Research on 3D measurement of underground displacement based on tipping capacitance

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Abstract: At present, there are many research methods for underground displacement measurement at home and abroad, such as borehole inclinometer technology, TDR technology, multi-point displacement meter, etc., but none of them can truly realize the three-dimensional measurement of underground displacement. In view of this, the author has designed an experimental device of underground displacement three-dimensional measurement method based on twitch capacitor. The device is mainly composed of a twitch type capacitance device, a mutual inductance device, an inclination angle and an azimuth angle measuring sensor device, which realizes the measurement of the size and angle of the moving position after the device moves, obtains data through an STM32 singlechip, and transmits the measured data to an upper computer through a 485 bus, realizing remote control and real-time underground displacement three-dimensional monitoring.

1. Introduction

Landslide refers to a geological phenomenon that is caused by natural environment or human factors and threatens human property and even life. It is the surface layer of the earth's lithosphere crust. Under the interaction of atmosphere, hydrosphere and biosphere, the geological environment has undergone great changes, thus bringing life threats and property losses to human beings. Apart from direct hazards and accidents, landslide disasters have far-reaching indirect impacts on human social, economic and social development, including the psychological burden of residents, social stability, soil erosion, environmental deterioration, etc. In view of the geological landslide phenomenon, many methods for measuring underground deformation have been studied at home and abroad, including borehole inclinometer technology, TDR technology and multipoint displacement meter. Borehole inclinometer technology cannot measure the vertical displacement of landslide at different depths. TDR technology is difficult to determine the sliding direction of landslide, and the scalability of coaxial cable is very poor. The multipoint displacement meter can only measure one-dimensional displacement. None of these methods can measure the three-dimensional change of underground displacement.

In view of this, the author proposes a three-dimensional underground displacement measurement method based on twitch capacitor, which can obtain the magnitude and direction of underground displacement with high accuracy and realize remote real-time monitoring of underground displacement measurement.
2. Design of 3D Measurement Method for Underground Displacement

2.1. Overall design scheme

This paper is based on the research of three-dimensional underground displacement measurement of twitch capacitor. The overall structure of the research is shown in Figure 1 below. The whole structure consists of a host computer, a communication bus and a series of identical sensor units. When landslide displacement occurs, two or two sensor units generate relative inclination angle and horizontal and vertical displacement, and the singlechip transmits the obtained data to the host through 485 bus, thus obtaining the three-dimensional change of underground displacement.

![Figure 1. Overall structure diagram.](image)

Fig. 2 is a structural diagram of a single two-sensor system. When landslide occurs, sensor unit 1 and sensor unit 2 have horizontal displacement x and vertical displacement z. The linear displacement distance L of the two sensor units is obtained through a capacitance tester. L is related to x and z:

\[
L = \sqrt{X^2 + Z^2} \quad (1)
\]

Then, a voltage value u is obtained through the upper and lower mutual inductance coils 1 and 2, the coil is completely placed in the sensor unit, and then an acceleration sensor is placed on the sensor unit 2 to obtain an inclination angle θ, the relationship between the voltage and x, z, θ is obtained:

\[
U_{out} = f(X, Z, \theta) \quad (2)
\]

The relational expressions are obtained through relational expressions (1) and (2):

\[
U_{out} = f(X, L, \theta) \quad (3)
\]

Given the three variables u, l, θ, the horizontal displacement value x can be obtained by relation (3), and the vertical displacement z can be obtained by relation 1. Therefore, horizontal displacement and vertical displacement of underground three-dimensional displacement are obtained.

![Figure 2. Structure diagram between sensor units](image)

![Figure 3. Azimuth map between sensor units](image)

To know the underground three-dimensional displacement, in addition to the above-mentioned changes in relative position size, we must also know the direction angle @, tilt and orientation.
measurement sensors of the two sensors. It integrates a triaxial accelerometer and a triaxial magnetometer, and can measure not only the tilt angle $\theta$ but also the tilt direction $\phi$. So as to obtain the displacement direction of the sensor and realize real three-dimensional measurement of underground deformation.

2.2 Tipping capacitor for measuring linear distance $l$

2.2.1 Principle of capacitance measuring distance $l$.

A flat capacitor consisting of two parallel metal plates separated by a bonding medium has a capacitance of:

$$ C = \frac{\varepsilon A}{d} \quad (4) $$

Where $\varepsilon$ is that relative dielectric constant of the medium between the polar plate; $A$ is the area covered by two parallel plates; $d$ is the distance between two parallel plates.

In the experiment, $d$ and $\varepsilon$ are unchanged, and the size of $A$ is changed, that is, the size of capacitance is changed. When the area $\Delta A$ is changed, there is a formula (5), and then the change amount of capacitance is obtained.

During the experiment, as shown in fig. 4, a twitch type capacitance experiment device is formed by coaxial cable and steel wire rope with rubber. The coaxial cable retains the copper net and the sheath, and the steel wire rope with rubber covers replaces the copper core to twitch. When the steel wire rope inside is stretched, the relative distance between the steel wire rope and the copper wire net and the circumference of the steel wire rope and the copper wire net form a relative area change, then capacitance change occurs, and the changed capacitance value is proportional to the relative distance $l$ between the steel wire rope and the steel wire net twitch, and the value of the distance $l$ is obtained from the experiment.

$$ \Delta C = \frac{\varepsilon \Delta A}{d} \quad (5) $$

Figure 4. Structure diagram of capacitance part experimental device

2.2.2 Principle of capacitance measurement by PACAP02 capacitance measurement chip

Capacitance is measured by charging and discharging. The measured capacitor $C_x$ and the reference capacitor $C_{\text{ref}}$ (the reference capacitor itself is externally connected with 30pf) are connected with the same resistor. Voltage VDD charges $C_x$ and charges $C_{\text{ref}}$ at the same time. After charging, the same resistor is discharged until a controllable threshold voltage is recorded by the high-precision digital converter TDC inside the chip to obtain two times $T_x$ and $T_{\text{ref}}$. The value of the measured capacitance can be obtained by obtaining the ratio of time, which is equivalent to the ratio of capacitance.
2.2.3 PACAP02 Capacitance Measurement Chip Module Circuit
The PCAP02 capacitance measuring chip transmits the measured data to STM32F030F4 single chip computer through SPI interface, and STM32F030F4 single chip computer transmits the obtained data to upper computer through serial port, thus obtaining the experimental capacitance value.

2.2.4 Device diagram of capacitance measuring distance \( l \)
As shown in fig. 5, the left side is a three-axis motion platform, which can realize the \( x \), \( y \) and \( z \) motions of the experimental device. The experimental device is placed on the motion arm to simulate the underground three-dimensional motion. In the middle is a drawing of a twitch type experimental device. The twitch type capacitance experimental device uses upper and lower 3-D printed disks to control its up and down movement, and on the right is a 3-D printed analog structure drawing.

2.3 Mutual inductance ranging experiment
As shown in fig. 6 below, the left side of fig. 7 is a schematic diagram and the right side is a coil diagram for experiment. When coil II inputs sinusoidal voltage signals with fixed frequency and amplitude, when the changing current in coil II or the changing relative distance \( l \) between coil II and coil I causes coil I to generate a changing magnetic field, thus generating mutual inductance voltage. Here, the relative distance \( l \) between coil II and coil I is only changed, and the sensor unit II and sensor unit I have an inclination angle \( \theta \), then there is a mutual inductance voltage relation (6), and the relation between distance and voltage can be obtained.

\[
U_{out} = f(X, Z, \theta)
\]

3. Data structure
3.1 The host computer operation interface compiled
The upper computer is written with Visual Studio 2015 software and C# language. The console window can send commands to control the X, Y and Z movements of the three-axis motion platform. The lower computer window can send a start measurement command to the lower computer. After receiving the command, the lower computer starts measurement. The measured data is transmitted to the upper computer. At the same time, the serial port between the console and the lower computer can be opened to start capacitance measurement of capacitance experiment. The measured data window receives data and saves the data into EXCEL. The upper computer interface is shown in fig. 7.

![Upper computer interface](image)

**Figure 7. Upper computer interface**

### 3.2 L experimental data of twitch capacitance ranging

The twitch type capacitance experiment uses the vertical direction to twitch the capacitance experiment device. Table 1 below shows the first 8 data of 80mm twitches per 1 mm. Table 2 shows the first 10 data of 160 twitches of 80mm in units of 0.5 mm.

**Table 1. The first 8 data of 80mm twitches made every 1 mm**

| True value/mm | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|---------------|----|----|----|----|----|----|----|----|
| Measured value/mm | 0.2629 | 1.0814 | 2.5885 | 3.2378 | 4.4054 | 5.7320 | 6.8718 | 7.2947 |

**Table 2. The first 8 data of 160 times for every 0.5 mm for 80 mm**

| True value/mm | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Measured value/mm | 0.1972 | 0.6293 | 1.3793 | 1.9920 | 2.6994 | 3.0512 | 3.5344 | 4.2955 |

Fig. 8 is an experimental curve showing a total twitch of 80mm for 80 times per 1 mm .. Among them, the left is a simulation curve established by MATLAB with one experiment data, and the right is a fitting of three experiments. Fig. 9 is an experimental curve of a total twitch of 80mm for 160 times per 0.5 mm. Among them, the left is a simulation curve established by MATLAB with one experiment data, and the right is a fitting of three experiments.
Figure 8. A total of 80mm twitches were made in 80 experimental curves per 1 mm

Figure 9. The experimental curve of 80mm twitch is 160 times per 0.5 mm

4. Conclusion
This paper designs a set of three-dimensional underground displacement measurement experimental device based on twitch capacitance. Through capacitance and mutual inductance coil and the experimental device for measuring inclination angle and azimuth angle, the underground deformation is simulated, and the horizontal and vertical displacement and azimuth angle measurement of the measuring device after the position change are realized. It provides convenience for the research and development of experimental devices for preventing landslides.

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