Desain of Multi-sensor IMU for Land Vehicle

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Design of Multi-sensor IMU for Land Vehicle

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***Abstract*—Inertial Measurement Unit (IMU) to measure the angular rate and acceleration in three axes is an important part of the land vehicle navigation control system. Land vehicle motion has more wide range of acceleration in x axis and angular rate in z axis than the other axis. A sensor with high sensitivity has a short range of measurement, and vice versa. To get the optimum sensitivities of all sensors, multi-sensor system should be applied in wide range of motion. The main components of IMU are microcontroller, gyroscope, and accelerometer. Micro-controller received two accelerations data in x axis and two anguler rate data in z axis. Selecting algorithms of sensor data are used to obtain six Degree of Freedom (6-DOF) of land vehicle. IMU was tested using variation of acceleration and angular rate motion, and shown that the proposed method gives the angular rate and acceleration data with the higher sensitivity. IMU has good linearity of measurement in acceleration and angular rate. This system can be used to look at the driver when he accelerate or brake suddenly.**

Keywords*—*IMU; multi-sensor; selecting algorithm; sensitivity

I. Introduction

IMU which be applied in many navigation systems such as for mobile platforms [1], spin-stabilized of sounding rocket [2], autonomous of vehicle navigation [3], and personal navigator [4] uses either the accelerometer or the gyroscope or both as the main component. Gyroscope, the angular rate sensor, and accelerometer, the acceleration sensor, are used to detect the rotational motion and the translational motion, respectively. In general, sensor has limited range of measurement, so a sensor with high sensitivity has a short range of measurement, and vice versa. The land vehicle IMU requires a high sensitivity and wide range of measurement therefore we proposed multi-sensor system that should be applied in IMU design. Various methods to get wide range of measurement have been proposed in the literature using free gyro system from 9 accelerometers [5,6] to 13 accelerometers [7]. Kalman filter has been used to estimate sensor parameter [2], error of parameter [3], and to remove noise [8]. Exponential filter is used to remove noise [9] and double exponential smoothers run faster than Kalman filter in equivalent prediction performance [10]. This paper propose methode for width range mesurement and improve the sensitivity. This paper is organized as follows. The underlying is presented in Section II. Section III details the design of hardware and software of IMU proposed in this paper. Experimental results are given in Sections IV. Finally, Section V summarizes the main conclusions of this paper.

II. The Underlying

A. Motion of Land Vehicle

The land vehicle has 6-DOF, translational and rotational, along and about the land vehicle axes. The acceleration and angular rate sensors are used to detect the translational and rotational motions, respectively. The wide range of acceleration in x axis and rotation in z axis can be divided into 2 segments proportionally as shown in Fig. 1 and Fig. 2.

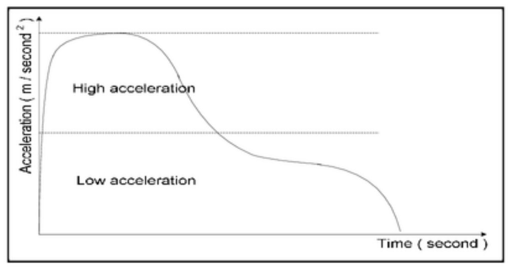

Fig. 1. Acceleration level.

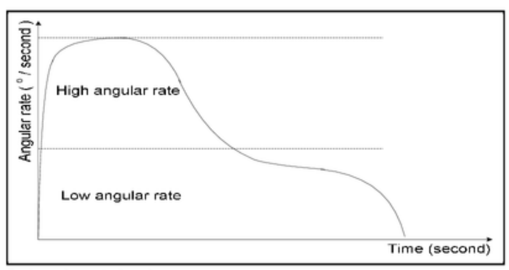

Fig. 2. Angular rate level.

B. Sensors

Design of multi-sensor IMU used 2 types of gyroscope, i.e. LPR503AL and LPR530AL, and an accelerometer, i.e. MMA7361L. The gyroscopes are low cost, low current, and has good resistance to shock. LPR503AL and LPR530AL are

2-axis gyroscope sensor with angular velocity ± 30°/s and 1-axis gyroscope sensor with angular velocity ± 300°/s respectively. The sensors can be operated by a voltage range between 2.7 V and 3.6 V and a temperature range between -40° C and +125° C. Sensor will damages despite of the shock acceleration is up to ±3000 g. The MMA7361L has signal conditioning, a 1-pole low pass filter, temperature compensation, and g-select which allows for the selection between 2 sensitivities. Sensitivity can be selected between 800 mV/g and 206 mV/g at maximum acceleration to ± 1.5 g and at maximum acceleration to ± 6g, respectively. Sensor will not be damaged despite the shock acceleration up to ± 500g and be operated at a temperature of -40° C to +125° C.

C. *Microcontroller*

XMega128A1 is a microcontroller which has a speed of 1 million instructions per second (MIPS) per 1 MHz crystal frequency. This microcontroller is equipped with an internal crystal with a frequency of 32 MHz and has six 8-bit ports, i.e. port A to port F. There are 2 ports, namely A and B ports, which can be used as an ADC input. There are 4 ports that can be used as serial ports, i.e. C, D, E, and F ports respectively.

III. Design of IMU

Design of IMU have been done for two steps: (1) Design of hardware and (2) Design of software.

A. *Design of Hardware*

IMU employs 4 gyroscopes and 4 accelerometers. Two gyroscopes and 2 accelerometers are in z axis and in x axis, respectivelly, and in the other axes, we use a gyroscope and an accelerometer. Outputs of 4 accelerometer and 4 gyroscopes are received by microcontroller via port A and port B, respectively. However, the outputs of sensor have much noise and to reduce it used the analog low pass filter. Digital data of sensors are selected to obtain of 6 DOF and filtered digitally by exponential filter. Design of IMU is shown in Fig. 3.

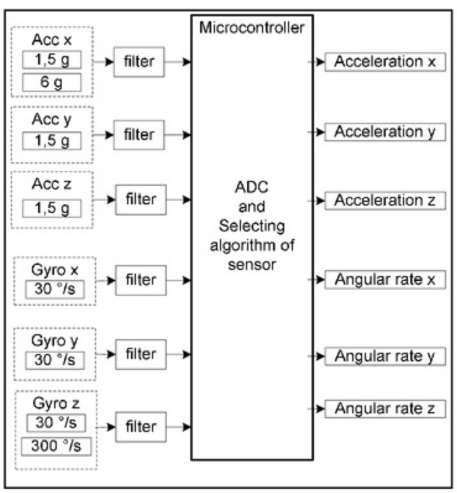

Fig. 3. Design of IMU.

Hardware of multi-sensor IMU is shown in Fig.4.

Fig. 4. Hardware of IMU.

Before applied in land vehicle, IMU shoud be calibrated. The three-axis motion simulator model ST-3176-TC-10 was used to calibrate IMU. This simulator is a high accuracy position and rate system designed for the test and calibration of high performances inertial guidance systems, combined technology guidance equipments, inertial grade sensors. The fist axis, inner or roll axis has a max rate 1000 °/s. The second axis, middle or pitch axis has a max rate 600 °/s. The third axis, outer or yaw axis has a max rate 400 °/s. The resolutions of all axes are 0.00001. Calibration process was done under the room temperature. Before calibration, IMU should be installed in chamber of standard device and connected with all data cable and power supply to computer via DB 25 connector. Fig. 5 shows three-axis motion simulator.

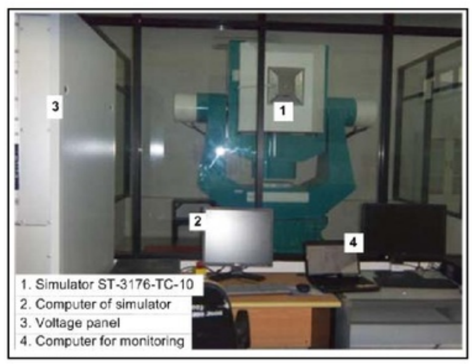

Fig. 5. Three-axis motion simulator.

Experiment setup of gyroscope and accelerometer calibration was divided into two steps which calculate scale factors and run test the calibrated sensors. Algorithm to calculate scale factors is as following; 1) rotate the chamber as the axis and angle target determined, 2) read all sensor data and calculate the sensitivity and scale factor. The algorithm to run test of IMU can be summarized in the following steps; 1) use the calibration result of each sensor, 2) rotate the chamber in three-axis as the angle target determined, 3) compare the measurement angle using IMU and the angle target.

B. *Design of Sofware*

Algorithm of Selecting the Sensor Data (SSD) is used to select sensors with higher sensitivity. The SSD algorithms for angular rate and acceleration are shown as flowchart in Fig.6 and Fig.7, respectively. The microcontroller reads all of acceleration and angular rate data of all the sensors that are used. The data were taken from the sensor with higher sensitivity, in order to obtain more accurate of measurement results.

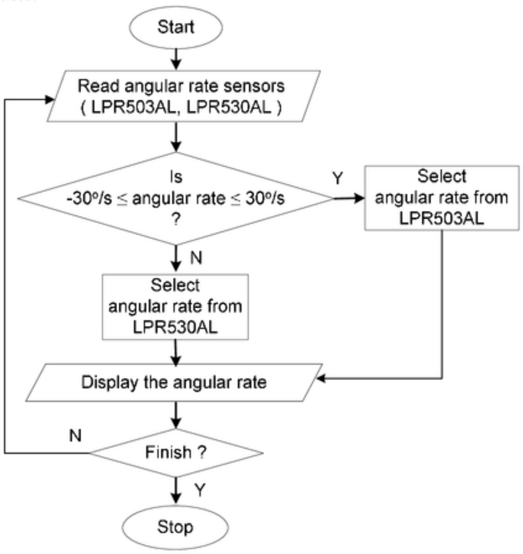

Fig. 6. Flowchart of selecting anguler rate data.

Microcontroller read angular rate data from LPR503L and LPR530L. If angular rate is more or equal than -30° or less or equal 30°, angular rate data will be display from LPR503L.

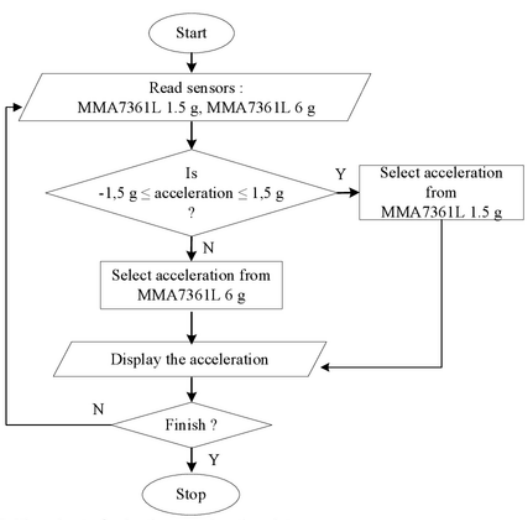

Fig. 7. Flowchart of selecting acceleration data.

Microcontroller acceleration data from MMA7361L 1.5 g and MMA7361L 6 g. If acceleration is more or equal than -1.5 g or less or equal 1.5 g, acceleration data will be display from MMA7361L 1.5 g.

IV. Experiment Results

Testing of SSD algorithm with certain acceleration is done on MMA7361L 1.5 g and MMA7361L 6 g. Testing of IMU with certain acceleration is worked by giving shocks to the sensor when the sensor has an acceleration of 1 g and -1 g until acceleration data of MMA7361L 1.5 g is clipped. Fig. 8 shows the testing of the SSD algorithm on certain acceleration. Result shows that MMA7361L 1.5 g is limited to a certain value, while MMA7361L 6 g can still detect the acceleration. Fig. 9 shows the result of the selection of acceleration sensors which is shown in Fig. 8 by using the SSD algorithm.

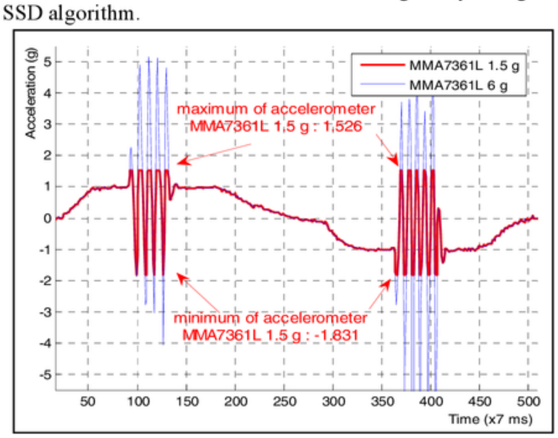

Fig. 8. Acceleration on the test of SSD algorithm.

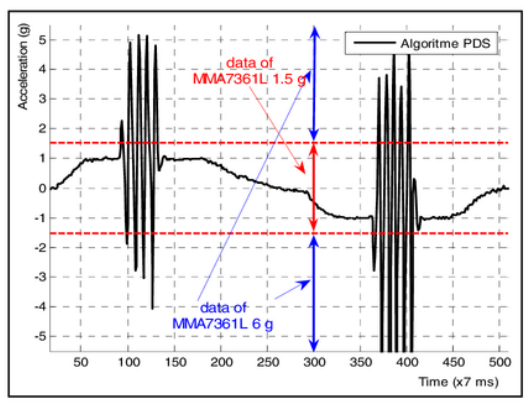

Fig. 9. Acceleration by SSD algorithm.

SSD algorithm selects the sensor data from MMA7361L 1.5 g when the acceleration is between -1.5 g and 1.5 g. When MMA7361L 1.5 g and 1.5 g MMA7361L can detect acceleration that is between -1.5 g and 1.5 g, SSD algorithm selects the data from the sensor with higher sensitivity. When acceleration is greater than or equal to 1.5 g or acceleration is smaller or equal to -1.5 g, SSD algorithm selects the data from MMA7361L 6 g. MMA7361L 1.5 g was used in normally drive of land vehicle and MMA7361L 6 g can be used to look at the driver when he accelerate or brake suddenly.

Testing of SSD algorithm with a certain angular rate is applied to LPR503AL and LPR530AL. Testing is done by rotating the IMU in the clockwise (CW) and counterclockwise (CCW) with certain angular velocity, until LPR503AL and LPR530AL reach the minimum and maximum limits. Fig. 10 shows the angular rate of the three gyroscopes when given certain angular rate. LPR503AL has been cut, while LPR530AL still be able to detect certain angular rate. Fig. 10 also shows that the minimum angular rate and maximum angular rate of LPR503AL and LPR530AL are different. The selection of angular rate of sensor data using the SSD algorithm from Fig. 10 is shown in Fig. 11.

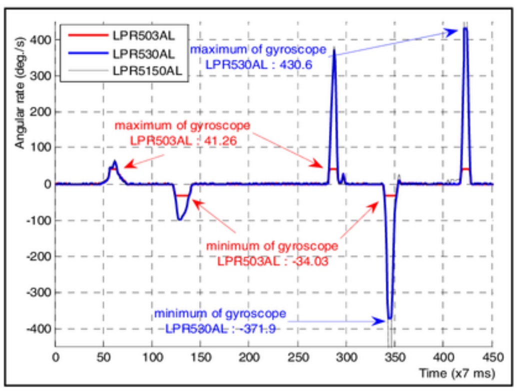

Fig. 10. Angular rate on the test of SSD algorithm.

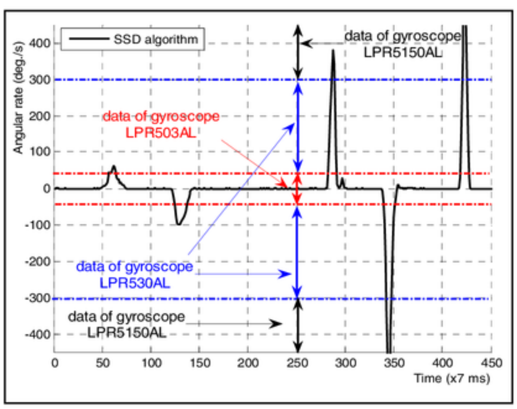

Fig. 11. Angular rate on the test of SSD.

If an angular rate is between -30°/s and 30°/s, then the SSD algorithm selects the angular rate data from LPR503AL. If an angular rate is greater than -300°/s and less than or equal to -30°/s, or greater than or equal to 30°/s and smaller than 300°/s, then the angular rate data is taken from LPR530AL. LPR503AL was used in normally drive of land vehicle and LPR503AL can be used to detect of driver when he rotates steering of land vehicle suddenly.

V. Conclusion

Testing of SSD algorithm with certain acceleration and angular rate is done on multi-sensor of accelerometer and gyroscope, respectively. SSD algorithm can be used to select sensor with higher sensitivity. Sensors with short range, MMA7361L 1.5 g and LPR503AL are used in normally drive.

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