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Accelerometer-based Wave Motion Compensation on Ship Mounted Weaponry

Mel James P. Diaz[1], Christopher Evan A. Mariano[2], Angelo A. Beltran Jr.[3]
School of GS and School of EECE, Mapua Institute of Technology, Philippines
[1]meljames_diaz@yahoo.com, [2]nave_onairam@yahoo.com.ph, [3]abeltranjr@hotmail.com

Abstract**—*****This paper proposes the usage of a gyroscope Freescale MMA8451QT-ND module as a sensor for change in angular position for an automated naval weapon system. It is intended to feed information to a controller that will control the driver to a motor in order to maintain its target position regardless of any vertical movement of the platform. It uses both direct accuracy estimation from test data and sigma levels to estimate the accuracy over various maximum misalignment specifications. The effectiveness of the proposed method and control algorithm is further demonstrated by an experimental study on the control system. Data is gathered over a small fixed distance and the angular accuracy is computed. The overall result in the evaluation of the system is used as a reference. The proposed control system implemented to an automated weapon increased its accuracy as compared to the change in position due to wave motion without gyro stabilizer.***

Keywords**—Accelerometer, Pitch, Stabilizer, Wave motion, Ship mounted weaponry**

I. Introduction

Weapon accuracy is first determined by first identifying the initial target, attempting to align the nozzle against that target, and measuring the distance of area hit from the desired point of impact. However, when weapons are mounted on ships, even the first step becomes a challenge as the motion of the waves against the ship can cause disturbances in its targeting method and thus; affects all the proceeding steps. This is especially true for light weight naval ships or boats where the wave motion is more pronounced compared to heavier models. The gyroscopes and accelerometers are widely used in navigational instruments and monitoring of changes in direction, bearing, or angular position. There is a possibility that these devices can aid in obtaining the relative displacement of the weapon nozzle from its original target. There are also various motors in the market that can be used to control this variation. Combinations of devices would be necessary to exert a more effective, and flexible control over changes in position. This paper is intended to build a prototype system that will simulate the changes in the machine gun alignment to its target. It will therefore include a system which continuously monitor and re-adjust the gun alignment to increase its overall accuracy. Any improvement in accuracy for weapons is considered significant not only due to efficient consumption of ammunition but also improves effectiveness and survivability of our nation heroes of whom will fight to defend our freedom and honor. It is also an application which can be re scaled to be integrated to other types of weapon systems. The devices to be tested in this research paper are limited to gyroscopes, accelerometers, DC motors, electronic devices components which are necessary to simulate the whole system. It will be focus in accuracy improvements of 50 caliber machine guns but will not fire any live rounds, which are quite potentially dangerous. This paper is organized as it follows: Section II briefly presents the methodology of the study. Section III is devoted to the experimental results which are carried out in order to verify the goodness of the study. Conclusion ends the paper at section IV.

II. Methodology

The system is intended to control the frame of a weapon system, and thus; a prototype is built to simulate the frame but with enough space to mount a weapon. This is done by using an accelerometer, microcontroller, relays, and DC motor as the main components. By designing a mechanical fixture to simulate the frame, an experimental set up is done to identify the current capability of the system. Although, the result is quite far from ideal, certain improvements are possible by upgrading certain parts of the prototype.

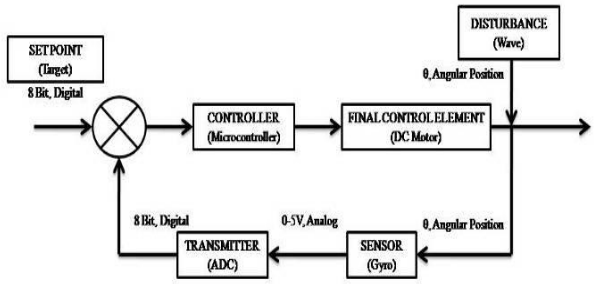

Fig. 1. Conceptual framework structure of the proposed control system.

The system is a typical feedback loop whose error is measured by the accelerometer whose reading is received by the microcontroller through a 14 bit resolution I2C digital signal. Depending on its input results, the control of the system will be directly applied to the DC motor, which will apply the correction. Data will be taken to measure the mis alignment from the ideal position, and this will be use to measure the current accuracy of the system, and project it over different distances. The main concept of the design follows the concept as shown in Fig. 1. An initial setting is programmed into the microcontroller; this data is used as a reference against the response from the gyroscope, which is converted through an analog to digital converter. Although the initial setting is fixed, it is possible to make it a variable input from an external controller with respect to a targeting system. Depending on the difference, the microcontroller shall calculate the necessary changes to control the input to the DC motor which drives a positioning element of the equipment. Based on the hardware design, the processing power required is easily met using Microchip PIC16FXXX or PIC18FXXX family of 8-bit microcontrollers. For the

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accelerometer, the researchers use the module eGizmo Freescale MMA8451QT-ND kit which is a three axis, 14bit resolution I2C output that uses capacitive micro-machining process to make a functionally complete and also a low cost acceleration sensor integrated with all of the required electronics on one chip. The accelerometer will provide a 14 bit digital data depending on its position as shown in Fig. 1. This digital data will be compare to the set point which is the target. Based on the difference between the set point and the data from accelerometer, the microcontroller shall activate the DC motor to compensate the changes on the angular position. Below then summarizes the main hardware and the components used in the development of prototype.

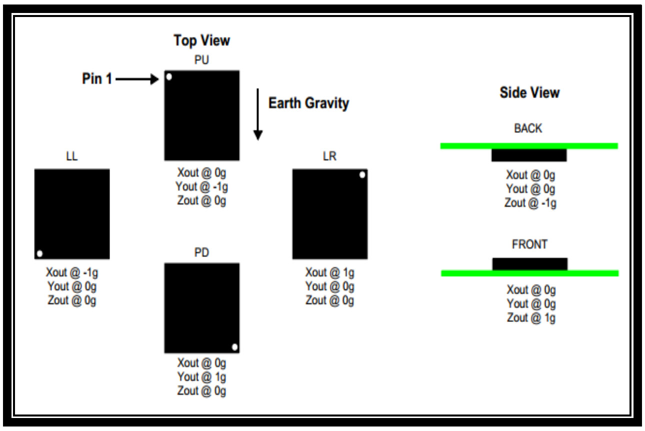

Fig. 2. Accelerometer output with respect to orientation [3].

The Proteus ISIS is used to design, simulate the circuit, evaluate the circuit integrity, and perform also the program simulation to determine any function errors in the developed firmware. The schematic diagram is shown in Fig. 7. In the firmware program for the PIC microcontroller, the MPLAB IDE v8.64 is utilized from Microchip. Assembly language is used in the development of the firmware. The Altium Designer PCB software was used for designing the schematic printed circuit board. An ultraviolet sensitive copper board was also used for photolithography and have the design transferred through a UV light box for reliable resolution.

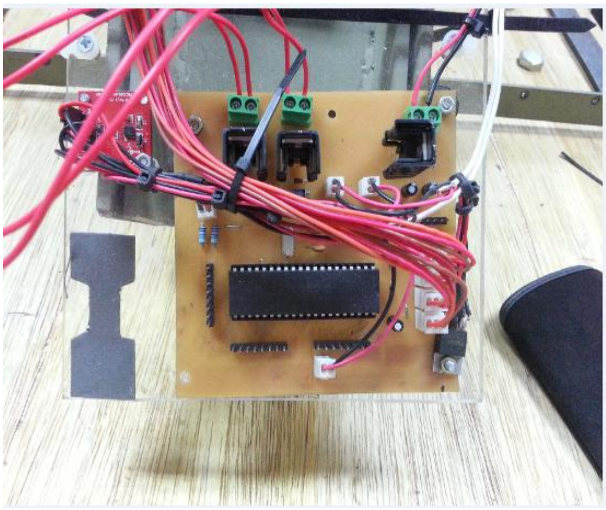

Fig. 3. Fabricated PCB with components (top view).

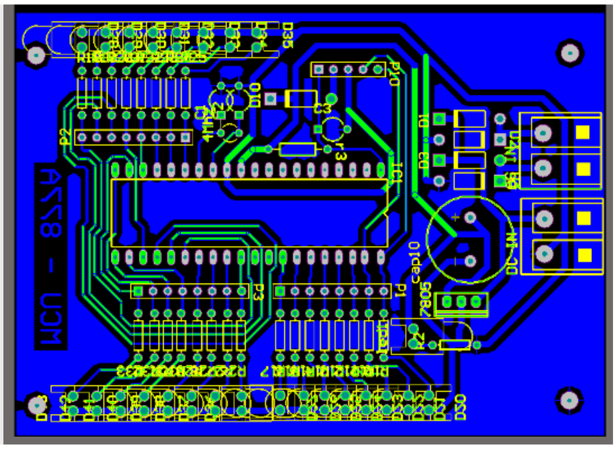

Fig. 4. PCB design.

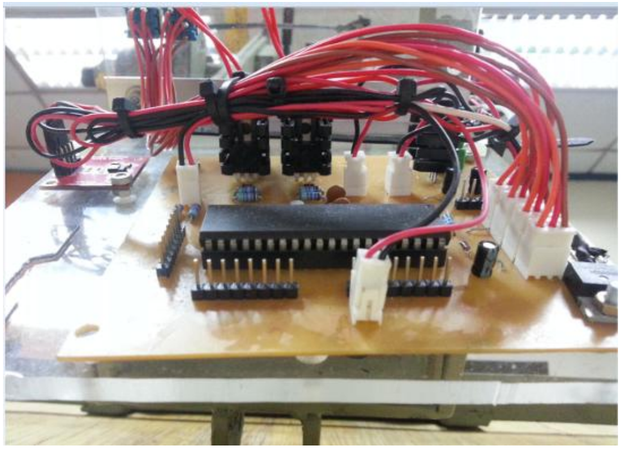

Fig. 5. Fabricated PCB with components (front view).

Fig. 6. Experimental setup.

To simulate the design, the prototype is mounted on a bearing which is manually moved. This is a flexible option to easily simulate quick and the forceful changes in position of the equipment. In order to come up then with the measureable outcome, a laser pointer is included to indicate the position of the nozzle and aligned it in the middle of a circle with a diameter of 2.5 inches, with a target of 1 meter distance. The size of the target is relatively small given the intended targets in a naval setting. The amount of variation over a longer distance can be projected assuming a constant speed and heading of the

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bullet. Testing process is done by logging the distance from the center point of the target on a fixed frequency given the continuous wave motion to the equipment.

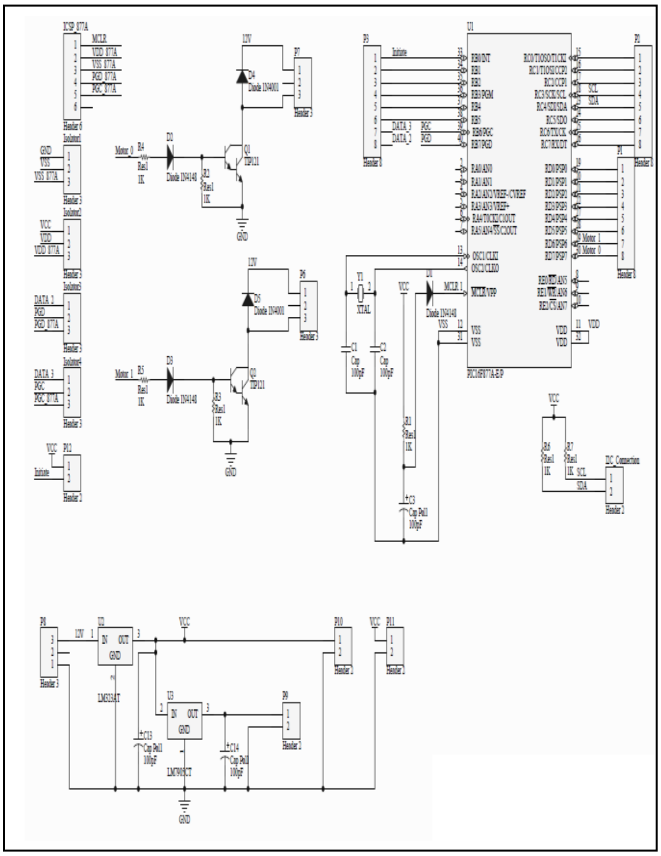

Fig. 7. Schematic diagram.

Statistical analysis is used to ensure the validity of the gathered data. On the data, the amount variation is logged and plotted in a histogram to determine the frequency of occurrence for each delta. Standard deviation and sigma statistical analysis is applied to determine the reliability of the system. Standard variation is a measure of variance; hence, a higher standard deviation gives lower accuracy due to high variation of the end position in the laser pointer, (indicator of position on target) thus; this results to a lower sigma level. Variation of the system is a good starting parameter to be identified since it should be the first to be corrected for it to produce repeatable results before making adjustments to make the mean closer to the target. Note that the parameters established for this application creates the results, which can be recommended for future related research. Sigma is a measure of how many standard deviations does the total population fit within the specified limits. This then is a good representation of accuracy when assuming a normal distribution since a sigma (or standard deviation) distance from the mean results to nearly 68% of data points being within the average, and 95% in using two-sigma; thus, the higher value represents a better accuracy.

Standard Deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

Sigma Calculation:

$$S = \frac{\mu - Lower\ Spec\ Limit}{\sigma}\ OR\ \frac{Upper\ Spec\ Limit - \mu}{\sigma}$$

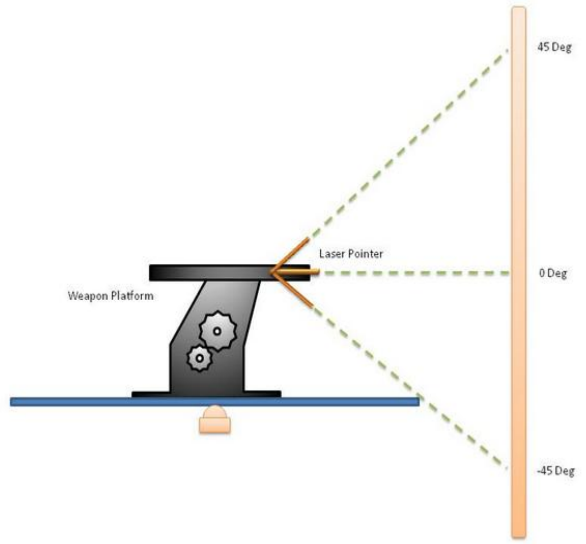

Fig. 8. Illustration of measurement accuracy.

III. Experimental Results

The misalignment averages to the 1.09˚ with a standard deviation of 0.84˚. The sigma level is then dependent on the maximum angular displacement allowable. For example, if a target is 2 square meters in size at a distance 25m away from the weapon, the maximum angular displacement is at 2.29˚. Although, the current data could have been 84% more accurate against the maximum limit and still have some difficulties on how well it can perform with actual runs whose effective data points shall be in the thousands due to the continuous nature of its environment and applications. This is why the sigma level becomes important as it statistically provides insight to possible long term accuracy. Knowing that at 3-sigma, it can be expected that around 93.32% of the output shall be within the spec limits and at 4-sigma 99.379% [4]. The researchers are able to extrapolate the accuracy on any other sigma level that is in between or lower. Continuing the assumption that the target area is 2 square meters at 25m distance, then the resulting sigma level is at 1.4. Therefore, the extrapolated accuracy is around 83.63%, which is relatively close to the accuracy of the 25 measured trials that performed. Depending on the resulting maximum allowable misalignment computed based on target size and distance, the accuracy of the test varies as shown by the blue line in Fig. 10. The six sigma level varies linearly due to the usage of extrapolation which also greatly affects the resulting projected accuracy when considering data points above the average.

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Table 1: Data gathered.

TRIAL	TARGET (cm|°)		MEASURED (cm|°)		MIS-ALIGNMENT (°)
1	14	6.66	17	8.07	1.41
2	14	6.66	14	6.66	0.00
3	14	6.66	17	8.07	1.41
4	14	6.66	19	9.00	2.34
5	14	6.66	16	7.60	0.94
6	14	6.66	19	9.00	2.34
7	14	6.66	13	6.19	0.47
8	14	6.66	17	8.07	1.41
9	14	6.66	14	6.66	0.00
10	14	6.66	16	7.60	0.94
11	14	6.66	12	5.71	0.94
12	14	6.66	10	4.77	1.89
13	14	6.66	18	8.54	1.88
14	14	6.66	13	6.19	0.47
15	14	6.66	14	6.66	0.00
16	14	6.66	19	9.00	2.34
17	14	6.66	12	5.71	0.94
18	14	6.66	19	9.00	2.34
19	14	6.66	11	5.24	1.42
20	14	6.66	14	6.66	0.00
21	14	6.66	15	7.13	0.47
22	14	6.66	18	8.54	1.88
23	14	6.66	14	6.66	0.00
24	14	6.66	17	8.07	1.41
25	14	6.66	14	6.66	0.00

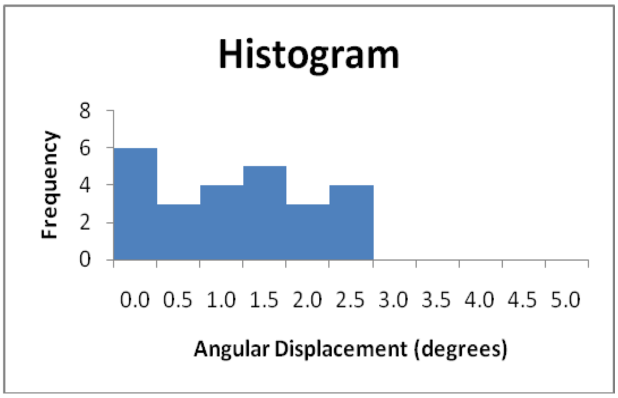

Fig. 9. Histogram of frequency versus angular displacement.

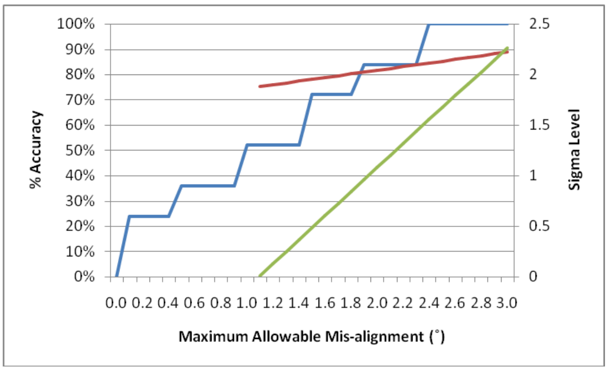

Fig. 10. Accuracy and sigma level.

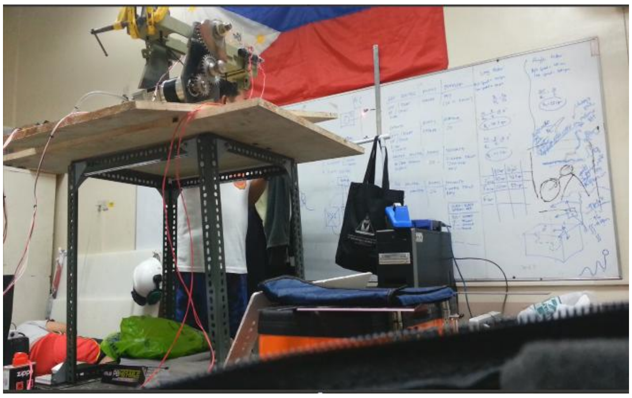

Fig. 11. Tilt up experiment setup.

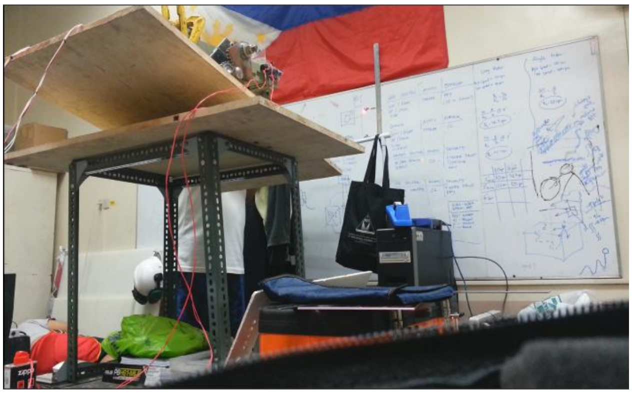

Fig. 12. Tilt down experiment setup.

IV. Conclusion

The accelerometer can be used as a reliable detector of angular displacement to provide information regarding the change in vertical orientation of an automated weapon mounted on a ship. The accuracy that is at six sigma level can be attained only if the maximum allowable displacement is at least 3.6˚ which is not optimized over long distances in a naval setting especially for high caliber weaponry. The researchers recommend added system for optimization of the adjustment parameters of the vertical position that shall account for any added variation on the environmental setting of the system over time. Also, the usage of MOSFET instead of relays on the hardware is far better for increasing the response speed during the activation of the motor as it would be essential when experiencing high impact waves on the sea. The usage of a real time clock (RTC) shall also further improve the accuracy of the measured gyro-meter response since it feeds the data on the rate of change of angular position. Finally, the usage of gears with smaller teeth on the platform would be highly recommended in order to have much smoother movement during the re-adjustment by the DC motor.

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ii. *eGizmo (2011), "ADXR300 Module Information"*
iii. *Freescale (2003), "MMA8451QT-ND Information Sheet"*
iv. *Human Capital Associates (2003), "Lean6sigma: Accelerating Performance Improvement"*