IMU for Vessel and Offshore Piping Survey

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Abstract  “The Inertial Measurement Unit (IMU) is an electronic unit which records angular velocity and linear acceleration data which is fed into a central processing unit for data interpreting and logging. The unit constitutes of two independent sensors. The first sensor is the 3-axis gyroscope and second sensor is the 3-axis accelerometer. The IMU should also have a data interpreter that can draw the track it went through. This should enable the engineers to calculate the co-ordinates, based on longitude and latitude measures. To improve the effectiveness of the device, the device could possibly be designed to transfer the data wirelessly using Bluetooth technology to the nearby data logging machine, which can simultaneously calculate the algorithms to figure the correct of the vessel piping system.

Keywords  IMU, Shipboard, Piping, Gyroscope, Accelerometer

1. Introduction

In modern day naval architecture, ships are designed to be very smooth skewed shapes to give them the ability to propel and maneuver at the least resistance, in order to maximize the propulsive efficiency. Therefore it has been a norm for many years to design a vessel with the storage tanks on the side of skin, or what we call as side-shell. In the process of vessel design, it is an unavoidable thing to not design curved wing tanks and deep tanks, for different type of liquid storage.

Due to the skewed shape of the vessel geometry the access to those tanks are really difficult. And the Code of Regulations requires that there should be vent pipes for all independent, fixed, non-pressure pipes tanks. But for the construction and repairing necessities over the years these piping system has to be properly located and physically accessed.

As already mentioned, access to the shape of the vessel can cause extremely difficulty for the engineers to gain access to the tanks and therefore locate the piping system. In order to do that, Professor Brandon Taravella of the Naval Architecture and Marine Engineering department from University of New Orleans has brought up the proposal to investigate this certain problem affecting the shipbuilding industry. In order to solve this issue, research was conducted to find a unique solution that can record the routing of a complicated piping system.

Co-relation between IMU and Ship’s Degrees of Freedom:

To begin the investigation, we employed the idea of inertial measurement units (IMU) that can record the track path of all kinds of piping system. For a complicated system inside a vessel, we needed multiple units, which should give us several data even for extreme remote locations. One example of such IMU device is InvenSense MPU-6050 which uses motion interface. This use of motion interface can interact with the other devices by tracking motion in free space and delivering the data as an input to the data interpreter. [1]

The six degree of freedom (DOF) of MPU-6050 can expressed in terms of the naval architectural nomenclature. They are:

Heave, Pitch, Roll, Sway, Surge, Yaw

Figure 1.  A ship’s 6 DOF
Application of IMU is not new in the shipbuilding industry. IMU units are being used by several companies for heave compensation applications for ships under operations. In further development, the inertial measurement units (IMU) can be comprised of analog-digital converters (ADC), a microcontroller (CPU) and inertial measurement system (IMS) which can transform the co-ordinates based on a relative origin.

2. System Architecture

The key advantages of using MPU-6050 is the device can be operated within a very small package size, at low power consumption, high accuracy and repeatability, high shock tolerance and programmed based on the requirement of the application. Therefore dropping or running the IMU through the long pipes at high velocity is not risky. [2] Also MPU-6050 can support configurable features such as gesture recognition, panning and zooming, scrolling, tap detection and shake detection.

The MPU 6050 consists of Digital Motion Processor (DMP) which includes both the gyroscope and the accelerometer. The DMP can sensor timing synchronization and gesture detection. The algorithms inside the IMU can perform over run-time bias and compass calibration. This device can also be programmed with temperature sensor reading so that different liquids flowing through the different pipes can be easily detected. [1]

![Figure 2. MPU 6050 representation of 6-DOF](image)

There are certain features that make the IMU suitable for such applications. To list the capabilities the controller inside the IMU features [3]:

- Two-axis stabilized
- Overcurrent protection
- Thermal protection
- Under voltage protection
- Wrong polarity protection

In order to suit the IMU for the purpose of measuring the complicated piping system of a ship, a calibration of the axis and validation of the accuracy of the hardware is essential. Considering the acceleration, the unit would continuously compute the following equation of motion relative to the earth’s axis:

$$a_G = a_T + \dot{\Omega} \times \vec{r} + \Omega \times (\Omega \times \vec{r}) + 2\dot{\Omega} \times \dot{\vec{r}} + a_{rel}$$

![Figure 3. Geometric representation of the IMU orientation related to the earth axis](image)

The following illustration represents how the equation is executed within the accelerometer:

As the IMU travels through the pipes, the gyroscope within the accelerometer constantly records the orientation of the device. This would allow to record the changes in direction and pathways of the pipe. The gyroscope in combination with the accelerometers gives the ability to the IMU for an enormous direction- and motion-sensing.

The global co-ordinate frame is defined by gravity and the geomagnetic field. The local co-ordinate frame is expressed by the rotation about the global axes. [8]

$$\{ c_{xT}, c_{yT}, c_{zT}, \dot{c}_{xT}, \dot{c}_{yT}, \dot{c}_{zT}, \dot{c}_{xT}, \dot{c}_{yT}, \dot{c}_{zT}, \ddot{c}_{xT}, \ddot{c}_{yT}, \ddot{c}_{zT}, \}$$

The domain of the magnetometer, accelerometer and gyroscope is defined as:

$$\{ \text{accelerometer, magnetometer, gyroscope} \}$$

A recent journal article was published by the mechanical engineering department of University of Michigan examining the IMU functionality inside a baseball. A highly miniaturized wireless transmitter was attached to the IMU hardware. The entire unit was about a size of a quarter and provided accurate three axis sensing of acceleration and angular velocity. The IMU had 8Mbytes of memory attached to it which could later be connected to a computer for the data analysis. [4]

Based on the experiment, the researchers were able to publish data for the travel path of different balls, with different angular and linear velocity.
In similar manner, the IMU unit designed for the shipboard piping system can made to travel at high velocity within the pipe bends by the help of vacuum. A typical section of a ship structure can be very complicated. With all the structures, engineers usually bend the pipes to fit the inner hull with the least possible interference. Therefore each piping system, such like bilge, ballast, sounding pipes, etc., needs to have pre-construction schematic and routing diagram. Different schedule pipes should be taken into consideration, given that the IMU hardware has to have an unrestrained movement. Also pump locations are important because IMU hardware, if fed into pump propeller, can cause significant damage.

Different Scenarios:

Considering other IMU besides MPU 6050, a recent literature published by The Institution of Engineering and Technology [5] has proposed to use ultra-tight integration, based on the vector tracking, for IMU’s travelling at high speed. The ultra-tight integration can compensate for the Doppler shift, giving more accurate reading for the travel path and more accurate data reducing the number of false results from the IMUs. Another company came up with wireless miniature IMU for dynamic position tracking. This miniature unit can re-adjust magnetic field reference, since earth magnetic field can be distorted by metal or electromagnetic sources such like the hull of the ship. The unit is especially helpful where the battery is rechargeable and can run for up to ten hours without recharging. [6]

In order to get the IMU pass through the piping at high velocity, the hardware unit can be cushioned with foam or highly heat compensating elastic material. Keeping in mind that pipes usually contains liquids, an airtight and waterproof capsule can be a good option to insulate the hardware from possible damages. The pathway for the IMU unit can be as simple as it is shown:

Considering many utilization of IMU technology, Northrop Grumman introduces inertial fiber-optic gyro for space application named LN-200 (15). This IMU utilizes fiber optic gyros, radar stabilization, data transfer to user equipment with the help of digital serial bus. The scientific research of the device discussed in this paper also envisions to improve the IMU tracking device to be equipped with fiber optic gyros, stabilizer and low noise MEM technology. This would enable the device to broaden its use in military, air-force and naval applications. Also the future research would like to integrate low-energy consuming battery or power source, ensuring a longer usage hours. In future the IMU device may also include an error checking option using the MHD sensor, a sensor that utilizes the magnetometer, using the behavior of fluid interaction and its relation to the magnetic field.
3. Experimental Method

To simplify the experiment and effectively record the data a very sensitive but readily available device was used during the experimentation. A commercially available smartphone that uses IMU to co-ordinate with the device movement, position and orientation has been used to record the data and time frame. The device was dropped from several known heights, while an application known as “DataCollection” developed by Christopher Wozny recorded acceleration, gyroscopic and magnetometer data.

Data Collection:
Sample Magnetic Data Recorded

Table 1. Raw Magnetic Orientation Data

| Time(sec) | TYPE   | rx       | ry       | rz       | correction | POLAR CO-ORDINATES |
|----------|--------|----------|----------|----------|------------|---------------------|
| 0.1      | MAGNETO | 68.202056| -49.294922| 143.478516| -360.5672  | 397.0847517         |
| 0.2      | MAGNETO | 68.301566| -50.671875| 143.203125| -361.996887| 398.4741197         |
| 0.3      | MAGNETO | 68.401449| -49.845703| 146.232422| -362.282806| 399.7450571         |
| 0.4      | MAGNETO | 68.501436| -49.845703| 144.029297| -359.9953  | 396.8854939         |
| 0.5      | MAGNETO | 68.701545| -47.917969| 143.753906| -353.990601| 391.1400838         |
| 0.6      | MAGNETO | 68.801384| -48.193359| 142.376953| -351.989075| 388.8749619         |
| 0.7      | MAGNETO | 69.101485| -46.816406| 144.855469| -343.125    | 381.686039          |
| 0.8      | MAGNETO | 69.20149 | -46.541016| 146.232422| -342.67181 | 381.4258209         |
| 0.9      | MAGNETO | 69.301374| -40.482422| 143.478516| -342.67181 | 379.7030612         |
| 1.0      | MAGNETO | 69.401401| -40.482422| 144.580078| -342.83905 | 380.6539033         |
| 1.1      | MAGNETO | 69.501539| -38.003906| 143.753906| -339.121887| 376.7540319         |
| 1.2      | MAGNETO | 69.601657| -44.0625  | 144.304688| -341.409363| 379.6973672         |
| 1.3      | MAGNETO | 69.701944| -42.685547| 146.232422| -341.123413| 380.038415          |
| 1.4      | MAGNETO | 69.801539| -41.308594| 144.855469| -337.978119| 376.5514183         |
| 1.5      | MAGNETO | 69.901349| -42.410156| 144.855469| -340.265625| 378.7461186         |
| 1.6      | MAGNETO | 70.00142 | -45.164062| 143.203125| -340.837494| 378.9687634         |
| 1.7      | MAGNETO | 70.101439| -42.960938| 144.855469| -336.834351| 375.7663381         |
| 1.8      | MAGNETO | 70.200783| -42.960938| 144.304688| -340.837494| 379.1628822         |
| 1.9      | MAGNETO | 70.301361| -44.0625  | 143.753906| -343.696869| 381.6759208         |
| 2.0      | MAGNETO | 70.401552| -40.757812| 144.855469| -344.268738| 382.2586148         |
| 2.1      | MAGNETO | 70.501376| -38.554688| 144.855469| -348.271851| 385.6595611         |
| 2.2      | MAGNETO | 70.60145 | -37.728516| 146.232422| -347.985931| 385.8576617         |
| 2.3      | MAGNETO | 70.701375| -33.597656| 144.304688| -349.987488| 386.5780279         |
| 2.4      | MAGNETO | 70.801396| -34.148438| 145.957031| -352.274994| 389.332865          |
| 2.5      | MAGNETO | 70.901392| -30.292969| 145.957031| -349.987488| 386.9617139         |
| 2.6      | MAGNETO | 71.001359| -29.466797| 148.986328| -346.270325| 384.7200918         |
| 2.7      | MAGNETO | 71.101579| -29.466797| 147.884766| -346.842163| 384.8286849         |
| 2.8      | MAGNETO | 71.201439| -42.960938| 144.855469| -336.834351| 375.7663381         |
| 2.9      | MAGNETO | 71.301361| -44.0625  | 143.753906| -343.696869| 381.6759208         |
| 3.0      | MAGNETO | 71.401552| -40.757812| 144.855469| -344.268738| 382.2586148         |
A rotation about the Z axis, the Y axis or the X axis can be respectively described by a rotation matrix \( R(\psi), R(\theta), R(\phi) \), represented as following [11]

\[
R(\psi) = \begin{pmatrix}
\cos(\psi) & -\sin(\psi) & 0 \\
\sin(\psi) & \cos(\psi) & 0 \\
0 & 0 & 1
\end{pmatrix},
R(\theta) = \begin{pmatrix}
\cos(\theta) & 0 & -\sin(\theta) \\
0 & 1 & 0 \\
\sin(\theta) & 0 & \cos(\theta)
\end{pmatrix},
R(\phi) = \begin{pmatrix}
1 & 0 & 0 \\
0 & \cos(\phi) & \sin(\phi) \\
0 & -\sin(\phi) & \cos(\phi)
\end{pmatrix}
\]

The earth’s magnetic field can be expressed as

\[
B_d = R_c(\phi). R_y(\theta). R_z(\psi). g_r
\]

where,

\[
\phi = \arctan\left(\frac{g_{dy}}{g_{dx}}\right) \quad \text{and}
\theta = \arctan\left(\frac{B_{dz} \sin(\phi) - B_{dy} \cos(\phi)}{B_{dz} \cos(\theta) + B_{dy} \sin(\theta) \cos(\phi)}\right)
\]

thus the yaw angle can be computed as :

\[
\psi = \arctan\left(\frac{B_{dx} \sin(\phi) - B_{dy} \cos(\phi)}{B_{dx} \cos(\theta) + B_{dy} \sin(\theta) \cos(\phi)}\right)
\]

**Table 2. Raw Attitude Data**

| Time(sec) | Type     | sx       | sy       | sz       | Error Correction Factor | Path     |
|-----------|----------|----------|----------|----------|-------------------------|----------|
| 0.1       | ATTITUDE | 68.2011  | 41.94169 | 7.640745 | 165.836                 | 80.42933 |
| 0.2       | ATTITUDE | 68.30103 | 42.49074 | 7.70151  | 165.6191                | 80.80722 |
| 0.3       | ATTITUDE | 68.40107 | 43.2191  | 7.992622 | 165.3977                | 81.30485 |
| 0.4       | ATTITUDE | 68.50104 | 44.01197 | 8.546804 | 165.0776                | 82.73979 |
| 0.5       | ATTITUDE | 68.60103 | 45.57906 | 7.875237 | 165.2284                | 82.73979 |
| 0.6       | ATTITUDE | 68.70111 | 50.45467 | 4.987447 | 164.9167                | 85.38378 |
| 0.7       | ATTITUDE | 68.80101 | 55.84766 | 1.065572 | 165.0378                | 88.62096 |
| 0.8       | ATTITUDE | 68.90098 | 63.00094 | -0.62247 | 162.2695                | 93.36048 |
| 0.9       | ATTITUDE | 69.00111 | 66.75767 | 0.597862 | 159.2173                | 96.01092 |
| 1.0       | ATTITUDE | 69.10109 | 66.9104  | 5.844283 | 153.2799                | 96.3801  |
| 1.1       | ATTITUDE | 69.20102 | 67.19265 | 10.48429 | 147.2604                | 97.02347 |
| 1.2       | ATTITUDE | 69.30098 | 65.27968 | 14.14434 | 144.041                 | 96.25032 |
| 1.3       | ATTITUDE | 69.40102 | 64.90123 | 19.25221 | 139.3948                | 96.95009 |
| 1.4       | ATTITUDE | 69.50112 | 67.02292 | 27.05239 | 132.4404                | 100.2712 |
| 1.5       | ATTITUDE | 69.60127 | 67.74294 | 28.13908 | 132.1196                | 101.12   |
| 1.6       | ATTITUDE | 69.70133 | 67.37363 | 25.61815 | 133.5289                | 100.2685 |
| 1.7       | ATTITUDE | 69.80106 | 67.72675 | 26.44433 | 132.3881                | 100.7889 |
| 1.8       | ATTITUDE | 69.90099 | 69.0429  | 22.5932 | 135.2934                | 100.98   |
| 1.9       | ATTITUDE | 70.001  | 70.73888 | 23.0037  | 135.3206                | 102.1435 |
| 2.0       | ATTITUDE | 70.10081 | 70.61021 | 24.85609 | 133.4844                | 102.5561 |
| 2.1       | ATTITUDE | 70.2001  | 70.35778 | 22.65919 | 134.2603                | 101.9397 |
| 2.2       | ATTITUDE | 70.30098 | 72.45841 | 11.9999 | 139.3311                | 101.6683 |
| 2.3       | ATTITUDE | 70.40106 | 70.62062 | 3.825249 | 137.7068                | 99.79085 |
| 2.4       | ATTITUDE | 70.50095 | 67.7084  | 6.946391 | 124.8216                | 97.99522 |
| 2.5       | ATTITUDE | 70.60106 | 67.76712 | 9.223646 | 120.3969                | 97.68326 |
| 2.6       | ATTITUDE | 70.70101 | 66.56321 | 10.56764 | 115.8955                | 97.67788 |
| 2.7       | ATTITUDE | 70.80101 | 65.99468 | 4.919901 | 112.2923                | 96.91381 |
| 2.8       | ATTITUDE | 70.90101 | 68.28716 | 4.116206 | 110.7499                | 98.52427 |
| 2.9       | ATTITUDE | 71.001  | 72.46886 | 2.607612 | 109.2425                | 101.4873 |
| 3.0       | ATTITUDE | 71.10121 | 76.64315 | 4.660504 | 105.036                 | 104.6483 |
The gyrometer inside the IMU is being modelled by:

\[ \overline{\Omega} = \Omega + b + \eta \]

where \( \Omega \) the true value, \( b \) is the slowly time-varying bias and \( \eta \) zero mean noise. This is electronic sub-structure of the IMU, but what it represents is the raw estimates of the roll \( \Theta \) and pitch \( \theta \). The attitude matrix can be written as [12]:

\[
R = \begin{bmatrix}
C\phi C\gamma & -S\phi S\gamma & -C\phi S\gamma + C\phi C\gamma \\
C\phi S\gamma & C\phi C\gamma & -S\phi S\gamma + C\phi C\gamma \\
-S\phi C\gamma & S\phi C\gamma & C\phi S\gamma
\end{bmatrix}
\]

Table 3. Raw Acceleration Data Recorded

| Time(sec) | TYPE  | Raw Data from Experiment | Linear Acceleration |
|-----------|-------|--------------------------|---------------------|
| 0.1       | ACCEL | 68.201423                | -0.077179 0.742584 0.729187 68.20940698 |
| 0.2       | ACCEL | 68.301302                | -0.098236 0.738174 0.701935 68.30896807 |
| 0.3       | ACCEL | 68.401274                | -0.079544 0.738617 0.714432 68.40934743 |
| 0.4       | ACCEL | 68.501221                | -0.065781 0.799011 0.727478 68.50974844 |
| 0.5       | ACCEL | 68.601215                | 0.012573 1.064148 0.701248 68.61305282 |
| 0.6       | ACCEL | 68.70133                 | -0.026138 1.201385 0.559265 68.71411449 |
| 0.7       | ACCEL | 68.801177                | 0.040619 1.177307 0.761612 68.81547581 |
| 0.8       | ACCEL | 68.901213                | -0.095367 0.969162 0.505508 68.90994893 |
| 0.9       | ACCEL | 69.001338                | -0.120056 0.752563 0.496567 69.00732866 |
| 1         | ACCEL | 69.101274                | -0.130173 0.701294 0.594147 69.10750927 |
| 1.1       | ACCEL | 69.201266                | -0.053894 0.771225 0.425812 69.20689434 |
| 1.2       | ACCEL | 69.301158                | -0.045563 0.772491 0.459427 69.30701003 |
| 1.3       | ACCEL | 69.401187                | -0.153748 0.79039 0.438293 69.40724179 |
| 1.4       | ACCEL | 69.501316                | -0.23616 0.842422 0.304642 69.50749009 |
| 1.5       | ACCEL | 69.601443                | -0.10704 0.885269 0.402679 69.60831974 |
| 1.6       | ACCEL | 69.701653                | -0.152649 0.873413 0.33728 69.70810814 |
| 1.7       | ACCEL | 69.801279                | -0.218872 0.878693 0.316971 69.80787224 |
| 1.8       | ACCEL | 69.901444                | -0.070511 0.926254 0.235764 69.90771373 |
| 1.9       | ACCEL | 70.001203                | -0.069946 0.92717 0.221115 70.00772707 |
| 2         | ACCEL | 70.100968                | -0.187088 0.934341 0.230972 70.10782451 |
| 2.1       | ACCEL | 70.200295                | -0.157394 1.101261 0.463999 70.20928611 |
| 2.2       | ACCEL | 70.301143                | -0.065491 0.953339 0.188919 70.30789104 |
| 2.3       | ACCEL | 70.401221                | -0.038544 0.837036 0.296112 70.40683003 |
| 2.4       | ACCEL | 70.501162                | -0.009872 0.928497 0.535568 70.50931059 |
| 2.5       | ACCEL | 70.601232                | -0.056625 0.964066 0.467026 70.60938112 |
| 2.6       | ACCEL | 70.701168                | -0.099945 0.870132 0.463669 70.70811314 |
| 2.7       | ACCEL | 70.801181                | -0.022995 0.90209 0.422592 70.808424 |
| 2.8       | ACCEL | 70.901183                | -0.043747 0.915497 0.335678 70.90790139 |
| 2.9       | ACCEL | 71.001152                | -0.019897 0.966232 0.280701 71.00828387 |
| 3         | ACCEL | 71.101375                | -0.015305 0.959152 0.155731 71.10801633 |
Figure 9. Raw data of Linear Acceleration recorded over a time period of 10.00sec

The acceleration resulting from the IMU can be calculated as:
\[ \ddot{a} = \Omega \times (\Omega \times \rho r) \]

Where \( \Omega \) is the angular rate and \( \rho \) is the turn radius and \( r \) is unit vector from the center of turning. Linear acceleration in the three dimensions are the average of the acceleration accumulated from the surface of a cube.[13] Given by the equation, the average acceleration is:
\[ \bar{a} = \frac{a_x + a_x'}{2}, \frac{a_y + a_y'}{2}, \frac{a_z + a_z'}{2} \]

Considering the rotation, the acceleration changes to,
\[ \ddot{a} = (a_x, a_y, a_z) = (\frac{\Delta r}{r}, \frac{\Delta r}{r}, \frac{\Delta r}{r}) \]

But we need the angular acceleration normalized with unit radius,
\[ \ddot{a}_{\text{xy}} = (\frac{a_x}{r}, \frac{a_y}{r}, \frac{a_z}{r}) \]

Table 4. Raw Gyroscope Data Recorded

| Time | TYPE | Raw Data from Experiment |
|------|------|--------------------------|
| 0.1  | GYRO| 68.201553 -0.007944 -0.002394 -0.008751 |
| 0.2  | GYRO| 68.301413 -0.001288 -0.014124 -0.045426 |
| 0.3  | GYRO| 68.401382 0.047002 0.061948 -0.052688 |
| 0.4  | GYRO| 68.501329 0.531739 -0.36349 0.111419 |
| 0.5  | GYRO| 68.601328 1.126556 -0.614649 0.037606 |
| 0.6  | GYRO| 68.701442 1.598032 -0.507508 -0.238727 |
| 0.7  | GYRO| 68.801282 1.060218 -0.528968 -0.313446 |
| 0.8  | GYRO| 68.901709 0.122029 0.411756 -0.436814 |
| 0.9  | GYRO| 69.001456 -0.041032 -0.064252 -0.516182 |
| 1.1  | GYRO| 69.101383 -0.273649 0.098875 -0.255871 |
| 1.2  | GYRO| 69.201387 -0.278631 0.229686 -0.208122 |
| 1.3  | GYRO| 69.301255 0.615041 0.27739 -0.348275 |
| 1.4  | GYRO| 69.401298 0.122029 0.411756 -0.436814 |
| 1.5  | GYRO| 69.501343 -0.041032 -0.064252 -0.516182 |
| 1.6  | GYRO| 69.601552 0.363717 -0.476707 0.072459 |
| 1.7  | GYRO| 69.701273 0.55788 -0.467455 0.142628 |
| 1.8  | GYRO| 69.801288 0.67702 -0.286937 -0.0157 |
| 1.9  | GYRO| 70.001255 -0.33867 0.086264 0.220372 |
| 2.1  | GYRO| 70.200535 -0.744097 0.3551 |
| 2.2  | GYRO| 70.301255 -0.131176 -1.429203 -0.05425 |
| 2.3  | GYRO| 70.401379 -0.796534 -2.948191 -0.824675 |
| 2.4  | GYRO| 70.501273 -0.029066 0.027871 -0.04231 |
| 2.5  | GYRO| 70.601343 -0.249378 0.146411 -0.067616 |
| 2.6  | GYRO| 70.701273 -0.43301 -1.536566 -0.232054 |
| 2.7  | GYRO| 70.801288 0.363717 -0.476707 0.072429 |
| 2.8  | GYRO| 70.90129 0.55788 -0.467455 0.142628 |
| 2.9  | GYRO| 71.001258 -0.286937 -0.0157 |
| 3.0  | GYRO| 71.101482 0.475449 -0.478554 0.042794 |
4. Conclusions

This idea still has a lot of potential to grow. The shipbuilding industry has lot more complications which could be solved by using such simple and cost-effective IMU units. Using inexpensive computer programming codes and the IMU raw data from the device, the shipyard and construction engineers can conduct very practical and cost effective piping surveys. The development of such a device has the applicability in military sectors and law enforcement. Such devices can be used to identify hidden paths/tracks, retrieve information of underground inaccessible places and can be modified to suit specific to US Navy, Army and Marines. Not only military, but commercial oil and gas industry in the deep water horizon can also benefit from such a technology. Survey, construction, pipeline laying in deep sea, LNG, petrochemical industries could potentially expand the use IMU technology to fit their uses. More research would result in better simplification of the hardware unit, thus further improvement can excel the technology towards the benefit of engineering and scientific sectors.

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