Gyroscopic Effect Analysis of a Battle Bot – a Service-Learning Project

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Abstract

The following paper documents a service-learning project conducted jointly by the department of engineering at Geneva College and the Central Valley High School robotics team in 2012/2013 academic year. The team consisted of a robotics class at the local high school and a senior mechanical engineering student from Geneva College. The goal for the high school was to build a battle robot that would enter in a competition against other schools. One of the winning strategies was to flip enemy robots in order to incapacitate them. The high school robotics team designed a horizontally spinning 'blade' attached to the front of the robot. It was meant to catch the bottom of opposing robots and flip them.

One of the problems with the design was that when the robot made a turn, the spinning blade exerted a moment which tended to tip the robot about a horizontal axis extending through the front and back of the robot. How to balance the conflicting goals of maximizing the effectiveness of the blade while maintaining the stability of the robot was a challenge. Under the supervision of a college professor and the high school robotics teacher, the college student developed a dynamics model to help the robotics team deal with the problematic side effect of the spinning blade. When speed went up, the blade began to exert significant gyroscopic moments on the robot under certain conditions. The gyroscopic model the college student created provided the high school team some design

guidelines to follow. It was a gratifying experience for the college student because he was able to use his analytical skills gained from years of engineering science study at the college level and apply it to a real problem. It was an enriching learning experience for the high school students as well, as they came to realize the power of physics and math at work in a battle bot competition.

Keywords: gyroscopic effect; service-learning; robotics; BOTS IQ; dynamic modeling

Introduction

Robotics competition has been gaining popularity among highschoolers[1]. Simply put, Bots IQ is battling robots. Two robots compete in a gladiator style fight to the finish in an enclosed arena. The robot left "standing" wins the fight. College level Bots IQ has a different weight scale than highschool Bots IQ[2]. SWPA Bots IQ was developed as an educational robotics competition for high school age students. It provides the students with a unique, hands-on experience that allows them to discover the possibilities of a career in the manufacturing sector, and other science, technology, engineering, or math (STEM) fields[3]

Bots IQ began as a matter of necessity. Several local companies and the National Tooling and Machining Association started Bots IQ in the South Western Pennsylvania region in 2004. In its inaugural year Bots IQ had 6 teams and has quickly grown to 52 teams. The purpose of the program was to spark an interest in high school age students in the areas of precision machining and engineering. Industry has recognized the problem it faces, an aging work force approaching retirement. In addition there have been very few students following the path into industry and engineering. A question needed to be answered, how to get students interested and excited about machining and design? Bots IQ was the answer.

The system works like this: companies sponsor local schools by providing them with money or materials, machining assistance and guidance through an industry advisor. The school provides at least one interested teacher to facilitate a team of at least four students. The robot must be student designed, assembled and operated. Students also assemble a documentation binder of all their research, material testing and information, and design work. Assistance can be provided for machining operations and complex design problems. Students begin their development in early October at a kick-off meeting and finish at the final two-day regional competition in April.

Central Valley High School[4] has been involved with the Bots IQ program since 2007. Student interest has grown each year propelling the success of the program. The Central Valley team has been very successful in competition and in the developments they have made in their designs. Students brainstorm, research, and design their robots in addition to being involved with machining processes throughout the development of creating the robots. Originally started as an afterschool engineering club that met once a week, the program has evolved into a class, which meets each day throughout the entire year. Central Valley students have had the opportunity, through Bots IQ, to speak at several community gatherings, present their robots at technology fairs, intern with local companies and gain employment working with robotic systems.

In the first year, not having much experience, the design focused on having a simple yet very strong robot able to be inverted and maintain functionality. The second robot kept the ability to invert and a blade was added. It was found that having a moving object on a mobile robot added significant complexities. The blade was under-designed in both size and strength. The third robot continued the ability to invert as all previous robots. A very durable material was utilized for the blade to increase toughness; however the forces involved were significantly underestimated for a large 8 inch diameter blade spinning at 30,000 RPM. Gyroscopic effect was experienced for the first time with the third robot and a solution needed to be found to lessen it. The following two robots incorporated much smaller and lighter blades allowing the team to essentially eliminate the gyroscopic problem. After several more designs and several more competitions the team found themselves at a critical point.

In designing for the Bots IQ competition several things should be identified. One, high school students do not always design what is practical, bigger is better and if a weapon can inflict damage that is considered bonus points. Two, the judges want to see a robot capable of control, able to inflict damage or incapacitate the opponent, and a clear strategy. Three, if a concept can be proven mathematically and can meet both the judges' criteria and the students' criteria, then it is a good place to start. The strategies and system improvements have caused the team to identify several critical questions. In addition to repeated design tests and video observations the team has been able to narrow their focus to one major design flaw, gyroscopic effect. They want to know how big and heavy the blade can be designed before gyroscopic effect is problematic. They also want to know how fast the blade can be turned so that operators can maintain control of the robot while still having the capacity to inflict as much damage as possible to the challenging robot. The team decided to ask for help from a mechanical engineering professor and his students at Geneva College.

Gyroscopic Effect Modeling

The service-learning project has involved helping the Central Valley High School robotics team. The team consists of a robotics class which builds a robot that is entered in a competition against other schools. The robot must flip enemy robots in order to incapacitate them, thus winning the match. To this end, the robotics team designed a horizontally spinning 'blade' attached to the front of the robot, see Figures 1 and 2.

Figure 1 Horizontally spinning 'blade' attached to the front of the robot

The blade is meant to catch the bottom of opposing robots to flip them. Figure 2 shows this robot flipping one of the competition teams' robot.

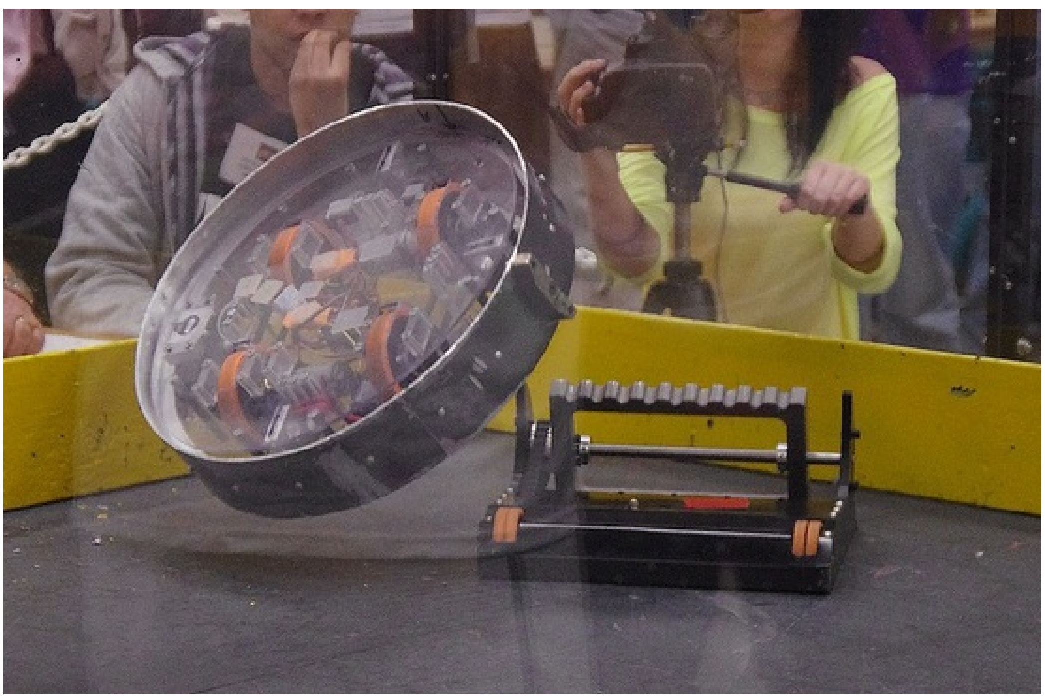

Figure 2 Flipping of an "Enemy" Robot (left) to the Air

The maximization of the effectiveness of the blade is clearly a primary concern. The other major concern is the maximization of the stability of the robot in order to best thwart attempts by opposing teams to flip the robot. Towards this end, the robotics team designed the robot to be built low to the ground with the greatest weight possible. Consequentially, they chose the maximum weight allowed in the competition rules, fifteen pounds. Because the competition area has a steel floor, the team also added magnets to the bottom of the robot, effectively increasing the weight of the robot by twenty pounds.

A senior engineering student (first author) was assigned to this service-learning project in the beginning of the Fall 2012 semester as part of a two-semester-long senior design project. During that period the student helped the robotics team deal with a problematic side effect of the spinning of the blade.

At full speed, the blade exerts significant gyroscopic moments on the robot under certain conditions. Specifically, when the robot makes a turn, the spinning blade exerts a moment that tends to tip the robot about a horizontal axis extending through the front and back of the robot. In previous years, this has been a problem for the team.

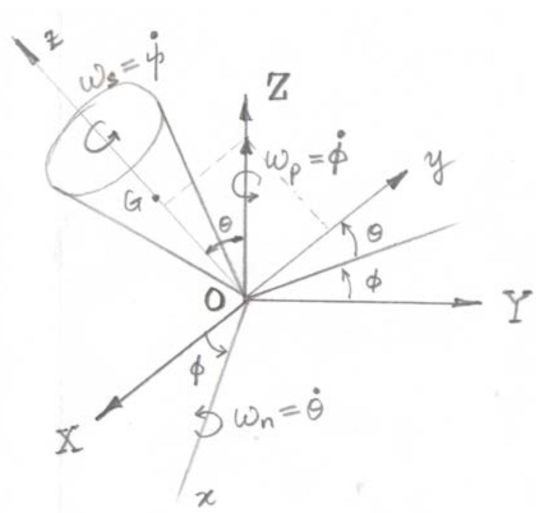

Figure 3 Gyroscopic effect modeling

As shown in Figure 3, a typical gyroscope is governed by this equation[5]

$$\Sigma M_x = I\left(\ddot{\theta} - \dot{\phi}^2 sin\theta cos\theta\right) + I_z\dot{\phi}sin\theta\left(\dot{\phi}cos\theta + \dot{\psi}\right) \qquad (1)$$

The left-hand-side of the equation generally describes the moment about the x axis caused by the gyroscopic effect. Let the x axis be the axis about which the robot tends to tilt. If this equation is solved for situations where there is no tipping, then the angular velocity and angular acceleration about the x axis will be zero:

$$\omega_n = \dot{\theta} = 0 \qquad (2)$$

and

$$\ddot{\theta} = 0 \tag{3}$$

Since the blade spins around a horizontal axis, the z axis must be horizontal. Therefore,

$$\theta = 90° \tag{4}$$

Given these assumptions, the general form of the equation above reduces to the much simpler equation:

$$\Sigma M_x = I_z \dot{\phi} \dot{\psi} \tag{5}$$

Figure 4 depicts the blade in this simplified dynamic model,

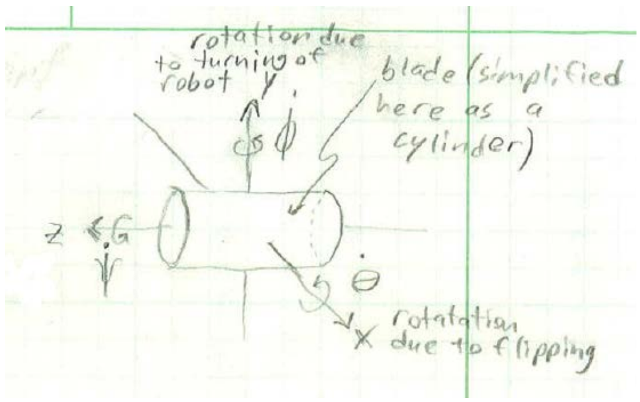

Figure 4 Gyroscopic Effect - Modeling of a Battle Bot

$\dot{\psi}$ is the angular velocity of the blade in its spinning direction in radians per second. $\dot{\phi}$ is the angular velocity of the blade in the direction the robot turns in radians per second. This will be the same magnitude as the angular velocity of the robot about its center of rotation. I_z is the moment of inertia of the blade about the z axis.

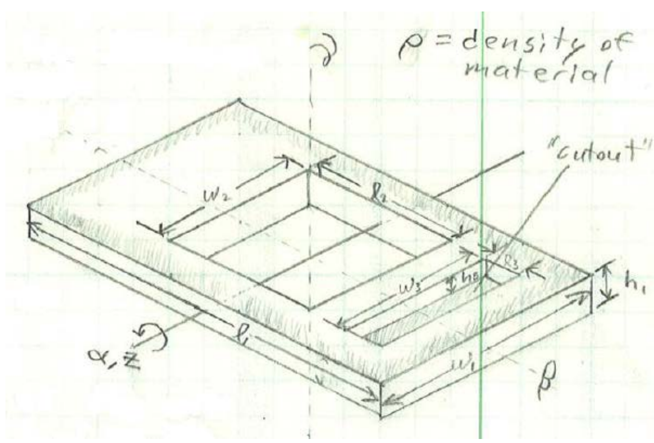

Figure 5 Blade Design

Figure 5 represents the blade and shows the general form that it will take. The “cut-out” has a symmetrical counterpart on the opposite side of the slab. The cut-out’s center of gravity is not on the α axis, so its moment of inertia is,

$$I_z = -2\left[\frac{1}{12}\rho l_3 w_3 h_3\left({l_3}^2 + {h_3}^2\right) + \rho l_3 h_3 w_3\left({C_\gamma}^2 + {C_\beta}^2\right)\right] \qquad (8)$$

where C_γ is the distance, in the γ direction, from the “cut-out” center of gravity to the α axis, and C_β is the distance, in the β direction, from the “cut-out” center of gravity to the α axis. The moment of inertia of the blade is the sum of these three,

$$I_z = \frac{1}{12}\rho l_1 w_1 h_1\left({l_1}^2 + {h_1}^2\right) - \frac{1}{12}\rho l_2 w_2 h_1\left({l_2}^2 + {h_1}^2\right) - 2\left[\frac{1}{12}\rho l_3 w_3 h_3\left({l_3}^2 + {h_3}^2\right) + \rho l_3 h_3 w_3\left({C_\gamma}^2 + {C_\beta}^2\right)\right] \qquad (9)$$

This is the I_z used to calculate the moment that the blade’s gyroscopic effect exerts on the robot, tending to flip it. The blade’s moment is countered by the moment of the weight of the robot times the distance from the center of gravity to the edge of the robot. As long as the moment exerted by the weight is larger than the gyroscopic effect, the robot will not tip. The effectiveness of the blade can be judged by its kinetic energy, which is found using the following equation,

$$KE = \frac{1}{2} I_z \dot{\psi}^2 \qquad (10)$$

The variables blade moment of inertia, blade spinning angular velocity, robot turning angular velocity, robot weight, and robot width should be adjusted accordingly.

The robotics team has designed the blade geometry in SolidWorks and has provided the authors with a printout of the moment of inertia information. From this, it has been calculated that the blade moment of inertia about the z axis is 5.24 lbm·in^2.

In order to obtain a good estimate of the angular velocity of the robot's blade, Fast Fourier Tranformation (FFT) analysis was used. An audio recording of the blade was made when it was at maximum angular velocity. The file was recorded as an MP3 and later converted to the WAV format as it includes a more complete range of frequencies. Matlab was then used to analyze the WAV file and perform a FFT of it. The code used was adapted from a Matlab wave file analysis tutorial on the website of Worcester Polytechnic Institute.[6]

The raw sound is shown in Figure 6. The wave FFT result is shown in Figure 7.

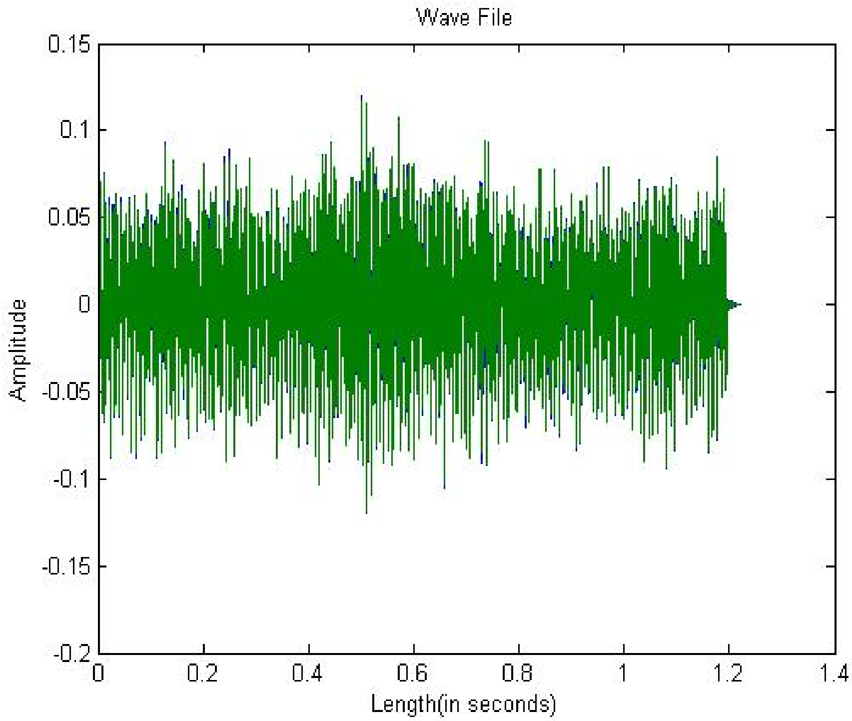

Figure 6 Raw Sound Data

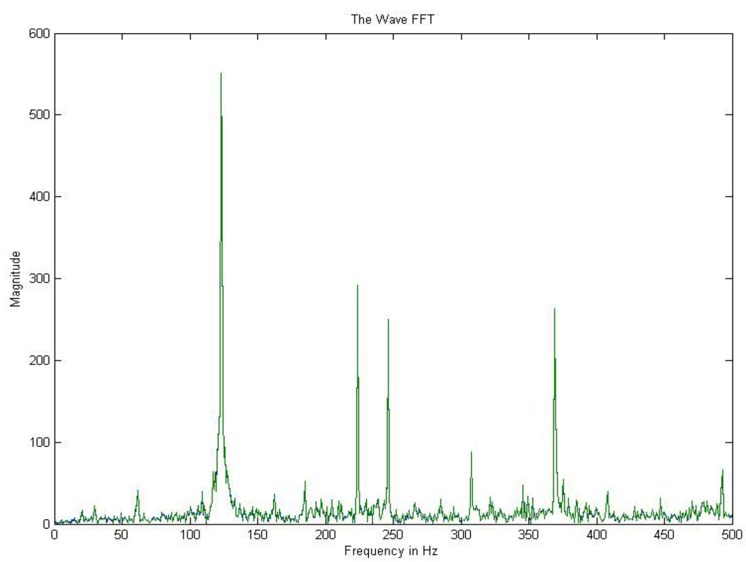

Figure 7 FFT Analysis of the Blade Sound

A spike at 125 Hz can be seen. The spike indicates the number of repetitions in the movement of the blade per second. To convert to rpm, the frequency is multiplied by 60 sec/min: (125 Hz) x (60 sec/min) = 7500 rpm. 7500 rpm is baseline angular velocity of the blade that was used.

With the width of the robot given by the team, it was found that the moment resisting tipping is 76 lbf·in when factoring in just the weight of the robot and 177 lbf·in when factoring in the weight of the robot and the force exerted by the magnets.

The equations were entered into an Excel spreadsheet and given to the high school team. The formula was also shared with other high school teams. Figure 8 shows the CAD model of the design.

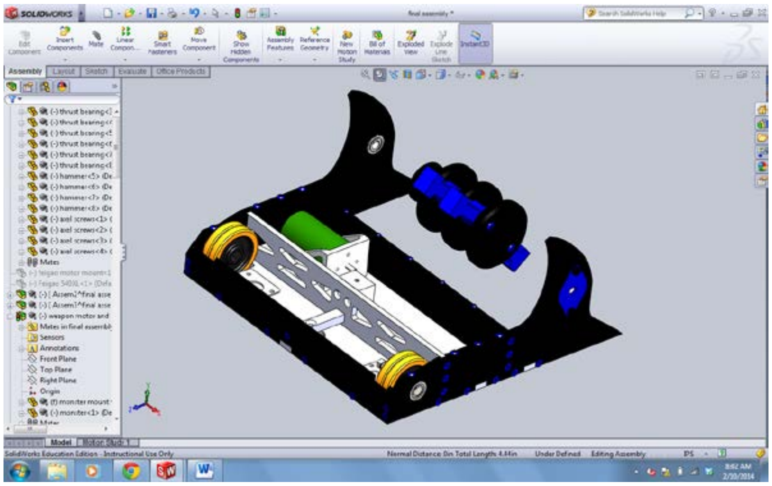

Figure 8 SolidWorks Model of the Battle Bot

Conclusions

The service-learning project achieved its goal of educating both the high school robotics team and our college student (the first author). The gyroscopic model provided the high school team some design guidelines to follow. The formula was also shared with other high school teams. It was a gratifying experience for the college student because he was able to use his analytical skills gained from years of engineering science study at the college level and apply it to a design problem. It was an enriching learning experience for the high school students as well, as they come to realize the power of physics and math at work in a battle bot competition. The high school students were later invited to tour the engineering department labs at the college and were given some books in the field of STEM as gifts.

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Biographical Information

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David Smith graduated from Geneva College with a B.S.E. degree in mechanical engineering. He is currently pursuing a M.S. degree in mechanical engineering at Baylor University, where he is researching fiber orientation in composites. He was an intern at Sig Sauer during the summer of 2012.

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David Che joined Geneva College in Beaver Falls, PA as an Associate Professor of Mechanical Engineering in 2008, where he also currently serves as the Director of the Pinkerton Center for Technology Development. He received his B.S.E in precision mechanical engineering from Harbin Institute of Technology, China, M.S from Ohio State University and Ph.D from University of Michigan, all in mechanical engineering. He was a senior research/project engineer at General Motors Corporation from 1997-2005. He also served as general manager of Stafast Products, Inc.'s Asia operations in China from 2005-2008.