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Automation and Validation of System Sensors

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Abstract*— Smart-phone has become an important part in daily life of people and these are equipped with the rich set of built-in sensors. The proposed method is used to develop the test equipment which will automate and validate the accelerometer, gyroscope and magnetometer/compass sensors. This equipment will rotate the device in 3 axis using Servo motors in linear steps. The Smart-phone/Tablet is placed on the test jig and connected to the host machine. This sends the command to servo motor and read the sensor data from Device Under Test (DUT). The sensor data is filtered using algorithms, which is implemented on host PC to get the earth gravity, degree of rotation and system stray magnetic fields.

***Index Terms*— Automation, Validation, Implementation, Sensors, Magnetic field.**

I. INTRODUCTION

Most of the portable devices have growing number of powerful embedded sensors that measure motion, orientation, and various environmental conditions. The most popular sensors in these devices are accelerometer, gyroscope, magnetometer, microphones, cameras etc. Orientation tracking has found extensive use in mobile games, virtual reality, also help in adjusting the display of the device according to the orientation with respect to the user [1]. This paper focuses on automation of sensor validation like accelerometer, gyroscope and magnetometer in Smart-phones/Tablets. The objective of automation is to improve the measurement accuracy and repeatability, eliminate the manual error and to reduce the time required for the testing. Since the portable devices equipped with 3 dimension sensor the test equipment is designed to rotate the DUT in 3 axis.

Accelerometer is a sensor which measures the acceleration of the device. The common application of accelerometer sensor is to measure the tilt of a Smart-phone and changes the display orientation accordingly. The earth's acceleration due to gravity, g is approximately equal to 9.81 m/s^2 [2]. Gyroscope is used to measure angular velocity. Gyroscope sensor has 3 axis to measure rotation along x, y and z. Measured acceleration values can be used to calculate the angular velocity; however it is not accurate [1]. Common application of gyroscope includes gaming, camera image stabilization etc. Magnetometer is used to measure the magnitude and direction of the magnetic field and this sensor has 3 axis measurements [1]. In Smart-phones this sensor is used to determine the device orientation/heading with respect earth North/South pole. Typical application of compass is Indoor/Outdoor Navigation.

The above mentioned sensors are critical components of Smart-phones/Tablets, hence it is important to measure the performance of the sensors. There are manual methods to measure the sensor performances; however it has limitations in accuracy. This can be addressed by automating the validation.

The test jig is designed with the 3 servo motors to rotate the DUT in the entire 3 axis. These servo motors are controlled by Arduino board which takes the command from the host machine. These commands are sent using Graphical User Interface (GUI) software running in host machine which executes python scripts. Fig 1 illustrates the model of test jig.

In order to capture the sensor data from DUT, AndroSensor App from play store is used. This application has an option to record all the sensor data and save it in local storage of device in Comma Separated Values (CSV) format. This CSV file is transferred into host machine using Android Debug Bridge (ADB) commands and test cases are run to validate the results.

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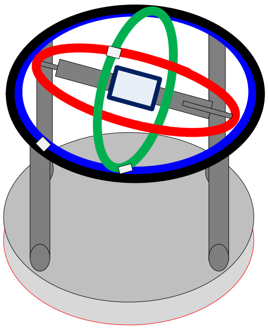

Fig 1 Model of test jig

II. VALIDATION METHODOLOGY

Following section describes about the validation methodology for accelerometer, gyroscope and magnetometer sensors in device.

Accelerometer: DUT is placed on test jig with device XY plane. With this starting position acceleration along Z axis of sensor is measured. This should ideally show 9.81 m/s^2. Next the host will issue the command to rotate the DUT by 90º along Y axis and Sensor measurement is taken along X axis. The procedure of rotation is repeated along X axis to get sensor measurement in Y axis. The entire process is scripted using python language, which also reports the results to indicate PASS/FAIL based on the measured value versus expected 9.81m/s^2.

Gyroscope: The DUT is placed on the test jig parallel to the XY plane. With the device in rest, the Android App is set to continuous capture mode with interval of 5ms. The host then issues a command to rotate the device by 30º (the rotation range for this test equipment varies from +90º to -90º). At the end of rotation, the recording is stopped and measurement is transferred to host machine for analysis. Using python scripts, integration of angular velocity with respect to time is calculated to get the total angle of rotation. This can be calculated using the area under normal curve [5], the formula to find area is given by (1). The calculated value should be within 30^0 +/-10% tolerance as PASS criterion.

$$\text{Area} = \int \left(\frac{Y_{N+1}+Y_N}{2}\right) X_{N+1} - X_N \qquad (1)$$

Where Y: Gyroscope value and X: Timestamp value measured from the DUT.

Magnetometer: Device which uses magnetometer has 2 factors influencing its reading – Soft iron effect and hard iron effect. The hard iron effect can be computed using a calibration algorithm [6]. It requires minimum of 4 magnetic field values measured at different points in space. To measure these values, DUT is placed on the test jig in horizontal plane. Command is sent from the host to DUT to record the sensor reading at rest position and the same is stored in CSV file. Measurement is repeated at 10º, 20º and 30º with respect to reference axis.

The specified algorithm with the following equations [6] are useful when the hard iron effect dominates and soft iron effects are ignored. This simplification results used in determining the hard iron vector V and the Geomagnetic strength B [6]. All values used for the algorithm is expressed in micro Tesla (μT).

In the absence of hard and soft-iron effects after rotations in smart-phones with yaw ψ, pitch θ and roll φ by the rotation matrices ***R****z*(ψ), ***R****y*(θ), and ***R****x*(Φ) , the magnetic field B_P is given by (2).

$$B_p = R_x(\Phi)R_x(\theta)R_x(\Psi)B_r = R_x(\Phi)R_x(\theta)R_x(\Psi)\begin{pmatrix}\cos\delta\\0\\\sin\delta\end{pmatrix} \qquad (2)$$

In the presence of hard iron and soft iron effects after rotation in smart-phone is given by (3).

$$B_p = WR_x(\Phi)R_x(\theta)R_x(\Psi)\begin{pmatrix}\cos\delta\\0\\\sin\delta\end{pmatrix} + V \qquad (3)$$

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Where W is Soft iron vector and V is Hard iron vector.

Irrespective of the magnetometer orientation, the vector magnitude of the measured field will be equal to the magnitude of the geomagnetic field. At a different orientation, individual geomagnetic field components will be different but the vector magnitude will not change. Under arbitrary rotation, the locus of the magnetometer measurements will lie on the surface of a sphere centered at zero field with radius equal to the geomagnetic field magnitude [9].

The addition of a hard-iron field adds a fixed vector offset to all measurements and displaces the locus of measurement by an amount equal to the hard-iron offset [9].

The residual error r(i) for the ith measurement is given by (4).

$$r(i) = \left(B_{px}(i)^2 + B_{py}(i)^2 + B_{pz}(i)^2\right) - \begin{bmatrix} B_{px}(i) \\ B_{py}(i) \\ B_{pz}(i) \\ 1 \end{bmatrix}^T \begin{bmatrix} 2V_x \\ 2V_y \\ 2V_z \\ B^2 - V_x^2 - V_y^2 - V_z^2 \end{bmatrix} \quad (4)$$

Where V_X, V_Y and V_Z are the components of the hard-iron vector, B_{PX}, B_{PY}, B_{PZ} are the components of the magnetometer measurement.

The residual error r(i) can be further abstracted to,

$$r = Y - X\beta \quad (5)$$

Where Y is the vector of the known dependent variables,

$$Y = \begin{bmatrix} B_{px}(0)^2 + B_{py}(0)^2 + B_{pz}(0)^2 \\ B_{px}(1)^2 + B_{py}(1)^2 + B_{pz}(1)^2 \\ \cdots \\ B_{px}(M-1)^2 + B_{py}(M-1)^2 + B_{pz}(M-1)^2 \end{bmatrix} \quad (6)$$

X is the matrix of known magnetometer measurements,

$$X = \begin{bmatrix} B_{px}(0) & B_{py}(0) & B_{pz}(0) & 1 \\ B_{px}(1) & B_{py}(1) & B_{pz}(1) & 1 \\ \cdots & \cdots & \cdots & 1 \\ B_{px}(M-1) & B_{py}(M-1) & B_{pz}(M-1) & 1 \end{bmatrix} \quad (7)$$

β is the solution vector from which the four calibration parameters can be easily determined,

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} 2V_x \\ 2V_y \\ 2V_z \\ B^2 - V_x^2 - V_y^2 - V_z^2 \end{bmatrix} \quad (8)$$

By free scale Application note as in [7], the equation for β is given by,

$$\beta = (X^T X)^{-1} X^T Y \quad (9)$$

Finally the stray field V_X, V_Y and V_Z and magnetic field, B can be calculated as using equation 10 and 11,

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \left(\frac{1}{2}\right) \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{bmatrix} \quad (10)$$

$$B = \sqrt{\beta_3 + V_x^2 + V_y^2 + V_z^2} \quad (11)$$

From above equations from 2 to 11, the stray field in X, Y, Z direction and geo magnetic field is calculated in µT. The standard geomagnetic field magnitude at the Earth's surface ranges from 25 to 65 µT. To qualify as PASS for the magnetometer sensor test, the RMS value of the 3 stray magnetic fields should be less than 10µT and calculated the geomagnetic field should lie between 25 to 65 µT.

III. IMPLEMENTATION

A. Hardware

The block diagram of the proposed methodology is given in Figure 2 and it has 3 major blocks.

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1. Windows Host machine
2. Test Jig
3. DUT, Ex: Smart-phones/Tablets

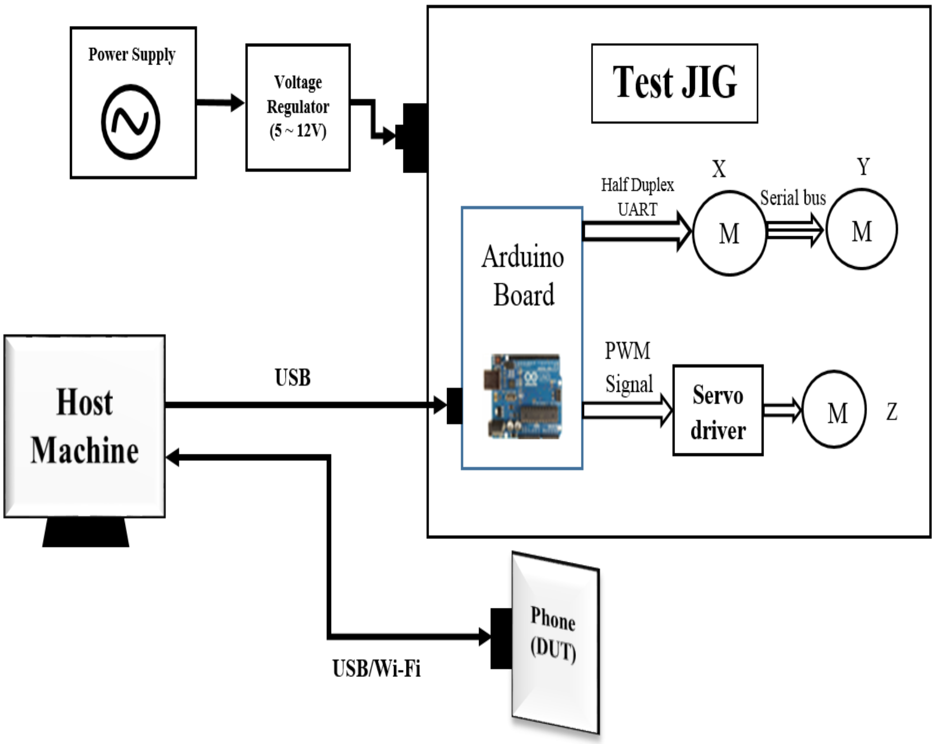

Fig 2 Block Diagram of Implementation

The host machine has GUI (Graphical User Interface) which is used to send the commands to the test jig. Test jig includes 3 servo motors, driver circuits to drive the servo motor, Arduino to control the motors and voltage regulator to provide a fixed voltage to the Arduino board, Servo motor and to its driver.

Servo motor is used here instead of stepper motor because it has advantages in delivering high torque and power, requires less maintenance and reliable operation [3]. It uses feedback such as PWM to determine the shaft position and that position can be controlled very precisely. This motor is small in size and it can directly interface to Arduino board. There are 3 motors used for 3 axes. UART interface for Motors controlling X axis and Y axis is connected in daisy chain topology to Arduino board. Z axis motor is controlled using PWM signals from Arduino board.

B. Software

Androsensor App is used to gather all sensor data from DUT in CSV format and post processing of this data is done in host machine to validate the measurement. This App has option to set the frequency of measurement and in this application it is set to 5ms.

Based on sensor under test, DUT will be subjected to rotation/tilt. The Androsensor App will record the sensor data during this period and store these in CSV file. This file is pulled to the host machine using ADB commands through USB/Wi-Fi via python scripts. This file is parsed in host machine to get the timestamp and sensor data using python script. This information is used to generate the report as discussed in section II. The flow diagram of the proposed methodology is as shown in Figure 3.

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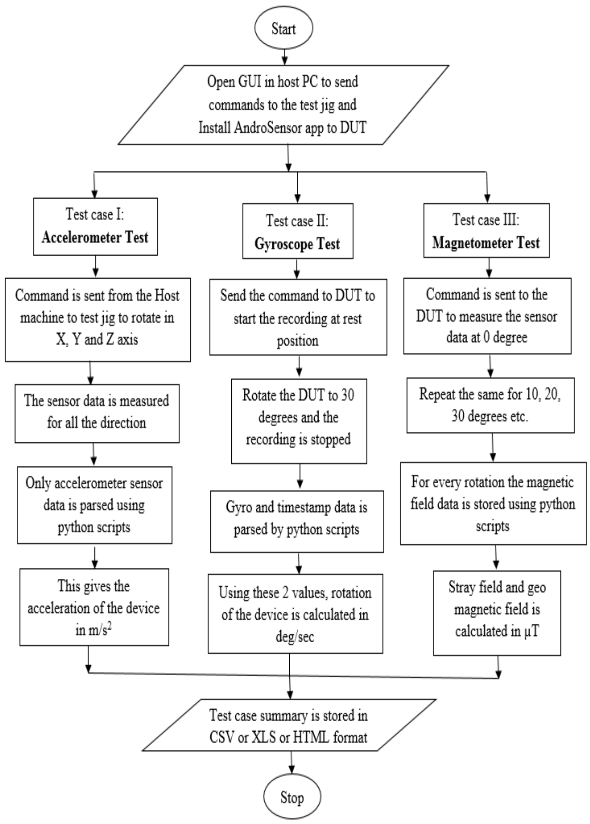

Fig 3 Flow Chart

IV. RESULTS

The proposed method has successfully automated and validated the accelerometer, gyroscope and compass sensors in Smart-phones/Tablet. This has the capability to rotate the device in all the 3 directions and can be moved in linear steps. The results obtained using this automated solution are summarized in the tables from 1 to 4.

(i) ***Accelerometer Test***

Table 1: Measurement of accelerometer sensor

ACC_TESTCASES	CRITERION	MEASURED_VALUE	PASS/FAIL
TestCase_Z	$9.81 m/s^2 \pm 10\%$	$9.384061\ m/s^2$	PASS
TestCase_Y	$9.81 m/s^2 \pm 10\%$	$9.391615\ m/s^2$	PASS
TestCase_X	$9.81 m/s^2 \pm 10\%$	$9.964171\ m/s^2$	PASS

Table 1 illustrates the accelerometer sensor validation results. The expected earth gravity value from the accelerometer sensor is $9.81 m/s^2$ and for the analysis purpose criteria is given as ±10% which ranges from $8.829 m/s^2$ to $10.791 m/s^2$. The obtained values are within the allowable range and thus the validation of accelerometer sensor gives result as PASS.

(ii) **Gyroscope Test**

Table 2: Gyroscope validation result

CRITERION	EXPECTED	MEASURED	PASS/FAIL
Rotation ± 10%	30°/sec	29.91914°/sec	PASS

The gyroscope sensor measures the degree of rotation of the device. For this experiment, the device is rotated to 30°. With the standard formulae which are explained before, the degree of rotation is calculated from the sensor data obtained from the phone. Since the calculated value 29.91914° in Table 2 is within the range of 27° to 33° which is ±10% of expected 30° of rotation, the test case is considered as PASS.

(iii) **Magnetometer Test**

Table 3(a) Stray magnetic field test result

EXPECTED	Stray_X	Stray_Y	Stray_Z	RMS_Stray	PASS/FAIL
<10µT	-5.95396µT	-2.4588µT	3.977284µT	7.57061µT	PASS

Table 3(b) Geomagnetic field test measurement from compass sensor

CRITERION	GeoMagneticField	PASS/FAIL
25 µT to 65 µT	35.84532µT	PASS

In the magnetometer test case, the stray magnetic field and Geo magnetic fields are calculated. The test criteria for stray magnetic field is less than 10µT and geomagnetic field for the location where the test setup is done is between 25µT to 65µT. The obtained results are tabulated in Table 3(a) and 3(b) and the results are within the defined margins of pass condition.

V. CONCLUSION AND FUTURE SCOPE

The solution has been successfully implementation and proven to improve the measurement accuracy, speed of validation and repeatability of measurement.

Future scope involves developing a complete host independent solution so that it can be used in factory setup and this solution can be enabled for windows devices. Also the same setup with the modified scripts the display testing can be automated.

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