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Design Study of Gyro-stabilized, Remote-controlled Weapon Station

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Abstract

Weaponry is a crucial element in a battlefield. Artillery should be stable and steady when it is fired to the target. However, when the target is moving, artillery becomes a challenge for the shooter to lock its target; the same case when the shooter is moving. Accuracy and precision is a must to avoid casualties and reserve resources. Hence, this study designed a weapon dock that is controlled remotely to have a stable aim on the target. The technology used sensors called gyroscope that is responsible for indicating change of direction and stabilization. A joystick was used as a remote controller for the pitch and yaw which help the shooter to point and lock its target for better accuracy. Quantitative results were gathered from gyro and joystick that aid the researchers to record errors and inaccuracy in the system as the baseline for the stabilization controller to correct. The study achieved the stabilized disturbance with its best response time of at least 630ms which may be improved with fast motor and self-tuning fuzzy proportional-integral-derivative (PID) controller.

***Keywords**:* gyroscope, pitch, yaw, stabilization, PID

1. Introduction

A weapon is any device used with the intent to inflict damage or harm to enemies, structures, or systems (Ramsey, 2016). On the other hand, it is also used for self-defense based on the situation. Weapons ranged from stick to guns and battle tanks. In military, soldiers use different kinds of weapons such as combat knives for stealth or for close range combat, handguns like

M9 and M11, long-ranged guns like sniper rifles and M39 enhanced Marksman rifle (EMR), and highly destructive weapons such as rocket launchers and tank guns. These destructive weapons are easy to use in a still ground, but it affects the accuracy and precision when mounted in a moving vehicle.

A remote controlled system is a remotely controlled weapon station which can be installed on any type of vehicle or other platforms. Such equipment is used on modern military vehicles, as it allows a gunner to remain in the relative protection of the vehicle (Altay, 2010). However, there are also weapons like joysticks that don't require the presence of any human being on site. The most known are the spot-and-shoot weapons used in Gaza by the Israeli army.

The proposition argues that this remote killing, from the distance, shouldn't be used in combats, combats that can also be unilateral. There is a significant difference between the first category, which requires the presence of human being on site and the second, which is like playing Counter-Strike with real persons. The first category gives certain equality for both parties when done in face to face combat while the second category would expose the enemy to a remote attack that may go wrong because it might hit others in the area. The latter should not be practice unless it is accurate and precise to hit the target.

On the other hand, the use of remotely controlled weapons systems (RCWS) could give new dimensions in tactics. RCW are becoming integral element in modern combat platforms - not only on armored vehicles, but also on tanks, aircraft, and naval crafts and even robotic platforms, where RCWS are empowering telepresence with lethal power, as robots are assuming more and more combat roles (Defense Update, 2007).

Elbit Systems' Remote Controlled Weapon Station (RCWS) (Elbit, 2017) is designed for dynamic or static operation using configuration, dual-axis and fully stabilized, which delivers high-speed engagement. A US military product, CS R-400(v)2, is a Stabilized Remote Weapon Station Single Weapon - capability for different calibers uses video track of targets and multi-axis stabilization (Stabilized Remote Weapon Station, 2017). The L-3 Integrated Optical Systems two axis stabilized lightweight Advanced Remote Weapon Station (ARWS) and the Integrated Surveillance Imaging System (ISIS) provides the image stabilization using three field-of-view Thermal Sensor and Eye-Safe Laser Rangefinder, which enables the gunner to identify the enemy at nearly two kilometers (Control Solutions, 2017). In this study, the researchers developed a system that stabilized the Gimbal using dual-axis stabilization technique to improve the accuracy of the project (Tolumba, 2012).

The RCWS is a study based on a gimbal system as well as controlling the machine (Zhou, 2015). A gimbal mechanism as shown in Figure 1, works to rotate a supported body about mutually orthogonal first and second axes (Ni *et al.,* 2006). The supported body is a mounting surface that is in a fixed position and is rotatable. The first support piece is the yaw and is attach to the second support piece that controls the pitch. The gyroscope sensor is located at the rotatable support piece that detects errors in the systems stability (Muchero, 2014).

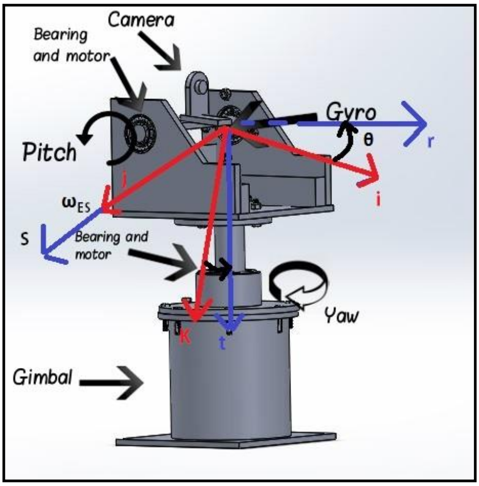

Figure 1. Gimbal Diagram

2. Methodology

2.1 Research Design and Setting

This research used an experimental research design. The components used in the study were determined through experimental means. Figure 2 shows the setup diagram of the remote controller and the weapon station platform interconnected via serial communication. Serial technologies today now improves signal integrity and transmission speed. Using a baud rate of 9,600

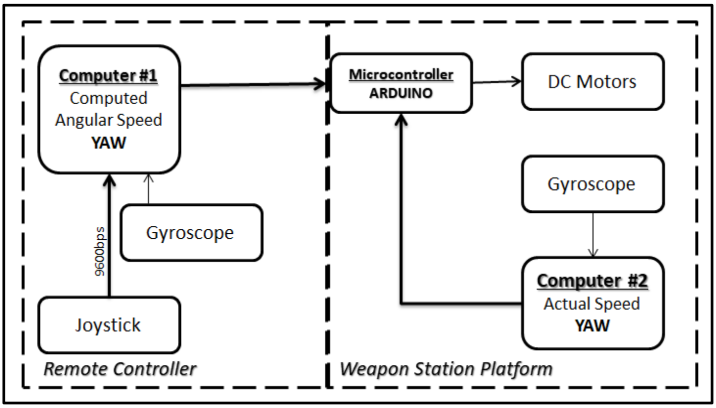

Figure 2. Setup diagram

bps, the maximum distance between the controller and the platform is 500 ft. which gives enough distance for the shooter to take cover. The microcontroller receives the calculated angular speed positioned by the joystick and the actual speed of the motors, thus this has the ability to adjust and control the speed via the PID controller, which serves as a feedback mechanism.

The hardware of the RCWS consists of gimbal, the microcontroller Arduino Uno (Atmega328P), the sensors consist of three-axis gyroscope with accelerometer installed on the gimbal and brushed DC motors for the movement of the gimbal.

2.2 Research Instrumentations

To make sure values and inputs are precise and as much as possible accurate, the following instruments were used. For hardware, multi-tester was used for checking PWM output voltage. Suitable power supply was used to regulate the voltage and current supply to the system. Laptops were used for PID and gyroscope sensor data reading. While for the software side, the arduino IDE is for programming the Arduino microcontroller. The software Visual Studio 2010 facilitated and gathered the data (setpoint) from joystick to the Arduino and the Microsoft Excel as repository of data gathered.

2.3 Gimbal Platform

A gimbal is a platform that can pivot. It means that instead of being fixed to an unmoving base, the object on a gimbal can rotate along at least one axis.

In the world of aeronautics, these axes are roll, pitch and yaw. However, in this study, only pitch and yaw are the axis of RCWS gimbal (Grewal *et al.*, 2001).

The general goal for designing a gimbal is to make it simple and lightweight. The gimbal design has requirements that share the same design of the motion-simulating platforms, which are the following: simple design, lightweight, manufacturable, responsive, simple assembly, aesthetically pleasing, and electronically actuated.

2.4 Controller Design

A PID controller is a control loop feedback mechanism controller commonly used in industrial control systems. The two classical methods for determining the parameter of PID controller were presented by Ziegler and Nichols in 1942. These methods are still widely used, either in their original form or in some modification. They often form the basis for tuning procedure used by controller manufacturers and process industry. The methods are based on determination of some features of process dynamics. The controller parameters are then expressed in terms of the features by simple formula (Meshram, 2012).

A PID controller continuously calculates an error value as the difference between a desired Setpoint and a measured process variable. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)\, dt + K_d \frac{de(t)}{dt} \quad (1)$$

where, K_p, K_i, and K_d, all non-negative, denote the coefficients for the proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D). The general structure diagram of the controller is shown in Figure 3.

2.5 Data Gathering

The researchers conducted several trials, gathered data and tallied the results. Two computers were used to gather the data since using a joystick alone uses the serial communication, and if at the same time gathering data from the gyro would overlap the use of the serial which causes to have erroneous data.

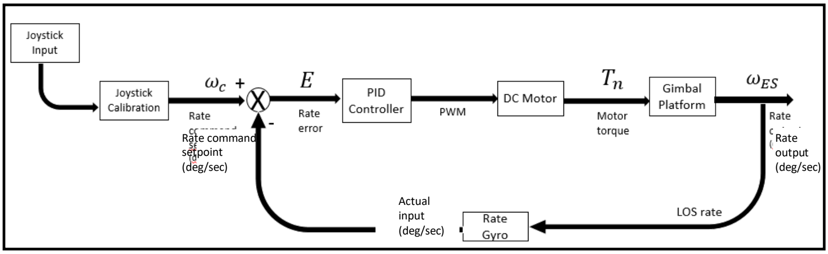

Figure 3. Structure of PID controller for RCWS

The joystick was setup to connect to the first computer which gave the desire angular speed for the yaw that was directly sent to arduino through serial communication. The two gyroscope sensors were used in the testing period: the first gyroscope was connected to the arduino which was connected to the first computer unit. While the second gyroscope was connected to the second arduino that was also connected to the second computer, for data gathering purposes only, to record the actual angular speed of the yaw in the spreadsheet.

3. Results and Discussion

Figure 4 shows a graph of pitch's input and gyro-reading in a setpoint of 0 (zero). The gain set for K_p, was equal to 1.5, K_i equal to 0.15, and K_d equal to 0.5. The setpoint is the desired angular speed of the pitch. When the target is locked, it will set into 0 (zero) and then stabilize. As you can observe in the graph, it needs a lot more of tuning for it to totally stabilize in K_p= 5.1 , K_i= 0.15 and K_d= 0.5.

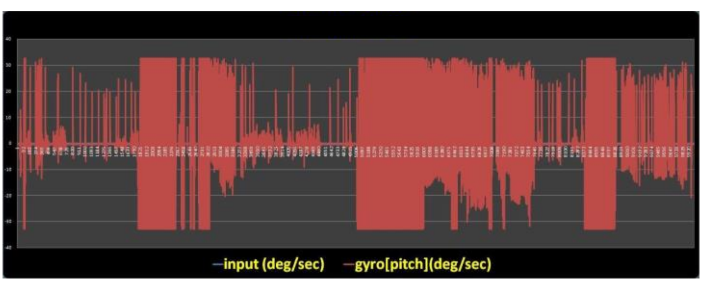

Figure 4. Results data (Pitch graph in Setpoint 0) for
K_p= 5.1, K_i= 0.15 and K_d= 0.5

The data that had been recorded was set in setpoint 0 (zero), these data was gathered while the gimbal was shaken with the same intensity as if it was mounted or inside a moving car. The gathered frequency was between 16.667 Hz and 25Hz. In Figure 5, it shows a graph of the data gathered for the pitch using a joystick. The gain set for K_p was equal to 5.1, and K_i & K_d were set as 0 (zero). Like in pitch, its setpoint is set to 0 (zero), it also needs a lot more of tuning to make it fully stabilized. The frequency gathered was between 16.66667 Hz and 25Hz.

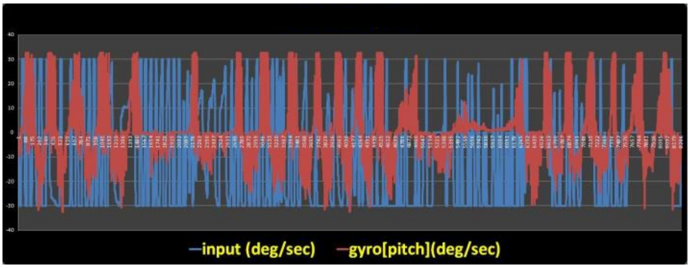

Figure 5. Results Data (Pitch graph with Joystick) for K_p= 5.1, K_i= 0 and K_d=0

Furthermore, Figure 6 shows the graph gathered for the yaw's input and gyro-reading with a Setpoint of 0 (zero). The gain set for K_p was 40, and K_i & K_d was set to 0 (zero). The setpoint is the desired angular speed of the yaw. When the target is locked, it will set into setpoint 0 (zero) and stabilized but as you can see, it also needed for more development and tuning for it to fully stabilized. The gathered frequency is between 16.6667 Hz and 25Hz. It shows a response time of *630ms* and *710ms* to reach the stable state.

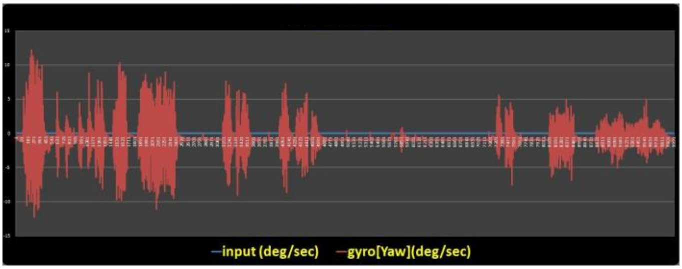

Figure 6. Results data of (Yaw Graph in Setpoint 0) for K_p = 40 , K_i = 0 and K_d= 0

The Figure 7 shows a graph of the data gathered for yaw using a joystick. The gain set for K_p was 0.5, and the K_i & K_d were set as 0 (zero). The system response time is *984ms* to reach stable state. Though it was less than a second to stabilize, it needs advanced tuning technique to stabilize faster.

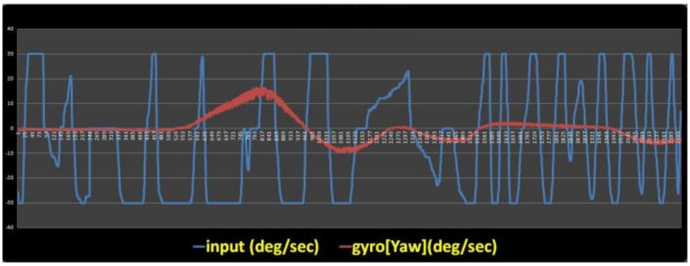

Figure 7. Results Data (Yaw Graph with Joystick)
for K_p = 0.5, K_i = 0 and K_d= 0

Instead, the input was the actual angular speed of the yaw from the gyroscope sensor and as a result, as the input data varies in the system, it reached a stable state using the designed PID controller. From the remote controller to the weapon station, the communication link can handle a maximum of *9,600 bits per second* data transfer with a response time at its best of *630ms*.

The following are the findings of the study. (1) In tuning for the pitch, if the value of K_p is high; assuming that high is the range greater than 7, the response will overshoot. If the K_p is within 6 to 7 range, the system will oscillate. If K_p is in 5, the oscillation decreases, you increase K_p values, i.e. values from 5.1 to 5.9, until it approaches to a steady state error. (2) K_p gain for the yaw should be in very high values that be able to counteract the disturbances. K_p values is found to have values of 200 that is ideal for this system. (3) It is recommended t use a high power brushless DC motor. High resolution absolution encoder is to be used to determine position at power on and ultra-high resolution incremental encoder to provide smooth and precise movement, and gyro stabilization. (4) Controller design should be a self-tuning fuzzy PID controller where PID gains will be tuned by fuzzy logic. The reason for this is that when there is nonlinear and uncertain condition, PID controller doesn’t work well. By using self-tuning fuzzy PID controller, more stable behavior of the system can be achieved. (5) The gimbal design should be lightweight and has a fast response time. (6) Two gyros are suggested to be use, one located on the camera and gun, the second is placed on the base. (7) Passing of data from joystick to arduino has a delay due to the serial communication between visual basic and arduino serial port. It is recommended to use faster communication link between the joystick and microcontroller to avoid communication delays.

4. Conclusions and Recommendation

Design and development of algorithm for interfacing the Arduino Uno ATMEGA328P with gyroscope have been done and validated. The Arduino Uno obtains the raw data gathered and analyzes it. Gyroscope is located in the gimbal structure platform that sense disturbances subjected to the system. The gyroscope sensor considers the horizontal axis.

In this study, the pitch can only be titled from -40 to 27 degrees. The H-bridge motor driver that controls the DC motor using PWM signal is implemented and validated. Gyroscope sensor acts as the measuring tool for tilt angle and was able to control the shaft of motor clockwise or counter clockwise to even out surrounding disturbances. The PWM generated by the microcontroller fed the motor controls and was able to stabilize the platform thus by this, it cancels out the error cause by disturbances.

In addition, this study has achieved two axes platform stabilization and can be extended to cover the third axis, by taking high RPM motors to improve the motor response time.

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