring of building inclination. The three-dimensional point cloud spatial distribution formed by the actual inclination of the building is used as a control group. Under traditional mechanical probe measurement, three-dimensional modeling is used to demonstrate the monitoring accuracy of building inclination, which is lower compared to measurement robots. The results of building tilt monitoring based on measuring robots are better matched with the actual situation. In order to further verify the higher monitoring accuracy of the author's research method, the monitoring accuracy of the two methods was compared and analyzed, and the comparison results are shown in Table 4.1 [17].

From Table 4.1, it can be seen that the monitoring accuracy of building inclination based on traditional mechanical probe measurement is 92%, and the monitoring accuracy based on measurement robots is 99%, which is 7% higher than the former. It can be seen that the monitoring accuracy based on measurement robots is higher.

5. Discussion. Improving the accuracy of measurement data by measuring robots

According to the actual situation of buildings, the following measures can be taken to improve the accuracy of measurement data:

1. When using high-precision measurement robots for monitoring, it is necessary to isolate the boundaries, walls, and other areas of the building from the surrounding environment to ensure the accuracy of measurement data.
2. When monitoring buildings, it is necessary to strictly follow the construction plan for monitoring, and the internal structure of the building must be the main measurement object during measurement.
3. When conducting measurements, it is necessary to ensure that the monitoring environment is dry, clean, and tidy, and to repair cracks, holes, and other defects on the building's exterior walls and walls.
4. When conducting measurements, it is necessary to ensure that the measuring robot has good stability and reliability. If there are problems in their work, they should be promptly contacted by the staff to replace them [18].
5. When monitoring buildings, it is necessary to ensure that the instruments and equipment used can meet the relevant detection requirements.

When using measurement robots for building tilt stability monitoring, it is necessary to choose appropriate measurement methods based on the actual situation to improve measurement efficiency. For example, Total station and Dumpy level can be used for slope stability monitoring. In order to ensure the safety of buildings, various parts of the building should be monitored. Due to the fact that using measurement robots can reduce the number of measurements, it can improve work efficiency.

In addition, the use of measurement robots can improve the accuracy and accuracy of monitoring, thereby reducing monitoring costs. When using high-precision measurement robots for building tilt stability monitoring, it can not only improve work efficiency but also reduce monitoring costs. In traditional building tilt stability monitoring, it is usually necessary to measure and calculate the results multiple times. Therefore, it is necessary to measure multiple monitoring points simultaneously and calculate the results [19,20].

6. Conclusion. The use of measuring robots to monitor the inclination of buildings has broken the research process of traditional building inclination observation methods, greatly improving monitoring efficiency. The use of monitoring data can quickly calculate the inclination of building materials, and the monitoring results have high accuracy and reliability. The robot measurement method can deeply measure the inclination of buildings, and use 3D models to display the monitoring accuracy of building inclination. Compared with traditional methods, it has higher accuracy and is in line with the actual situation, resulting in better measurement results. The use of measurement robots to monitor the inclination of buildings has a significant impact on the measurement results. In the following research, heuristic search algorithms such as genetic algorithms will be used to further optimize the design and layout of monitoring points, thereby improving monitoring accuracy.

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