Underwater Datalogger for Accurate Position and Location Estmation and Tracking

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***Abstract*— In this poster, we show the design of an underwater datalogger that can achieve accurate position and location estimation and tracking on the order of centimeters. The prototype of underwater datalogger utilizes a 9-axis inertial measurement unit (IMU) and a microcontroller, which is housed in a sphere with a diameter of 11 cm. A novel calibration procedure is developed to achieve the accuracy and precision which is of great importance in civil engineering experiments that measure water flow and sediment movement.**

Keywords—waterflow measurement, underwater datalogger, path tracking, IMU data process

I. Introduction

Lab experiments in civil engineering often require particle tracking in water flow and other underwater environments. Particle tracking may be achieved by several methods. One is the velocimetry method which measures velocity of particles in a fluid by a laser Doppler profiler. The profiler is usually installed at a fixed location and can track some seeded particles passing through the imaging plane of the laser profiler.

Another method is the inertial measurement unit (IMU) sensor in an underwater datalogger. The datalogger may be mixed with other particles in the experiment and flow through the course of the experiment. Their acceleration and angular velocity are individually recorded by the IMU and their position and locations are derived.

Compared with laser sheets, datalogger has few advantages: 1) low cost, 2) works longer, 3) works in high particle density. However, the challenges of IMU datalogger include: 1) the size of the datalogger must be small to be comparable with the other particles in the experiment; 2) deriving the position and location of the dataloggers from their IMU measurement involves integration of the acceleration twice which often results in huge error. This work prototyped a small datalogger with a size of 11 cm diameter sphere, and developed a novel calibration procedure to achieve centimeter-level accuracy in position and location estimation.

II. Design of Datalogger

The hardware of the datalogger consists of a coin battery, inertial measurement unit board and the microcontroller board, as shown in figure 1. The inertial measurement unit provides angular velocity and acceleration data. The microcontroller controls the inertial measurement unit and record the measured data in its flash memory.

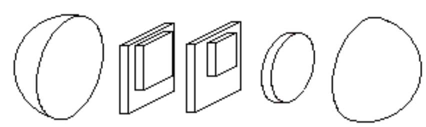

Fig. 1. Strcture of the datalogger

A few different connections are used in the datalogger design. Between PC and datalogger, JTAG connection are used for programing the datalogger, UART connection are used for downloading command and uploading data.A GUI program is designed for users to send command and download data via a UART connection between a PC and the datalogger.

A program to process the data is designed for underwater path tracking experiments researchers. Since the output of IMU is not the real acceleration and real angular velocity, the program do calibrations when processing data. For common IMU, the angular velocity data contains real angular velocity, earth rotation, system errors and random errors. The acceleration data contains real acceleration, earth gravity, system errors and random errors. In civil engineering underwater experiment data calibration, the earth rotation and random errors could be ignored. Other terms should be removed. A simple experiment is needed for calibration. Researchers need to put datalogger in a cube. Put the cube on same location on a stable plain by it six different surface. Then record six different acceleration data $\boldsymbol{a}_{1\sim6}$, and six angular velocity data $\boldsymbol{\omega}_{1\sim6}$. Then program follows the following steps to process data.

A. Angular velocity calibration

When the datalogger lies on the plain, every term except system errors in angular velocity data turns into zero, thus the average value is the system error. Remove it from data.

$$\boldsymbol{\omega}_{system\_error} = \text{average}(\boldsymbol{\omega}_{1\sim6}) \quad (1)$$

B. Position process

After removing the system errors from angular velocity data, we have the angular velocity. By using the DCM method, we got the rotation in every moment and then the position in every moment. Take $\boldsymbol{R_n}$ as the rotation matrix at the nth moment. Then the DCM matrix for the ith moment is

$$\boldsymbol{L_i} = \boldsymbol{L_0}\prod_{j=0}^{i-1}\boldsymbol{R_j} \quad (2)$$

C. Acceleration calibration

The system error in the acceleration data stay as a constant value while the earth gravity changes with the position. When the cube lies on one surface, the acceleration became zero and the data is

$$\boldsymbol{a_i} = \boldsymbol{a}_{system\_error} + \boldsymbol{L_i G} \quad (3)$$

Note for the opposite surfaces, the value in DCM matrixes are opposite. Thus, the system error is

$$\boldsymbol{a}_{system\_error} = \text{average}(\boldsymbol{a_i}) \quad (6)$$

Since the vector of earth gravity keeps pointing to the ground. It can be removed easily after processing rotation. The real acceleration in the ith moment became

$$\boldsymbol{a} = \boldsymbol{L_i}(\boldsymbol{a}_{data} - \boldsymbol{a}_{system\_error}) - \boldsymbol{G} \quad (7)$$

D. Location process

The result of integrate the acceleration twice is the location of the datalogger. Even if the gravity and the system error in acceleration data is removed, the random error in double integration may cause collapse in the location. The velocity at the beginning and the end should be zero. And the total distance $\boldsymbol{S}$ that the datalogger moved can be measure. Then removing a constant from the acceleration data can help to process location. If the total time steps is i, he velocity and the location will be

$$\boldsymbol{v} = \int \boldsymbol{a} - \text{average}(\boldsymbol{a})dt$$

$$\boldsymbol{S} = \int \boldsymbol{v} - \text{average}(\boldsymbol{v}) + \boldsymbol{S}/N\, dt$$

III. Initial Results

We made few dataloggers which can record the acceleration and angular velocity for 416s at 100 Hz sampling rate. The datalogger is housed in a 11 cm sphere designed by 3D printer, as shown in figure 2.

Fig. 2. Datalogger for testing

For data processing, we made breakthrough in the angular velocity part. The result of the process shown the position of the datalogger. Figure 3 shows the path of three axes in one of our experiments.

Fig. 3. Path of three axes

But as figure 4 shown, the result of acceleration process still not able to show the path of the datalogger. Thus we are still looking for a way to minimize the error of acceleration.

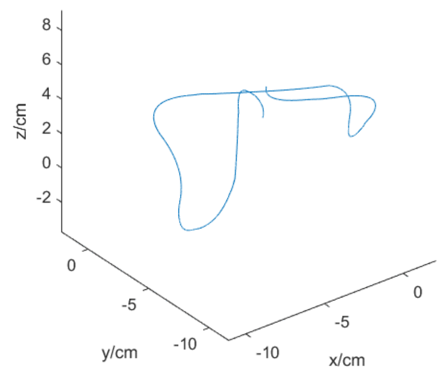

Fig. 4. Path of datalogger

IV. Concluding Remarks

The current biggest challenge of this project is to process the acceleration data. The error should be small enough to prohibit the collapse in double integration. A higher quality calibration is needed.

Another important improvement could be minimize the size of the datalogger. The current datalogger for testing are in size of 20 mm. In the particle tracking method for water flow tracking, the particle should be small enough to move with the water. The current datalogger could be used in an experiment that study how river flow interacts with the rocks.