A Novel Approach to Vibration Isolation in Small, Unmanned Aerial Vehicles

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Abstract—*Small accelerometers currently used in ground, robotic platforms measure inclination of vehicles and positions of actuators. However, the vibration of aerial vehicles due to rotors makes them it impracticable. The sensor cannot provide the precision necessary to control an aerial platform and distinguish between vibration and inclination. An isolator that is configurable, lightweight and axis-independent would be advantageous. Tempur-pedic® foam provides these capabilities and initial tests have resulted in over a 50% reduction in measurement error. This can lead to improved aerial control and performance, making the impracticable, practicable again. Furthermore, improved autonomous flight that is less dependent on human interaction and skill becomes more plausible. Small unmanned aerial vehicles, especially helicopter-type, can provide some significant advantages and capabilities where an unmanned ground vehicle is unsuitable, impracticable or limited.*

1. Introduction

Since the beginning of the War on Terrorism with deployments to Afghanistan and Iraq, the proliferation of robots, large and small, continues to expand and grow as essential elements to units in those forward-deployed areas. Robotic companies have developed an array of Unmanned Ground Vehicles (UGV) that is soldier transportable, while Unmanned Aerial Vehicles (UAV) continue to be limited to airplane-type configurations.

In an urban environment, the use of a Raven or similar UAV provides a large or top-down, aerial view with little capability of a static, localized or ground-view perspective, i.e. observation into a second floor window or an area inaccessible by ground. Helicopter-type configurations lag years behind in concept, development and implementation because of cost, propulsion, endurance, sensors and miniaturization. Many Micro Air Vehicles (MAV) have been developed and tested, but only airplane-type have been produced and utilized in many difference regions around the world. Many insect-type and helicopter type continue to be in simulation and prototype phases.[1]

While there are many radio-controlled helicopters that would suffice in capabilities, they require a skilled radio control (RC) pilot. Many companies are developing RC-type helicopters, but sensor packages, endurance and video surveillance requirements can quickly exceed payload capabilities. Large aerial systems can use larger, gyroscopic accelerometers because they have the power and payload while small systems cannot. State-of-the-art accelerometers are small, light-weight and require little power, but they are extremely susceptible to vibration. Many vibration isolators currently in use—spring, rubber or elastomeric—add significant weight to dampen low harmonic frequencies and may only provide dampening in one axis.

This paper describes the selection of the isolator, the equipment selected, tests conducted, results of these tests, comparison with other experiments, error mitigation and conclusion with future work.

2. Theory

Choice of Vibration Isolator

The author proposes the use of a foam-type isolator, Tempur-pedic® foam, to reduce high-frequency vibration imparted onto electrical accelerometers from a quad-propeller system. As demonstrated in a TV commercial, a mattress-sized piece of the foam could negate low frequency vibrations, but would it significantly reduce higher frequencies used in RC helicopters? Through touch alone, there is a noticeable difference in the amount of vibration imparted to the aircraft before and after this piece of foam.

Figure 1 – Sample Foam

There are various types of damping materials. Amongst them, neoprene and natural rubber have one of the lowest damping factors, and therefore, not well-suited for low frequency vibrations.[2] The foam pictured above has a higher damping factor to account for high frequency vibrations as well as the many, harmonic lower frequency vibrations associated with a multi-bladed helicopter system. With an increase in the damping factor, the natural frequency of the isolator system decreases which causes a reduction of the transmitted vibrations because transmissibility is the highest at the natural frequency. An increase in transmissibility amplifies the amount of vibrations instead of reducing it.[3]

3. Test Equipment and Procedures

Hardware

A quad-propeller system is beneficial in that it provides static propeller orientation and full electrical control while a single-propeller system requires a combination of mechanical and electrical control. Using an RC toy as a platform, the author used a BASIC Stamp2p installed on a Board of Education (BOE) and a MEMSIC 2125 dual-axis accelerometer mounted on the BOE. The BOE was either mounted directly onto the system or on the 3”x4”x1” foam.

Figure 2 – Helicopter System

Software

The Stamp2p controlled the DC motors by TTL utilizing a power MOSFET circuit for each motor. The program created a Pulse-Width Modulation (PWM) signal to control the duty cycle for each motor. The program extracted accelerometer readings from a 50 to 100% duty cycle with 50 iterations at each setting. Less than 50% was unnecessary because the vehicle would be in a non-flying profile under any power or load conditions.

Performance Adjustments

Instead of the 12 volts nominally rated for the DC motors, the voltage was reduced to six volts for analysis to prevent the system from flying and thus impart additional movement and vibration error. For analysis and comparison, measurement results from all four propellers operating simultaneously provided the desired effect of normal operation of the aerial system.

4. Results and Discussion

Performance

During testing, the foam provided a 53% (pitch) and 61% (roll) overall reduction in the axes over the range of vibration measurements as compared to the stationary value. The differences between axes can be attributed to the sensor not being mounted at the origin of the foam or system because of the structural configuration of the system. This corresponds to different length of the vibration transmission through the foam. This small piece of foam yielded remarkable results for this type of accelerometer.

Below, figure 3 shows the pitch and roll vibration variance from a fixed position without the foam. In figure 4 the BOE is mounted on the foam as shown in figure 5.

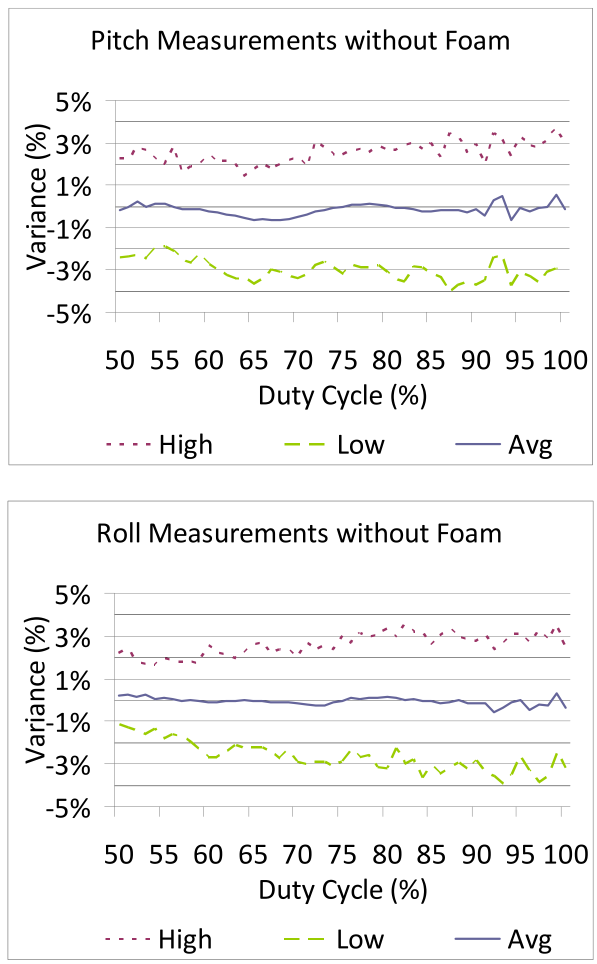

Figure 3 – Vibration Variance without Foam

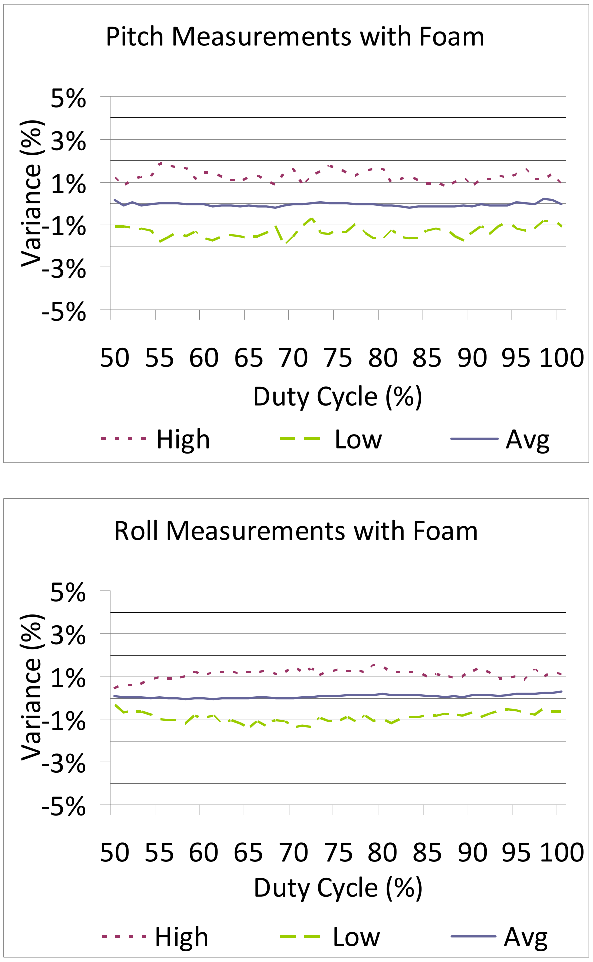

Figure 4 – Vibration Variance with Foam

Moreover, the foam provided a 65% (pitch) and 60% (roll) improvement based on the averages for each speed setting. Furthermore, this demonstrated that the average of multiple measurements with a small variance can yield the desired measurement. The cost associated with additional measurements is additional time which reduces a system's response time to apply flight corrections. The foam can reduce the number of iterations and time required for acceptable measurements.

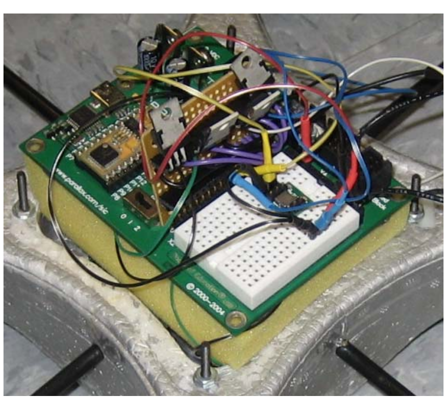

Figure 5 – Sensor Mounted with Foam

Since the foam is nonsymmetrical, additional tests verified that an increase in foam transmission length corresponded to an increase in vibration reduction. The results between the two axes correspond to the difference between the length and width of the foam.

Other Vibration Isolators

Other designers have tested various types of materials—springs, silicone gel, neoprene and rubber—to reduce vibration transmission along one axis. These devices typically weigh more because of material density and mounting hardware. For applications in a small aerial platform, excess weight is a significant concern requiring compensation through the reduction of battery size or removal of other system components. For small UAVs, a foam-type isolation system is a better choice in terms of weight and vibration isolation for multiple axes.

One group had designed a single-bladed helicopter system using several neoprene isolators, a large and heavy package with gyros and accelerometers, a CPU and additional equipment and sensors to perform autonomous aggressive maneuvers.[4] This is a complex solution to a complex problem and does not leave much capability for mission equipment and capability in its current design and not conducive to the author's design.

Supplemental Benefits

Because the foam is lightweight, elastomeric and has memory, its use can provide significant complementary advantages for aerial vehicles. The foam can encapsulate sensors and mount in a cavity or on an external component, similar to the test system discussed in this paper.

Depending on the packaging of the sensor, the foam can also act as insulation, structural protection or an additional, structural component. Of note, the size and the amount of compression of the foam affect the amount of vibration isolation. While a larger piece of foam can further reduce vibration transmission, compression of the foam to fit within a cavity of a UAV can reduce the desired benefit. Consequently, the size and shape of the foam must be designed for its system.

5. Error Mitigation

The mounting of the sensor and configuration of the foam is critical to the amount of error imparted to the results. One main concern is to isolate the vibration imparted by the motors from the movement of the aircraft. The reduction of voltage to the motors reduced the amount of movement of the system, while the modulation of the PWM to the motor continued to provide vibration for analysis.

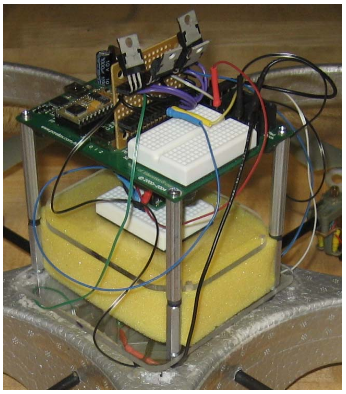

Figure 6 – Improper Mounting

Secondly, the length of vibration transmission through the foam affected the results. The foam measured 3"x4"x1" in dimension. If the foam was attached to a piece of acrylic shown above in Figure 6 which allowed easier attachment to the aircraft, only one inch of foam could isolate vibration. Additionally, vibration from all directions would constructively combine at mounting locations and transmit throughout the acrylic uniformly which inhibited the ability of the foam to disperse the vibrations beneficial to its structure. This mounting also seemed to impart more vehicle movement to the entire foam which increased the amount of error in the vibration measurements.

During one sequence of testing based on the above configuration, the measurement results were negligible between tests with and without the foam. These results demonstrate the need for proper mounting that both increase the amount of vibration transmission length and the constructive benefit of the structure of the foam. Figure 5 shows the configuration that utilizes these aspects of the foam.

6. Conclusion

While this foam was designed for larger applications and lower frequencies of vibration, these tests demonstrate that it is useful in small, high-frequency devices such as a semi-autonomous aerial reconnaissance robotic platform. The foam reduces the amount of vibration, and hence the error of measured values, which reduces the number of iterations for an average to yield accurate results for an aerial platform in this configuration. Utilization of foam in this system can result in reduced weight, power requirements and response time for accurate sensor data. Future tests will incorporate iterative sensor analysis, higher power settings, flight tests and additional accelerometers.

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8. References

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