Gyroscopic Stabilization of Unstable Vehicles

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A B S T R A C T

The purpose of this project is to design and build a rapid prototype control moment gyro (CMG) stabilized vehicle to demonstrate a proof of concept and help advance further research into the idea of terrestrial robotic stabilization with CMGs. In the constructed first generation prototype, a single CMG was mounted onto an unstable 2 degrees of freedom (DOF) vehicle, currently only capable of a rolling motion, and balanced said vehicle by countering external disturbances through use of the precession effect. An external torque applied to the vehicle causes the CMG react by turning on an axis that is perpendicular to both the spin axis and torque axis and creates a restoring torque on the vehicle, returning it to its desired position. The active control of the gimbal rate angle, and the resulting torque, forms the basis of the actuating mechanics. The vehicle created does successfully demonstrate the ability to self-stabilize and return to equilibrium when disturbed, showing a successful implementation of hardware and principles. Future models will see a vehicle with no umbilical tether to allow for further range of movements, a 4 DOF model capable of pitch and yaw in addition to roll, and eventually a robot with two mounted CMGs to allow for stable self-propelled motion.

1. Introduction

The current use of control moment gyro (CMG) technology in the modern world is almost wholly restricted to the space industry. This is to be expected; CMG technology was invented for use in space as a convenient and efficient way to maneuver vehicles in an environment that has no solid surfaces to push off from, which is not a problem on land. However, the use of CMGs for the stabilization of terrestrial robots has the potential to revolutionize the field of robotic mobility.

Currently, bipedal robots are slow, clumsy machines, capable of only the simplest and slowest of movements. This problem stems from how robots are designed to walk. All terrestrial robotics maintain stability while walking by keeping their centers of gravity within a defined box, usually aligned with the balls of their feet. Should its center of gravity stray outside this zone of stability, the robot will inevitably fall. This narrow range of safety means that modern robots are not capable of a great range of movements.

With the inclusion of CMG technology, a robot will be capable of leaving this zone of stability and will be able to perform more complex and rapid movements while having the CMG it uses apply a correcting torque in its body to keep it from falling.

It is the purpose of this paper to show the feasibility of using a CMG to stabilize a land-based vehicle by building a rapid prototype vehicle to act as a springboard for future research prospects.

2. Methodology

Because the purpose of the build project was to prove the efficacy of the land-based use of CMGs for robotic stabilization in a quick and efficient manner, the group chose to start with a simple, easily testable design.

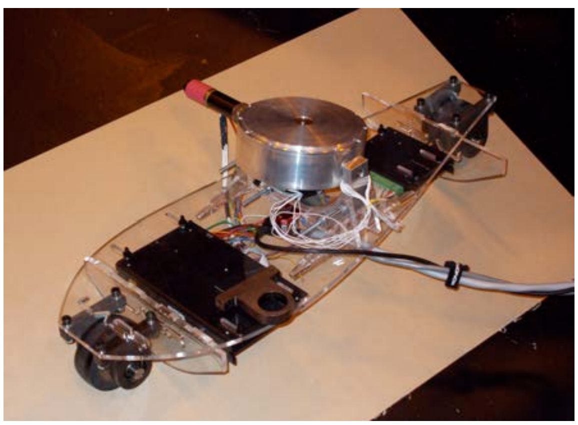

Fig. 1. Picture of experimental setup of CMG stabilized vehicle.

As such the first generation prototype was constructed (See Figure 1) with a single variable speed CMG, which was run at constant speed during the testing phase, mounted onto an unstable 2 degree of freedom (DOF) vehicle, only capable of a rolling motion, with a VN-100 Attitude Heading Reference System (A.H.R.S.) attached to determine the acceleration and roll angle of the vehicle. The wheel speed used for the CMG was determined to either be 3,000 or 5,000 rpm, depending on the output voltage used, 12 V or 24 V respectively. The vehicle's roll angle was restricted to ±35° by design to prevent damage to the CMG should the vehicle tip over, and only had a maximum gimbal rate of 12 rpm.

In addition to the hardware implemented for the experiment, a controller for the vehicle also needed to be created. This controller was derived from the Equations of Motion of this particular system, in order to provide the proper inputs to balance said vehicle.

The use of a CMG to balance an unstable body works through the gyroscopic unit countering any external disturbances to the system by use of the precession effect. When an external torque or force is applied to the vehicle, the VN-100 will pick up the acceleration and position of the body in real time and send the information to the controller, which will react by rotating the CMG on an axis, the y-axis in Figure 2, at some determined angular velocity, $\dot{\theta}$, that is perpendicular to both the spin axis (z-axis) and torque axis (x-axis) and thus create a restoring torque on the vehicle, returning it to its desired equilibrium position. The overall magnitude of the resultant torque is dependent upon the gimbal velocity of the CMG and its angular momentum. See Figure 2. The controller will then attempt to return the gimbal angle back to zero. The active control of this gimbal rate forms the basis of the actuating mechanics that balance the vehicle.

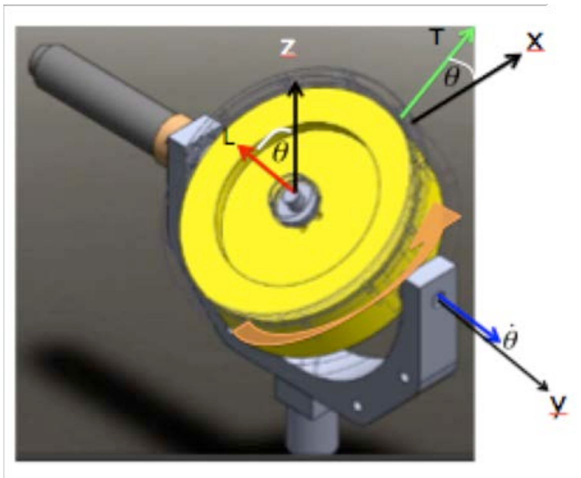

Fig. 2. CMG vectors and scalars defined.

3. Results and Discussion

The prototype vehicle created successfully demonstrates the ability to self-stabilize, return to, and stay in an equilibrium position when disturbed by some outside force, as demonstrated in Figure 3.

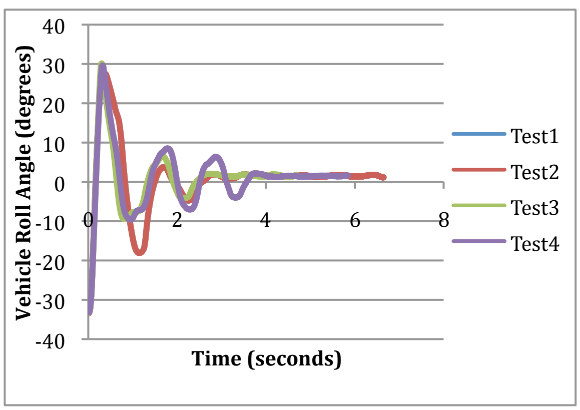

Fig. 3. Experimental results for multiple trials of vehicle roll angle over time. All trials show effective stabilization in less than 4 seconds.

The prototype, when set to begin at its maximum angle of tilt of approximately 35°, shows the ability to reorient itself to its neutral position in just about 4 seconds of actuation from the CMG.

This rapid and effective display clearly shows a proper implementation of hardware and principles, and proves the feasibility of terrestrial based CMG usage, at least on a small scale.

With the success of the current rapid prototype model, future more ambitious and complicated endeavors are already being planned by the LASR lab in order to fully explore the possibilities of the terrestrial use of CMGs.

Early stages for the continuation of the project will see a series of small steps forward. A vehicle with no umbilical tether to a power source and computer, as seen on the right-hand side of figure 1, to allow for a further range of movements and the inclusion of wheeled testing are some of the planned improvements. A 4 DOF model, capable of pitch and yaw motions in addition to the roll of the current prototype is also scheduled to be produced. In addition, the lab currently hopes to design and create a robot with two mounted CMGs, instead of one, on a wheeled, flexible base to allow for stable, self-propelled motion as the next significant step forward in research.

4. Conclusions

The implementation of CMGs on terrestrial based robots is feasible and future vehicle design and prototyping can commence.

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