An Inertial Measurement Unit Application for a GPR Tracking and Positioning

V.Prokhorenko, V.Ivashchuk, S.Korsun, O.Dykovska
VIY, Transient Technologies Company
P.O.Box 28, Kyiv 02147, Ukraine
E-mail: pvp@viy.com.ua

Abstract

Abilities of an inertial measurement unit (IMU) for ground penetrating radar (GPR) tracking and positioning are presented at this paper. The IMU operation principle is based on calculating of the device's orientation in space via measurement of linear accelerations and angular velocities. Features of the IMU, GPS and wheel odometer are compared. Principal scheme of the IMU consisted of low-g three-axis MEMS accelerometer; three acoustic gyroscopes and CPU with USB interface are described. It is shown that the IMU providing six coordinates (Cartesian and angular) allows to improve GPR trace positioning in space and to approach GPR profile presentation to real surface configuration. The IMU application simplifies the 3D mapping of the GPR surveying because of reducing of preparation time of the GPR system for measurements execution and fulfilling the field sounding in arbitrary mode. Since each radar waveform is matched with corresponding coordinate set the radar profiles reflect real surface and sounding direction. The IMU provides high precision GPR positioning for various test areas including tunnels, basements, caves, rough surfaces, etc. Experimental results of the IMU prototype examination are presented also.

Introduction

Quality of the GPR surveying is depended on conformity of sounding traces to real position on the surface. It is desired to know topographic coordinates of the sounding points. And knowledge of the GPR antenna system location concerning to sounding surface provides more data for the GPR profile reconstruction.

The GPR data positioning influences on the GPR profile quality representation. Examples of the profile representation with different topography data representation are shown on Fig. 1.

The simplest tracking unit is odometer (measurement wheel), which provides one coordinates – linear movement of the GPR across survey surface. In this case the GPR profile displays set of traces with the same zero level. This simplification is acceptable for roads sounding and similar applications where surface tilts are insignificant. Otherwise distortion of a target area response is observed (Fig. 1b). At present the method is widely used owing to use simplicity.

The Global Positioning System (GPS) application proposes more flexibility for the GPR surveying. It provides three Cartesian coordinates that allow the GPR traces arrangement in according with relief peculiarities. However some drawbacks limit the GPS applicability. There are insufficient precisions of commercial GPS, high prices of differential GPS, inabilities of operation in closed or radio opaque spaces (basements, tunnels, mines, caves, forests, etc.) And again the GPS doesn't provide information about the GPR antenna system position on the surface (yaw, pitch and roll angles). Therefore the GPS applicability is still limited by plain open spaces. The target shape and position is disfigured when uneven surface is examined (Fig. 2c).

An inertial measurement unit (IMU) presents complete information about the antenna system location in the space [1]. There are three Cartesian coordinates and three angular coordinates (turns) that present true antenna system location and orientation concerning the surface. The IMU is able to provide new quality level of the GPR data positioning. It provides maximum agreement between GPR profile and sounding medium (Fig. 1c).

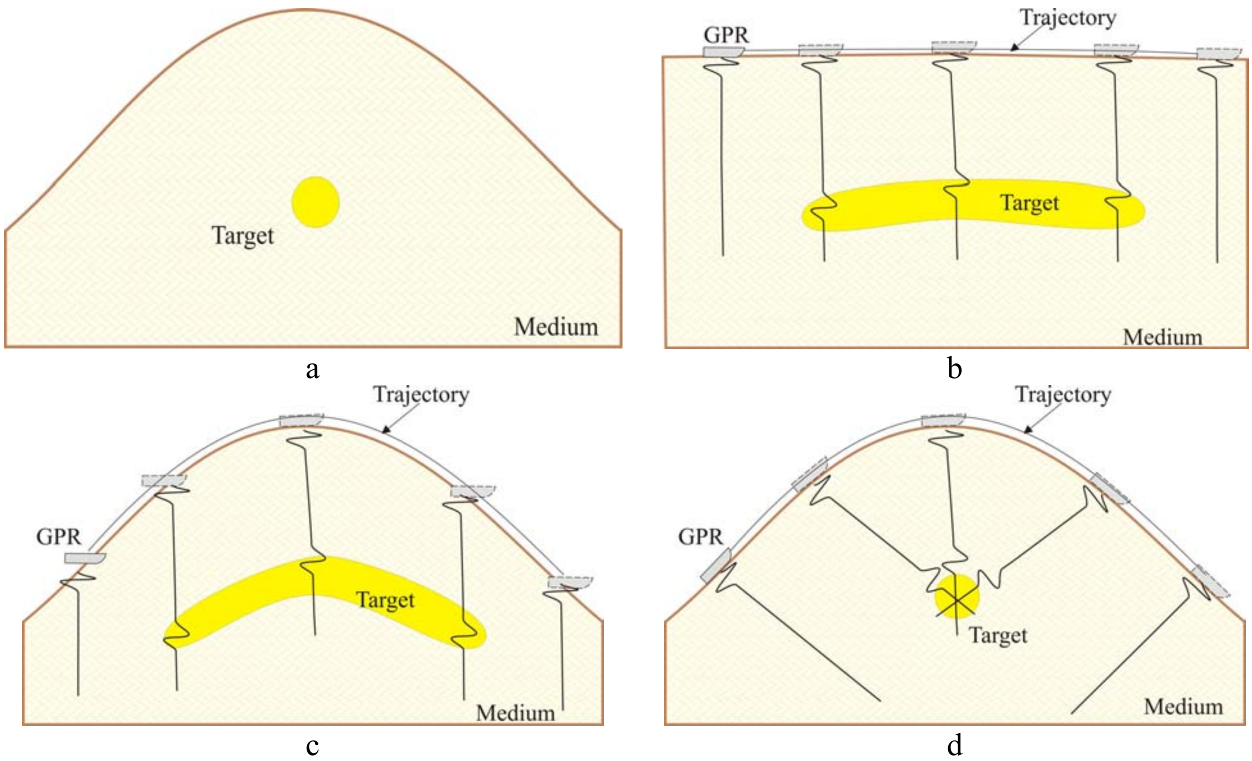

Figure 1. Model of the GPR data representation for different positioning methods: initial field model (a), GPR profiles based on odometer (b), GPS (c) and IMU (d) topographic data.

Development and examination of the IMU for the GPR tracking and positioning is a main goal of this paper.

The Inertial Measurement Unit

The Inertial Measurement Unit (IMU) calculates six coordinates (linear and angular) based on acceleration and rotation velocity measurements. Accelerometers measures linear accelerations, and gyroscopes measures rotation velocities. As a result true position of the GPR antenna system can be evaluated.

The GPR tracking procedure starts with calibrating process. The GPR should set motionless that all transients are finished and gravitation components (G_{x0}, G_{y0}, G_{z0}) are measured. After that initial angles of the GPR antenna system position are calculated (Fig. 2).

$$|\mathbf{G}| = G = \sqrt{G_{x0}^2 + G_{y0}^2 + G_{z0}^2} \quad (1)$$

$$\varphi_0 = arctg\left(\frac{G_{y0}}{G_{x0}}\right),$$
$$\psi_0 = arctg\left(\frac{G_{z0}}{G_{y0}}\right), \quad (2)$$
$$\theta_0 = arctg\left(\frac{G_{x0}}{G_{z0}}\right).$$

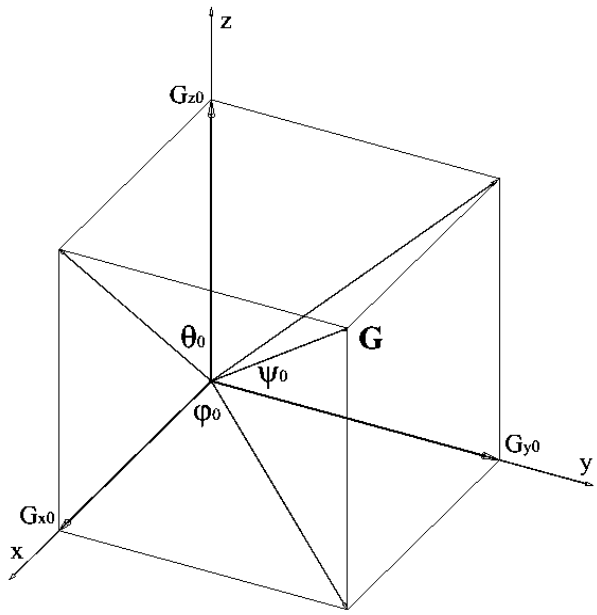

Figure 2. Components of gravitation vector

After the calibration the GPR tracking can be started. The IMU measures linear accelerations and angular velocities. Turns of the GPR antenna system are calculated with output signals of corresponding gyroscopes.

$$\Delta\varphi = \int Gyro_{\varphi}(t)dt,$$
$$\Delta\psi = \int Gyro_{\psi}(t)dt, \qquad (3)$$
$$\Delta\theta = \int Gyro_{\theta}(t)dt.$$

where

$Gyro_{\varphi}(t)$ gyroscope output signal by φ angle, proportional to angular velocity around z-axis;

$Gyro_{\psi}(t)$ gyroscope output signal by ψ angle, proportional to angular velocity around x-axis;

$Gyro_{\theta}(t)$ gyroscope output signal by θ angle, proportional to angular velocity around y-axis.

Both gravitation and acceleration because of movement are applicable to the GPS antenna system.

$$\mathbf{F} = \mathbf{G} + \mathbf{A}, \qquad (4)$$

where **G**, **A** and **F** are vectors of gravitation, acceleration and complete acceleration, accordingly.

The three-axis accelerometer allows measuring the complete acceleration vector **F**. The current value of the gravitation vector **G** can be calculated if turns of the GPR antenna system are known.

$$\varphi_n = \varphi_0 + \Delta\varphi,$$
$$\psi_n = \psi_0 + \Delta\psi, \qquad (5)$$
$$\theta_n = \theta_0 + \Delta\theta.$$

where

$\varphi_0, \psi_0, \theta_0$ are initial turn angles of gravitation vector **G** around respective axis;

$\varphi_n, \psi_n, \theta_n$ are current turn angles of gravitation vector **G** around respective axis;

$\Delta\varphi, \Delta\psi, \Delta\theta$ are angle increments, measured by gyroscopes.

$$G_x = \frac{G}{\sqrt{1 + tg^2\varphi_n + tg^2\theta_n}},$$
$$G_y = \frac{G}{\sqrt{1 + tg^2\varphi_n + tg^2\psi_n}}, \quad (6)$$
$$G_z = \frac{G}{\sqrt{1 + tg^2\psi_n + tg^2\theta_n}}.$$

where G_x, G_y, G_z are gravitation vector components, G is amplitude of gravitation vector **G**, acquired during calibrating process.

Current values of linear acceleration vector is calculating as

$$A_x = F_x - G_x,$$
$$A_y = F_y - G_y, \quad (7)$$
$$A_z = F_z - G_z.$$

where

A_x, A_y, A_z are components of acceleration vector **A**,

F_x, F_y, F_z are components of complete acceleration vector **F**,

G_x, G_y, G_z are components of gravitation vector **G**.

Current position of the GPR antenna system is evaluated by integration of the acceleration vector components.

$$L_x = \int dt \int A_x(t)dt,$$
$$L_y = \int dt \int A_y(t)dt, \quad (8)$$
$$L_z = \int dt \int A_z(t)dt.$$

The IMU Prototype

We developed IMU prototype that consists of three-axis accelerometer, three gyroscopes, data acquisition system, processing unit and USB interface (Fig. 3).

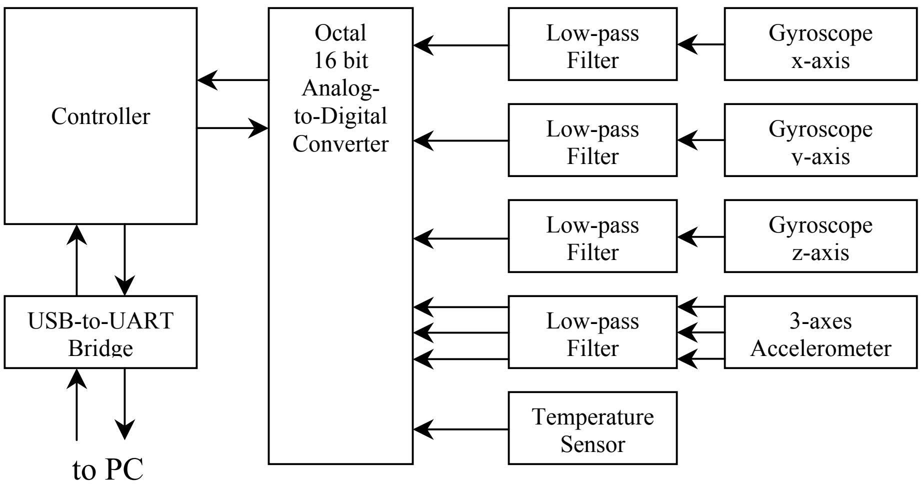

Figure 3. Block scheme of the IMU

Accelerations and rotation velocities are conditioned by low-pass filters, transform to digital and passed to computer along with temperature data. Computer makes advanced data processing (signal filtration, integration, normalizing etc.) and calculates current Cartesian coordinates of the GPR antenna system. The coordinates are added to the corresponding GPR trace. This allows making the GPR antenna system movement in arbitrary direction.

Low-pass filters limit fast response of the accelerometers and gyroscopes with 5Hz frequency in order to reduce influence of the GPR vibration during its movement by rough surface. Communication between PC and the IMU is realized via USB 2.0 interface.

For the IMU prototype we used MMA7260Q accelerometer by Freescale Communications, ENC-03R gyroscopes by Murata Manufacturing Co., Ltd., ADS8344 analog-to-digital converter by Texas Instruments, P89LPC916FDH microcontroller by NXP Semiconductors and CP2102GM USB-to-UART Bridge by Silicon Laboratories. Photography of the prototype is shown on the Figure 4.

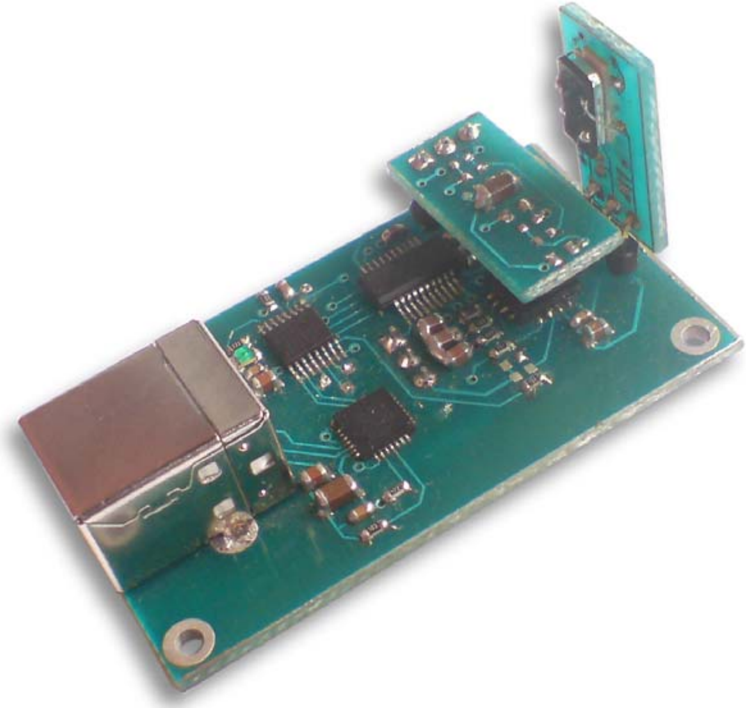

Figure 4. Photography of the IMU prototype

Experimental Results

A first result of the IMU examination is consideration of slope angle of the GPR antenna system. The dam of Kremenchug hydroelectric power station reservoir was a survey object. The goal was search of cavities under reinforced concrete plates with 15-cm thick (Fig. 5). The VIY 2-350 GPR was used for this purpose. Sounding depth was 5 meters.

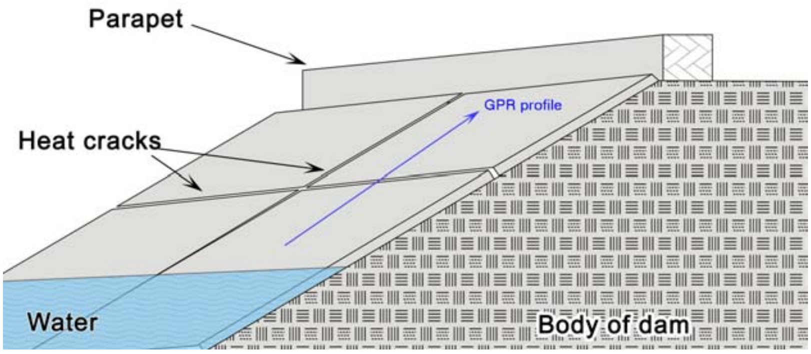

Figure 5. The dam configuration.

The Figure 6 shows GPR profile without (a) and with (b) the GPR slope angle consideration. It is shown that the GPR profile arrangement in accordance with antenna system slope angle improves representation of the targets (cavity and water level).

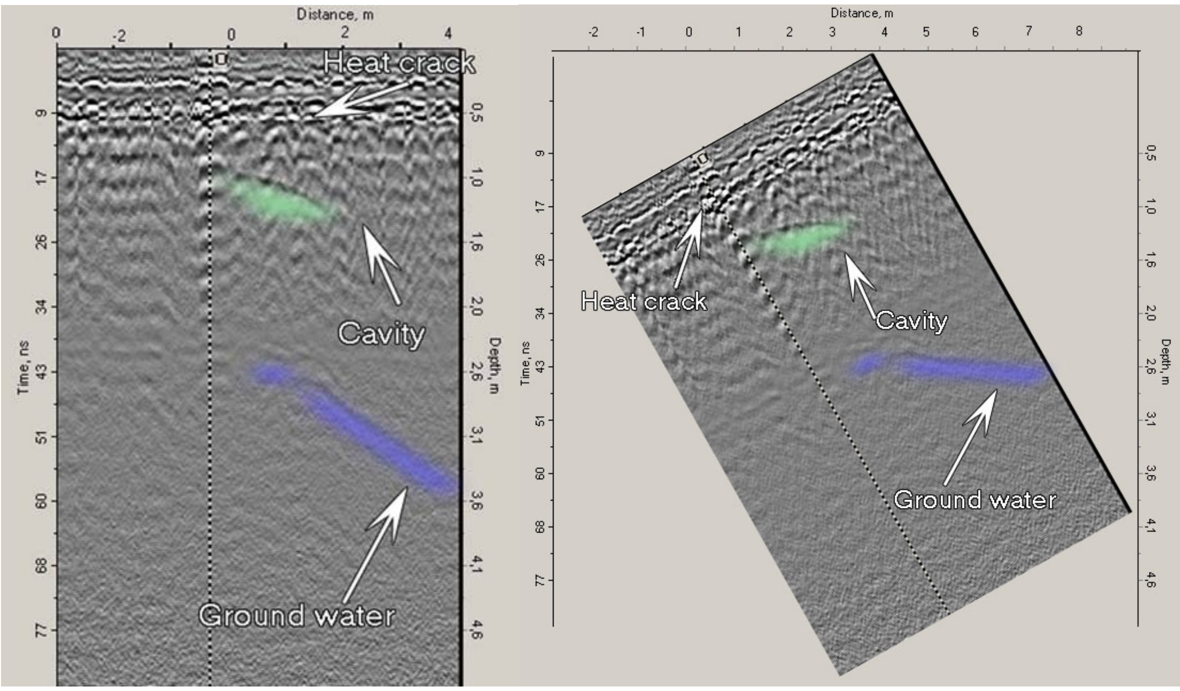

Figure 6. The initial (a) and slope angle corrected (b) GPR profile

Conclusions

Examinations of the IMU prototype show the following:

- Inertial measurements can be used for the GPR tracking and positioning;
- Temperature brings drifts of the output signals. It should be eliminated by temperature compensation or stabilization;
- Integration leads to very slow output signal fluctuation. It is necessary digital filtering application;
- The IMU simplifies the GPR surveying process and reduces deployment time;
- True 3D GPR profiling is possible with the IMU positioning data utilization.

The IMU prototype and appropriate software are still under development and further examination. We assume that this research will be result to commercial device suitable for field GPR surveying and building true 3D profiles.

References

1. "GPS-IMU: Development of a High Accuracy Pointing System for Maneuvering Platforms", Joseph M. Strus, Michael Kirkpatrick, and James W. Sinko, InsideGNSS, March/April 2008, pp. 30-36 (www.insidegnss.com)