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A new wireless base pit inclinometer based on NB-IoT

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ABSTRACT: *Aiming at the shortcomings of the existing foundation pit inclinometer, compared with the working mode and measuring method of the widely used drilling pit slanting instrument, combined with the latest long-distance wireless communication technology NB-IoT, a new semi-automatic base is proposed. Pit inclinometer. The tilt sensor SCA100T is used to greatly improve the accuracy of the angle measurement and solve the problem of low accuracy of the traditional inclinometer. In order to ensure the accuracy of the angle measurement of the tilt sensor, it is carefully considered from the hardware principle design, PCB layout to software design. Finally, the oblique data is sent remotely to the cloud server through the data transparent transmission module (WH-NB73). Mathematical modeling is performed on the data obtained from the cloud, and the data is presented in a more intuitive manner to realize remote intelligent monitoring of the foundation pit and its surrounding soil environment.*

Keywords: *Foundation pit, Inclinometer, NB-IoT, SCA100T, Mathematical modeling, Remote intelligent monitoring*

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I. INTRODUCTION

At the beginning of the 21st century, China's enthusiasm for infrastructure construction became high. All kinds of geotechnical engineering continuously improve the stability and accuracy of the inclinometer system. In particular, the engineering supervision system set up in China puts higher standards on the inclinometer technology and the inclinometer. Although the domestic inclinometer technology is constantly developing, there is still a certain distance from the level of inclination measurement in developed countries. The main performance is: the accuracy of the inclination measurement needs to be further improved, some high-precision advanced inclinometer products are also dependent on imports, and imported equipment is generally expensive. The inclinometer works relatively backward and cannot be rid of artificial dependence.

Therefore, in view of the shortcomings of the existing foundation pit tilting system, this paper analyzes and studies the tilting mode of the foundation pit inclinometer. Applying the latest MEMS biaxial acceleration tilt sensor and long-distance wireless NB-IoT narrowband communication related technology, a new semi-automatic inclinometer is proposed. And from the theoretical analysis, select the relevant hardware, hardware design and software design. Modeling and analyzing the data obtained from the experiment to realize the monitoring of the foundation pit and timely warning.

II. ANALYSIS OF THE PRINCIPLE OF FOUNDATION PIT INCLINATION

When monitoring the horizontal displacement of deep soil in the foundation pit, the inclined method commonly used in the industry is the drilling type foundation pit inclination method. The drilling type foundation pit inclination method is to embed a special inclination measuring pipe whose total length is larger than the depth of the measured soil body in a vertical direction in the soil to be tested. When the horizontal displacement changes occur in the soil to be measured in which the inclinometer is buried, the inclined pipeline will also deform correspondingly with the original vertical position of the soil. The principle of drilling type foundation pit inclination is shown in Figure 2.1.

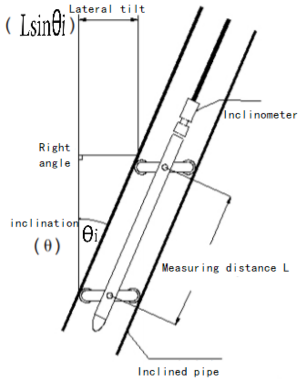

Figure 2.1 Schematic diagram of the drilling foundation pit

At this time, a module with an internal tilt sensor is placed in the tube, so that it can reciprocate in the inclinometer tube, and the angle between the axis of the measuring tube and the actual vertical direction is also measured in sections, also called the tilt angle. θ. After obtaining the inclination angle and combining the segment length L, the horizontal displacement of the soil layers at different depths can be calculated. This method is referred to as the inclination measurement in the engineering community. Set the horizontal displacement of the soil layer at a certain depth to S_i

$$S_i = L\sin\theta_i \tag{1}$$

Where L is the segmentation distance of the measuring point, the distance is determined according to the size of the project. The deeper the depth of the pit, the distance of the measuring point will increase appropriately, generally 0.5 m; θ_i is the inclination angle of the soil layer at a certain depth.

There are a total of four inner grooves spaced 90° apart from each other in the inclinometer tube, and the inclinometer is placed in the two opposite slots in the inclinometer tube. Therefore, when installing the inclinometer, an inner groove must be aligned with the deformation direction of the foundation pit or the ground slope should be monitored for the direction in which the displacement may occur. The relationship between the inclined tube groove and the support tilt is shown in Figure 2.2.

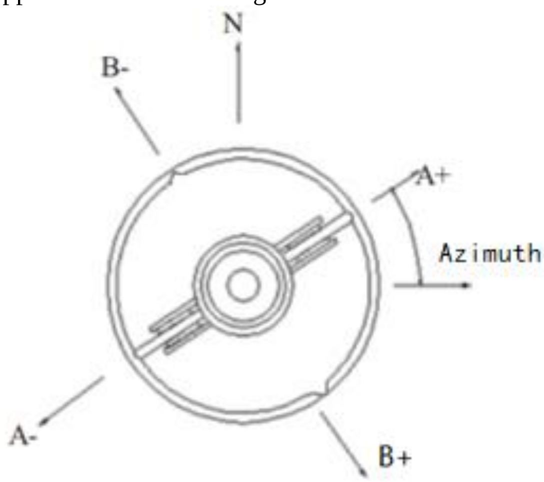

Figure 2.2 Schematic diagram of tilting the groove and support of the inclined tube

Considering that the more the base pit is farther away from the ground, the horizontal displacement deformation is less likely to occur. Generally, the inclinometer is buried into a relatively stable or non-deformed soil layer, that is, below the bottom of the foundation pit as a fixed point of displacement. Set the cumulative displacement of the horizontal displacement of the nozzle as S_n, and the displacement accumulation diagram is shown in Figure 2.3.

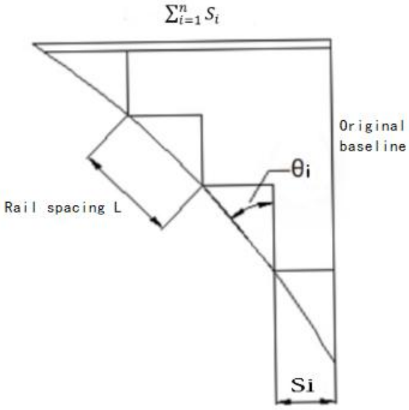

Figure 2.3 Schematic diagram of nozzle displacement accumulation

$$S_n = \sum_{i=1}^{n} L sin\theta_i \tag{2}$$

Of course, the above situation is only a normal state. If the horizontal displacement of the upper and lower ends of the inclinometer tube occurs, another method is needed to measure the actual horizontal displacement S_n of the nozzle, and then the respective monitoring is sequentially calculated downward. The horizontal displacement value of point m is S_m

$$S_m = S_n - \sum_{i=m+1}^{n} L sin\theta_i \tag{3}$$

For long-running instruments, systematic error is a problem that cannot be ignored. The long-term operation of the inclinometer produces a drift error K_0, which increases over time, but can be treated as a constant for an observation. In order to eliminate the systematic error generated during the measurement process, the one-time tilting task tilting module usually performs two measurements. Assume that the result of the initial measurement at a certain point is the forward path A+, and the measured inclination angle is θ, and the guide rail spacing is L, then there is

$$A+ = K_0 + L sin\theta \tag{4}$$

To eliminate the effects of drift errors, the inclinometer is rotated 180° along the axis of the inclinometer tube and placed in the tube for another measurement. Still at this point, the result of the measurement is the negative path A+. At this time, the measured inclination angle is -θ, and the guide rail spacing is L, then there is

$$A- = K_0 + L sin(-\theta) \tag{5}$$

By subtracting Equation 4 from Equation 5, the drift error K_0 is eliminated, and there is

$$(A+) - (A-) = 2L\sin\theta \tag{6}$$

Dividing Equation 6 by 2 will wait for the actual measured calculation at that point. Starting from the bottom of the inclinometer, the horizontal offset value of each monitoring point is taken as the value of the X-axis, and the distance between each monitoring point and the bottom of the tube is taken as the value of the Y-axis, and the deformation of the soil during the observation period is plotted.

III. INCLINOMETER HARDWARE DESIGN

3.1 Design goals

The ideal inclinometer should be strictly in accordance with the requirements of the Geotechnical Engineering Monitoring Code and the price is reasonable. Therefore, the reasonable inclinometer achieves the following objectives: 1. Using the inclinometer to achieve automatic forward and reverse measurement; 2. The measurement frequency is reasonable, the measurement frequency is adaptable, and can be set or modified in the field or remote working mode; Self-sufficiency and replenishment energy during the absence of the working network (AC grid); 4. Remote wireless interaction with measurement data, working mode settings, etc., to achieve remote monitoring and background processing.

3.2 Design plan

The system is divided into an inclination measuring unit, a remote wireless communication unit and a power supply unit to implement a tilt measurement scheme. The measuring and tilting sensing unit is composed of a MEMS biaxial angle sensor, a small stepping motor and its driving circuit, a microprocessor and a peripheral auxiliary module; the remote wireless communication unit is composed of a NB-IoT narrowband IoT communication module; the power unit is composed of a lithium battery. The group and the associated power conversion circuit are composed. The system structure block diagram is shown in Figure 3.1.

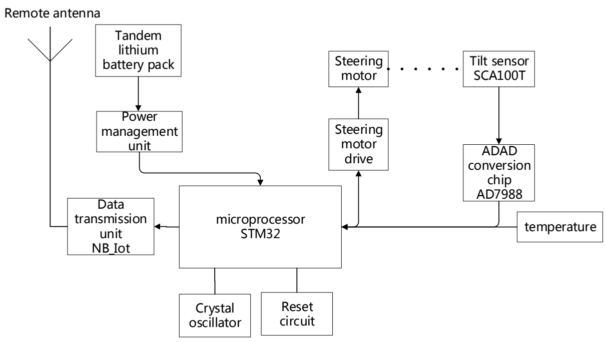

Figure 3.1 Block diagram of inclinometer system

IV. INCLINOMETER SOFTWARE DESIGN

This chapter is mainly based on the hardware that has been built to perform the software design of the inclinometer system. It lays a good foundation for the next experimental test and data analysis. The system software flow chart is shown in Figure 4.1.

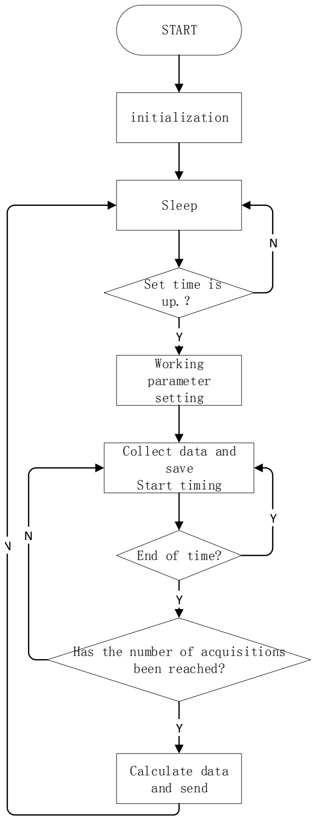

Figure 4.1 System overall software flow chart

After the system is powered on, the tilt sensing unit is initialized, and the remote wireless communication unit is in a sleep state. After the initialization is completed, the skew sensing unit starts to wait for a certain long time to wait for the external parameter setting. After the waiting time has elapsed, the skew sensing unit begins to be lowered. At a fixed time at a fixed time, the skew sensing unit begins to collect data. After the data of the forward and reverse are collected, the skew sensing unit performs data calculation. After the operation ends, the skew sensing unit wakes up the remote wireless communication unit through the UART, and transmits the calculated data to the remote wireless communication unit. When the remote wireless communication unit accepts, the data is sent to the cloud. The skew sensing unit and the remote wireless communication unit go to sleep.

V. DATA MODELING ANALYSIS

Assuming the lowest point is unchanged, use it as a reference point. The data is processed after the data is obtained. In order to reproduce the true tilt condition of the inclined pipe in the soil, the 3D image of the inclinometer is constructed by MATLAB according to the measured inclination value of the X-axis Y-axis.

5.1 Experimental environment one

This experimental environment is modeled on the data obtained from the overall commissioning. It is a combination of three sections of wood. Ten monitoring points were taken from each section of the board, and a total of 30 monitoring points were used to simulate a 30-meter deep foundation pit. The obtained data TXT file is imported into MATLAB, and then the valid information in the TXT file is extracted to obtain the inclination value of the X-axis Y-axis. The obtained tilt values of the X-axis and Y-axis are respectively subjected to a rotation matrix transformation to obtain an angle with the Z-axis, thereby drawing a 3D image. The experimental environment 1 measured data is shown in Table 5.1.

Table 5.1 Experimental environment one measured data

	1	**2**	**3**	**4**	**5**	**6**
X axis(°)	20.288	20.849	20.531	20.235	19.478	20.601
Y axis(°)	-1.658	-1.594	-0.601	-2.302	-0.988	-0.979
	7	**8**	**9**	**10**	**11**	**12**
X axis(°)	20.612	19.499	20.791	19.821	10.202	10.015
Y axis(°)	-0.382	-2.123	-1.342	-1.032	-1.228	-1.702
	13	**14**	**15**	**16**	**17**	**18**
X axis(°)	10.435	9.869	10.226	10.392	10.637	9.768
Y axis(°)	-1.478	-1.428	-2.741	-1.461	-1.937	-2.017
	19	**20**	**21**	**22**	**23**	**24**
X axis(°)	9.721	9.934	-0.179	-0.182	-0.181	-0.184
Y axis(°)	-1.976	-2.328	0.255	0.25	0.247	0.25
	25	**26**	**27**	**28**	**29**	**30**
X axis(°)	-0.278	-0.276	-0.273	-0.268	-0.268	-0.268
Y axis(°)	0.174	0.178	0.178	0.178	0.181	0.182

The constructed 3D image is shown in Figure 5.1.

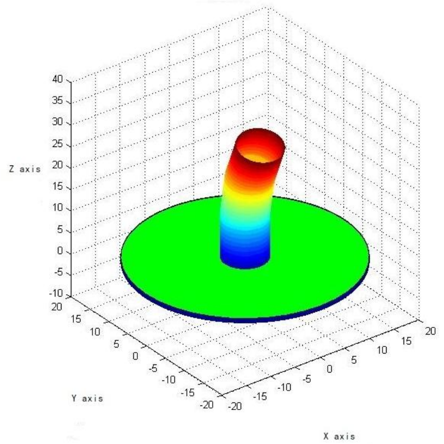

Figure 5.1 Simulated inclinometer tilting diagram

5.2 Experimental environment two

This experimental environment is modeled on the data obtained from the overall debugging, and the modeling method is similar to the first experimental environment. The difference is that the original model is transparent, that is, the line is used instead of the surface. To reflect the rotational offset of the Y-axis, add a cylinder as a reference. One is the red X-axis inclination and the Y-axis inclination is 0°. This root is for reference. The other is that the blue X and Y axis inclinations are unchanged. Ten monitoring points were taken on each section of the board, so a total of 30 monitoring points were used to simulate a 30-meter deep foundation pit. The obtained data TXT file is imported into MATLAB, and then the valid information in the TXT file is extracted to obtain the inclination value of the X-axis Y-axis. The obtained tilt values of the X-axis and Y-axis are respectively subjected to a rotation matrix transformation to obtain an angle with the Z-axis, and then the coordinates of the points are obtained, thereby drawing a 3D image. The data measured in the experimental environment three are shown in Table 5.2.

Table 5.2 Experimental environment two measured data

	1	2	3	4	5	6
X axis(°)	20.811	20.867	20.101	20.159	20.221	20.431
Y axis(°)	-7.317	-7.187	-5.202	-8.605	-5.975	-5.957
	7	**8**	**9**	**10**	**11**	**12**
X axis(°)	20.294	20.356	20.946	19.806	10.066	10.750
Y axis(°)	-4.764	-8.247	-6.683	-6.064	-2.455	-3.404
	13	**14**	**15**	**16**	**17**	**18**
X axis(°)	10.653	9.826	9.572	9.721	9.934	9.884
Y axis(°)	-2.955	-2.855	-5.483	-2.922	-3.874	-4.034
	19	**20**	**21**	**22**	**23**	**24**
X axis(°)	10.400	10.435	-0.278	-0.276	-0.273	0.174
Y axis(°)	-3.951	-4.656	0.509	0.499	0.494	0.501
	25	**26**	**27**	**28**	**29**	**30**
X axis(°)	-0.222	-0.221	-0.219	-0.218	-0.219	-0.218
Y axis(°)	0.348	0.356	0.356	0.355	0.362	0.364

The constructed 3D image is shown in Figure 5.2.

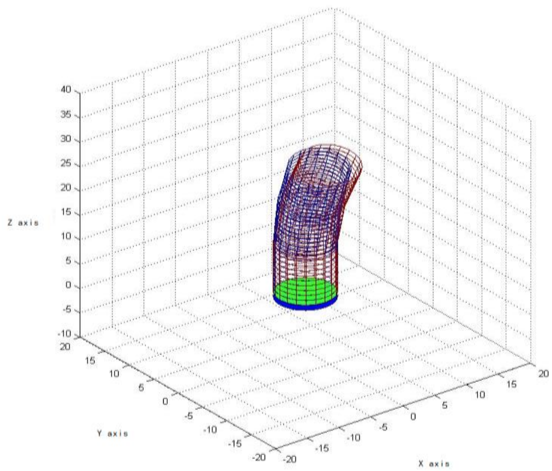

Figure 5.2 Simulation tilting tube tilting diagram

VI. CONCLUSION

In this paper, a new wireless base pit inclinometer is proposed for the existing base pit inclinometer with low precision, high cost and large artificial dependence. However, this article failed to achieve complete independence from labor, but reduced the number of labor from the original two to one. The next step is to make an on-board traction controller that can pull up and down the measurement sensing unit at a constant speed to achieve complete unmanned intervention, further improving measurement accuracy.

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