SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM (B2)
Space Navigation Systems and Services (5)

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# A COMPARISON OF ATTITUDE DETERMINATION METHODS: THEORY AND EXPERIMENTS

**Abstract**

This paper studies development and comparison of attitude estimation methods for small cube satellites using low-cost IMUs. The estimation is done using data from a 3-axis gyroscope, 3-axis accelerometer and a 3-axis magnetometer.

In this paper a new method for attitude estimation has been developed based on QUaternion ESTimation (QUEST). A major concern with QUEST is that it cannot handle non-vectorized measurements such as gyroscope data. Substantial improvements have been made to fuse vectorized and non-vectorized measurements, making the new Extended QUaternion ESTimation (EQUEST) more suitable for attitude estimation. The well known Extended Kalman Filter (EKF) is derived and implemented for comparison. Both methods have been implemented and simulated in MATLAB. The code have been rewritten using C language. The methods are compared both theoretically and experimentally with implementation and testing on an AVR microcontroller. Minimum power usage and number of arithmetic operations were considered during the software development.

Testing indicates that the EKF provides a smoother estimation than the newly developed EQUEST. In contrast to EQUEST, the EKF is able to estimate the magnetometer and accelerometer bias. However, the EQUEST is having a significantly faster settling time and is less computational costly. Compared to the EKF, EQUEST runs more than 5 times faster. It also requires only 8

The attitude control of CUBESATs is often done by magnetorquers, which will affect the local magnetic field. Hence, control and estimation should not be done simultaneously, resulting in the estimation and control switching on and off. For this reason, the long settling time of the EKF makes the EQUEST even more attractive.

The results in this paper indicate that the newly developed EQUEST is highly suitable for projects with either limited budget, space, weight or computational power. This work is part of the CUBESAT project at the Norwegian University of Science and Technology.