Improving the response time of inertial sensors using feedback and an advanced drive algorithm

Mounir Hinedi1, Lawrence Barrett1, Alex Stange1, Corey Pollock1, Josh Javor1, David Bishop2,3,4,5

1 – Division of Materials Science and Engineering, Brookline, Boston, MA 02446. 2 – Department of Mechanical Engineering, 110 Cumming Mall, Boston, MA 02215. 3 – Department of Physics, 590 Commonwealth Avenue, Boston, MA 02215. 4 – Department of Electrical and Computer Engineering, 8 St Marys St #324, Boston, MA 02215. 5 – Department of Biomedical Engineering, 44 Cumming Mall, Boston, MA 02215. 6 – St Christopher’s School, Block 841, 119 Rd No 4109, Isa Town, Bahrain

Introduction:
Inertial sensors are the principle of inertial to measure vector quantities. This is done through the mechanical shift of their internal system’s equilibrium position. Examples include accelerometers, magnetometers and gyroscopes.

The response speed of an inertial sensor depends on the time it takes to settle at a new equilibrium position. To decrease the time it takes to settle, ringing must be eliminated. Ringing is caused by the system continuously overoscillating as it tries to reach equilibrium.

The aim of this research is to produce an algorithm which will increase the response speed of the inertial sensors. This will be done by using a two step drive and feedback from an accelerometer and a magnetometer. This algorithm predicts the final equilibrium position and provides a counter impulse using the electromagnetic to prevent the system from overoscillating.

This investigation is important as it can increase inertial sensor detection speed. This is especially important if the stimulating force lasts for less time than the settling time of the system.

Methods:
To create and test the algorithm, a macroscopic model of an inertial sensor was used. The setup consisted of an accelerometer attached to a magnetic pendulum, an electromagnet, a magnetometer, and an arduino controlling an electromagnet. The electromagnet would produce a random force, pushing the pendulum away. The accelerometer and magnetometer would then detect the movement and output it back to the arduino.

Although accelerometers usually measure acceleration or force, an ADXL was configured to measure the angle of the pendulum. To do this two sets of proof masses and capacitors were used, both angled at 45° (Fig 4). The output of both capacitors was then run through a differential amplifier to measure the angle of the pendulum. To do this, two sets of proof masses and capacitors were used, both angled at 45° (Fig 4). The output of both capacitors was then run through a differential amplifier to measure the angle of the pendulum. To do this, two sets of proof masses and capacitors were used, both angled at 45° (Fig 4). The output of both capacitors was then run through a differential amplifier to measure the angle of the pendulum.

Using the double step feedback algorithm greatly reduces ringing as shown in Fig 10. The blue line shows the motion of the pendulum when it receives a random impulse for 4 seconds. We observe large amounts of overoscillation and the system is unable to settle within 4 seconds. This is what mainly contributes to its long settling time. Clearly, this ringing is undesirable and must be eliminated.

When the two step drive response algorithm was implemented, the settling time gets reduced significantly. This increases the response speed of the system. Previously, the settling time of the system was ≈5 seconds, however, after implementing the algorithm, the settling time is reduced to around 1 second. This gives an 80% decrease in settling time and increases in response speed. The reason for the slight overshoot during the double step (Fig 10) is that background noise causes a slight error in the prediction of the position of equilibrium. This leads to an undershoot or overshoot, causing a rise in settling time. Due to the size of an inertial sensor, there is much less noise and so the predictions are much more accurate. This would eliminate the small overshoot and further increase the response speed.

Results:
Comparison between two step drive and single step drive on inertial sensor model.

Two Step Drive:
Two step drives are advanced driving algorithms that use a series of impulses to move a system into a new position of equilibrium without causing ringing. The algorithm uses a digital two step drive. This means the full force is given for a small period of time (just enough to give it kinetic energy sufficient to carry it to the equilibrium position). No force is then given until the system overoscillates to the desired equilibrium position. The full magnitude of the force is reasserted to hold it in place. The absence of kinetic energy prevent the system from overoscillating.

Using the double step feedback algorithm greatly reduces ringing as shown in Fig 10. The blue line shows the motion of the pendulum when it receives a random impulse for 4 seconds. We observe large amounts of overoscillation and the system is unable to settle within 4 seconds. This is what mainly contributes to its long settling time. Clearly, this ringing is undesirable and must be eliminated.

When the two step drive response algorithm was implemented, the settling time gets reduced significantly. This increases the response speed of the system. Previously, the settling time of the system was ≈5 seconds, however, after implementing the algorithm, the settling time is reduced to around 1 second. This gives an 80% decrease in settling time and increases in response speed. The reason for the slight overshoot during the double step (Fig 10) is that background noise causes a slight error in the prediction of the position of equilibrium. This leads to an undershoot or overshoot, causing a rise in settling time. Due to the size of an inertial sensor, there is much less noise and so the predictions are much more accurate. This would eliminate the small overshoot and further increase the response speed.

Discussion / Conclusion:

In conclusion, the algorithm significantly decreased the settling time of the system by up to 50-80% depending on the magnitude of the drive. This would improve the response time of inertial sensors, specifically MEMS (Micro Electro Mechanical Systems), allowing them to measure forces faster.

On the small scale of MEMS, noise is significantly less and all distances are very small. This means that most relationships become linear. This would improve the accuracy of the predicting algorithm as there is less random error.

The next step for this algorithm is to be able to respond to a continuously changing signal. For this to occur, the algorithm must be able to predict and counteract as well as sense. Although the system of the point may not be at ground so that it must also be taken into account.

To further improve settling time after eliminating ringing, an override could be implemented. An override is when a larger magnitude of force is applied to the system and then the system is pulled by the same force to stop it at the desired equilibrium point where a corresponding force holds it in place. As shown in Fig 14, this is the fastest and most effective drive.

References: