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A NEW DEVICE FOR PREDICTING LANDSLIDES

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***Abstract-* The primary goal of this paper is to introduce the working principle and the application of a new device for predicting landslides. The attitude of a single sensor comprised of an accelerometer, a gyroscopes and a magnetometers is computed using quaternion algorithm and geomagnetic field. Then, Data from all the sensors converge on the PC. PC computes the coordinate which can reflect the movement of the ground in the reference coordinate system and thus predicts landslides. With the utilization of the device, the safety of life and properties of people will be better ensured.**

Keywords **–** predict landslide; quaternion algorithm; magnetometer; attitude solution; accelerometer; gyroscope

I. INTRODUCTION

Geological disaster does great harm to human being. In the first half of 2011, China has 10710 geological disasters altogether, which has caused 110 people dead or missing, a direct economic loss of 939 million Yuan. Since 1998, there was 3.29 million geological disasters occurred, killed 13925 people and the direct economic loss had reached 61.854 billion Yuan[1]. So the study of geological disaster warning devices is necessary for protecting the safety of the people and reducing the loss of people's property.

This device can predict landslides by monitoring the movement of the ground with accelerometers, gyroscopes and magnetometers. Therefore it can ensure the safety of life and properties of people.

II. THE COMPOSITION OF THE DEVICE

Figure (1) shows the composition block diagram of the device. The device is composed of underground sensor group, microcontroller under the ground, microcontroller on the ground and PC. The sensor uses the MPU-9150[2] integrated chips, which contain MEMS three-axis accelerometer, three-axis gyrometer and three-axis digital compass. It obtains the dynamic inclination and declination, thereby reflects the state of ground motion, and achieve the purpose of early warning of landslide.

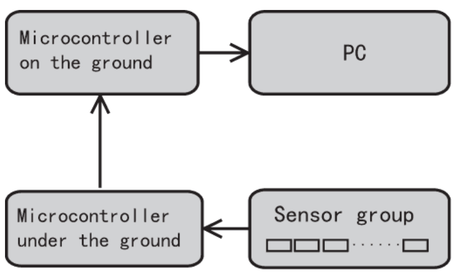

Fig.1 Composition Block Diagram of the Device

III. THE OPTIMUM TCT SOLUTION

The accelerometer and the gyroscope sensor coordinate system (b) is the right-handed coordinate system (XYZ), and the geographic coordinates (n) is ($X_0Y_0Z_0$) as shown in Figure (2). The attitude of the device can be expressed by Yaw (φ), Pitch (θ) and Roll (γ). So the movement of the device can be expressed as follows: Coordinate system ($X_0Y_0Z_0$) rotate to (XYZ). The transform order is Yaw, Pitch and Roll.

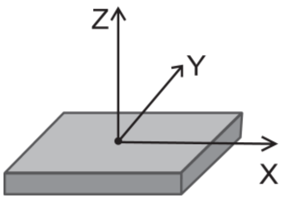

Fig.2 Coordinate System of Accelerometer and Gyroscope

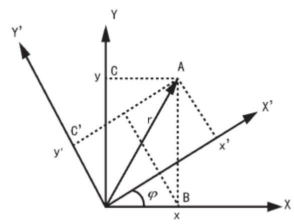

Fig.3 Relationships between the Transformation of Coordinate Systems

Describing rotations with the direction cosine matrix

Given that the coordinate system (OXY) transferred to the coordinate system (OX'Y') by rotating around Z axis counter clockwise, the rotation can be formulated as:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

Direction cosine matrix in the form of the Euler angles of this rotation is shown as follow:

$$C_1^2 = \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

In the similar way, with the geographical coordinates (n) transform to the coordinate system (b), it is easy to get the direction cosine matrix in the form of the Euler angles after three rotation[3]:

$$C_n^b = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \cos\varphi & -\sin\varphi & 0 \\ \sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \cos\gamma\cos\varphi & \sin\gamma\sin\varphi\sin\theta & -\sin\gamma\cos\theta \\ \sin\varphi\cos\theta & \cos\varphi\cos\theta & \sin\theta \\ \sin\gamma\cos\varphi - \cos\gamma\sin\varphi\sin\theta & -\sin\gamma\sin\varphi - \cos\gamma\cos\varphi\sin\theta & \cos\gamma\cos\theta \end{bmatrix}$$

Describing Rotations with Quaternions Differential Equation

Quaternions is a simpler way to describe such rotations of coordinate systems. For example, formula (3) describe that the vector R rotates relative to reference coordinate system and the angle of rotation is θ. The orientation of the rotation is defined by the imaginary part of the quaternions. $\cos\alpha$, $\cos\beta$ and $\cos\gamma$ indicate the value of direction cosine of rotation axis (n) relative to the reference coordinate system.

$$\vec{R'} = \vec{q}\vec{R}q'$$

$$\vec{q} = q_0 + q_1\vec{i} + q_2\vec{j} + q_3\vec{k}$$

$$q_0 = \cos\frac{\theta}{2}$$

$$q_1 = \sin\frac{\theta}{2}\cos\alpha$$

$$q_2 = \sin\frac{\theta}{2}\cos\beta$$

$$q_3 = \sin\frac{\theta}{2}\cos\gamma$$

Solving the Attitude

First, determine the initial quaternion:

$$\begin{bmatrix} q_0(0) \\ q_1(0) \\ q_2(0) \\ q_3(0) \end{bmatrix} = \begin{bmatrix} \cos\frac{\varphi_0}{2}\cos\frac{\theta_0}{2}\cos\frac{\gamma_0}{2} + \sin\frac{\varphi_0}{2}\sin\frac{\theta_0}{2}\sin\frac{\gamma_0}{2} \\ \cos\frac{\varphi_0}{2}\cos\frac{\theta_0}{2}\cos\frac{\gamma_0}{2} - \sin\frac{\varphi_0}{2}\sin\frac{\theta_0}{2}\sin\frac{\gamma_0}{2} \\ \sin\frac{\varphi_0}{2}\cos\frac{\theta_0}{2}\cos\frac{\gamma_0}{2} - \cos\frac{\varphi_0}{2}\sin\frac{\theta_0}{2}\sin\frac{\gamma_0}{2} \end{bmatrix}$$

$\varphi_{0,}\theta_{0,}\gamma_0$ are the initial attitude angles.

Second, given that the gyroscope input is $\Delta\theta = \int_t^{t+\Delta t}\omega_{ib}dt(\mathrm{i} = \mathrm{x, y, z})$, the real-time quaternions can be calculated with the Runge-Kutta two-order method:

$$\begin{cases} Y = q(t) + T\omega_b(t)q(t) \\ K_1 = \omega_b(t)q(t) \\ K_2 = \omega_b(t+T)Y \\ q(t+T) = q(t) + \left(\frac{T}{2}\right) * (K_1 + K_2) \end{cases}$$

Tired, Calculate the attitude matrix according to the real-time calculation of quaternions[4]:

$$C_n^b = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 + q_0q_3) & 2(q_1q_3q_0q_2) \\ 2(q_1q_2 - q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_0q_1 + q_2q_3) \\ 2(q_0q_2 + q_1q_3) & 2(q_2q_2 - q_0q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

Simple expression is:

$$C_n^b = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix}$$

Fourth, after the comparison of the direction cosine matrix in the form of the Euler angles and the attitude matrix expressed by the Quaternions, the attitude angles are obtained:

$$\begin{cases} \theta = \arcsin(T_{32}) \\ \gamma = \arctan\left(-\frac{T_{31}}{T_{33}}\right) \\ \varphi = \arctan\left(\frac{T_{12}}{T_{22}}\right) \end{cases}$$

IV. DIRECTION OF GEOGRAPHIC AZIMUTH

The device detects geomagnetic field with Kirchhoff principle. The orientation of axes of sensitivity for magnetometer is shown in Figure (4). The geomagnetic field is decomposed into three vectors: one is the horizontal vector and other two are perpendicular to the horizontal level and correspond to the three axis of the magnetometer. When the device is titled, the original coordinate system (X,Y,Z) will project to the horizontal plane and the new coordinate system in the horizontal plane is (X_0,Y_0,Z_0) as shown in Figure (5). Therefore, the geographic azimuth θ is the angle between geomagnetic north and X_0-axis.

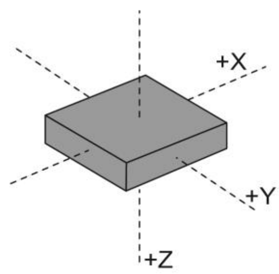

Fig.4 Orientation of Axes of Sensitivity for Magnetometer

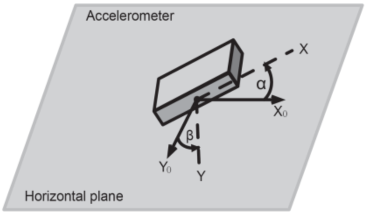

Fig.5 Tilted Sensor

Given that the magnetic force of X, Y and Z axis are H_X, H_Y and H_Z, the magnetic force of X_0, Y_0 and Z_0 axis are H_{X0}, H_{Y0} and H_{Z0}, the geographic azimuth θ can be obtained:

$$\theta = \arctan \frac{H_{Y0}}{H_{X0}}$$

When the sensor is horizontal, the magnetic force of X axis (H_X) and Y axis (H_Y) is the same as that of the X_0 axis (H_{X0}) and Y_0 axis (H_{X0}).

When the sensor is tilted, H_{X0} and H_{X0} should be obtained not by using the H_X and H_Y directly, but by calculating with the α angle and β angle in Figure (5):

The rotation motion can be decomposed into two motions: One is α degree rotation around the Y axis, the other is β degree rotation around the X axis. After the device finished the first motion, H_{X0}' is obtained:

$$H_{X0}' = H_X \cos(\alpha) + H_Z \sin(\alpha)$$

Then, after the device finished the next motion, H_{Y0}' is obtained:

$$H_{Y0}' = H_X \sin(\alpha)\sin(\beta) + H_Y \cos(\beta) + H_Z \sin(\beta)\cos(\alpha)$$

According to the formula, horizontal magnetic declination is

$$\theta = \arctan \frac{H_{Y0}'}{H_{X0}'}$$

Calibration of Geomagnetic Data

Geomagnetic field is relatively weak while magnetic field of external devices is relatively large. This feature results in interferences for the measurement of geomagnetism. Thus, the raw data should be calibrated before it is used to calculate the geographic azimuth.

When the magnetometer rotates in all directions in space, without the interferences of external magnetic fields, `all the measured values are located in the surface of a sphere, whose center is the origin of coordinate. However, external interference of the device to the magnetometer will make the "ball" deviates from the original as shown in Figure (6). In this case, measured magnetic intensity (α) is the comprised of geomagnetic filed intensity (β) and external magnetic field (γ):

$$\alpha = \beta + \gamma$$

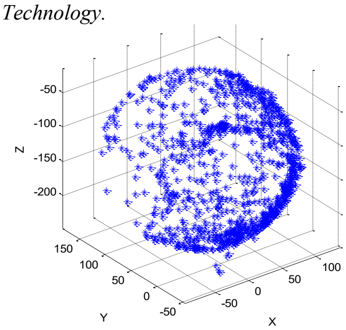

Fig.6 Raw Measured Data

A method to calibrate the data is to find the center of the sphere $O(\gamma_x, \gamma_y, \gamma_z)$ with about 1000 raw data distributed in the surface of the sphere evenly thus obtain the external magnetic field (γ):

$$(X-\gamma_x)^2 + (Y-\gamma_y)^2 + (Z-\gamma_z)^2 = R^2$$

So, a multiplication curve fitting is made and the result is:

$$(X-16.6)^2 + (Y-66.0)^2 + (Z+130.6)^2 = 114.9^2$$

Thus, after every raw data (x, y, z) subtract the center of sphere $O(-16.6, -66.0, 130.6)$ exact geomagnetic azimuth can be obtained according to the formula:

$$\theta = \arctan \frac{H_{Y_0}}{H_{X_0}}$$

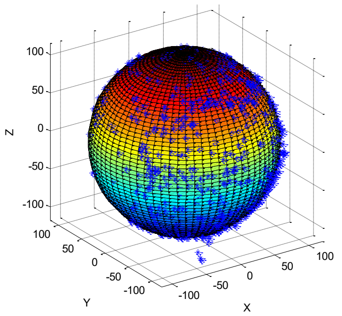

Fig.7 the Data Distribution after Calibration

V. THE WORKING PRINCIPLE OF INCLINOMETER

Figure (8) shows the installation of the inclinometer. The sensors (MPU-9150) are installed at the top of each inclinometer tubes which are linked by removable links one by one. In order to minimize the deviation and to prevent the angle caused by installation from changing, ten tubes are packaged on a layer of polypropylene films and then buried into the soil vertically.

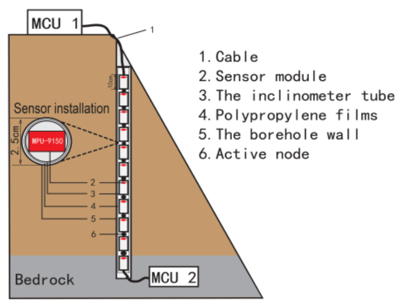

Fig.8 Inclinometer Schematic Diagram

When geological structure is changed, these tubes will be changed accordingly, thus they calculate the geographic azimuth (α_i) and the tilted angle (β_i) sensitively as shown in Figure (9).

Fig.9 Geographic Azimuth and the Tilted Angle

The Calculation of the Overall Displacement and the Deviation Angle

As shown in Figure (10), when the i'th tube moves relative to the (i+1)'th tube, the relative displacement (L_i) can be figured out:

$$L_i = l \cdot \sin\beta_{i-1}$$

In the formula, "l" on behalf of the length of each tube, which is generally assigned by "10 cm". By this way, the geographic azimuths and the tilted angle can be figured out.

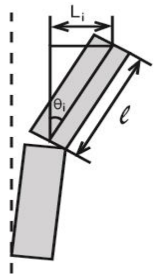

Fig.10 the i'th Tube and the (i+1)'th Tube

However, as the differences among the ten cubes' geographic azimuths, it is false to figure out the overall displacement by add each displacements together. Instead, the displacement is obtained by calculating the liner distance between the beginning spot and the spot that the apex of the last tube projects on the horizontal level as shown in Figure (11).

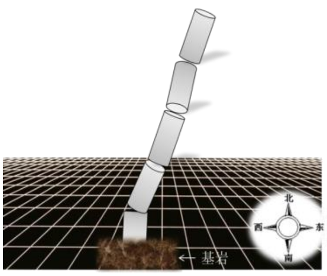

Fig.11 Schematic Diagram of Inclinometer Tube

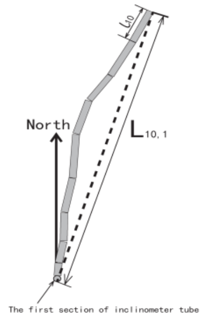

Fig.12 Horizontal Projection of Inclinometer Tube

Taking the situation of the ten tubes deviate to the first quadrant of the geographical location map (in Figure 9) as an example, the process of calculating the overall displacement is introduced as follow.

The overlooking picture of tubes projecting on the horizontal level has been given in Figure (12) for the convenience of observation. The length of each tube (L_i) can be figured out:

$$L_i = l \cdot \cos\beta_{i-1}$$

First, calculate the displacement between the first tube and the second tube. The first tube is buried into the bedrock, so it cannot slant and its projection to the horizontal plane is a point. Therefore, the displacement of the second tube relative to the first one is the length of the projection line of the tube in the horizontal plane as shown in Figure (13),

$$L_{21} = l_2$$

$$\gamma_1 = \alpha_2$$

In the formula, γ_1 is the overall deviation angle of the second tube relative to the first one.

Figure (13) shows the way of calculating the third tube's displacement relative to the first one with the law of cosine.

$$L_{31} = \sqrt{l_2^2 + l_3^2 - 2 l_2 l_3 \cos(\pi + |\alpha_2 + \alpha_3|)}$$

$$\begin{cases} \gamma_2 = \alpha_2 + \arccos\left(\dfrac{l_2^2 + L_{31}^2 - l_3^2}{2 l_2 L_{31}}\right)(\alpha_2 > \alpha_3) \\ \gamma_2 = \alpha_2 - \arccos\left(\dfrac{l_2^2 + L_{31}^2 - l_3^2}{2 l_2 L_{31}}\right)(\alpha_2 < \alpha_3) \end{cases}$$

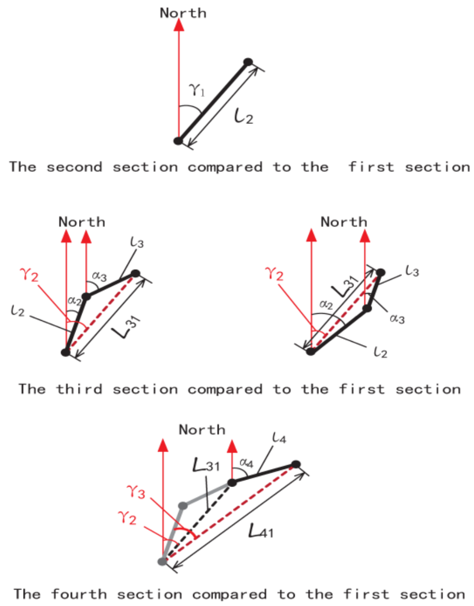

Fig.13 Schematic Diagram of the Calculation

The displacement of the fourth tube relative to the first one (L_{41}) can be calculated by reusing the formula above after replace l_2 and α_2 with L_{31} and γ_2. Finally, we can calculate the displacement of the tenth tube relative to the first one by the repetitive use of these formulas:

$$L_{41}=\sqrt{L_{31}{}^2+l_4{}^2-2L_{31}l_4\cos(\pi+|\gamma_2+\alpha_4|)}$$

$$L_{51}=\sqrt{L_{41}{}^2+l_5{}^2-2L_{41}l_5\cos(\pi+|\gamma_3+\alpha_5|)}$$

$$\vdots$$

$$L_{10,1}=\sqrt{L_{91}{}^2+l_{10}{}^2-2L_{91}l_{10}\cos(\pi+|\gamma_8+\alpha_{10}|)}$$

And the overall geographical azimuth is

$$\begin{cases}\gamma_9=\gamma_8+\arccos(\dfrac{l_{91}{}^2+L_{10,1}{}^2-l_{10}{}^2}{2L_{91}L_{10,1}})(\gamma_8>\alpha_{10})\\ \gamma_9=\gamma_8-\arccos(\dfrac{l_{91}{}^2+L_{10,1}{}^2-l_{10}{}^2}{2L_{91}L_{10,1}})(\gamma_8<\alpha_{10})\end{cases}$$

At the same time, we can build a reference frame whose x axis direction is east, y axis direction is north, z axis direction is up and the ordinate origin is the point of the bottom of the first tube. In this reference frame, the coordinate（x, y, z）of the tenth tube can be figured out as follows:

$$(L_{10,1}\cdot\sin\gamma_9,\ L_{10,1}\cdot\cos\gamma_9,\ H)$$

$$H=\sum_{i=1}^{10} l\cdot\sin\beta_i$$

VI. LABORATORY RESULT

In experiment environment, tests were taken in order to prove the accuracy of the measurement of angles.

Step1

With the values of Roll and geographic azimuths unchanged, we change the given value of Pitch and record the corresponding measured values as shown in table (1):

TABLE1 PITCH DATA

Pitch Given value (°)	0	30	60	120	180	240	270	300
Pitch Measu-red value (°)	0	29.81	59.84	119.85	179.90	240.11	270.09	300.12

Step2

With the values of Pitch and geographic azimuths unchanged, we change the given value of Roll and record the corresponding measured values as shown in table (2):

TABLE2 ROLL DATA

Roll Given value (°)	0	30	60	120	180	240	270	300
Roll Measu-red value (°)	0	30.02	60.03	120.02	180.05	240.04	270.04	300.05

Step3

With the values of Roll and Pitch unchanged, we change the given value of geographic azimuths and record the corresponding measured values as shown in table (3):

TABLE3 GEOMAGNIFICANT AZIMUTHS DATA

Given value (°)	0	30	60	120	180	240	270	300
Measu-red value (°)	0	29.1	68.9	119.0	180.2	241.5	271.8	301.4

According to the table 1, table 2 and table 3, errors of three angles are small. So it is viable to detect slight movement of the ground.

VII. CONCLUSIONS

With the rapid development of new technology and improvement of the devices relative to the prediction of natural disaster, systems of predicting disaster are becoming more and more perfect. Compared with the traditional inclinometer, this device can be more sensitive to reflecting real-time changes of ground and can save manpower and material resources, thus can be better used in landslide monitoring, disaster warning and promote the disaster monitoring technology to be automatic and digital.

ACKNOWLEDGMENT

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REFERENCES

[1] Ministry of National Defense of the People's Republic of China, “Statistical Data of Land and Resources in the First Half of 2011”.

[2] InvenSense Inc., “MPU-9150 Product Specification Revision 4.0”.

[3] QIN Yongyuan, “Inertial Navigation”, Beijing: Science Press, pp.5-8. ISBN: 7-03-016428-8.

[4] ZHANG Rong-hui, JIA Hong-guang, CHEN Tal, ZHANG Yue, “Attitude Solution for strapdowm inertial navigation system based on quaternion algorithm” Optics and Precision Engineering, Vol.16 No.10 Oct.2008.