

Development on the EQUEST method for attitude determination



Toril Bye Rinnan



Norwegian University of Science and Technology

Introduction

The NTNU Test Satellite (NUTS)

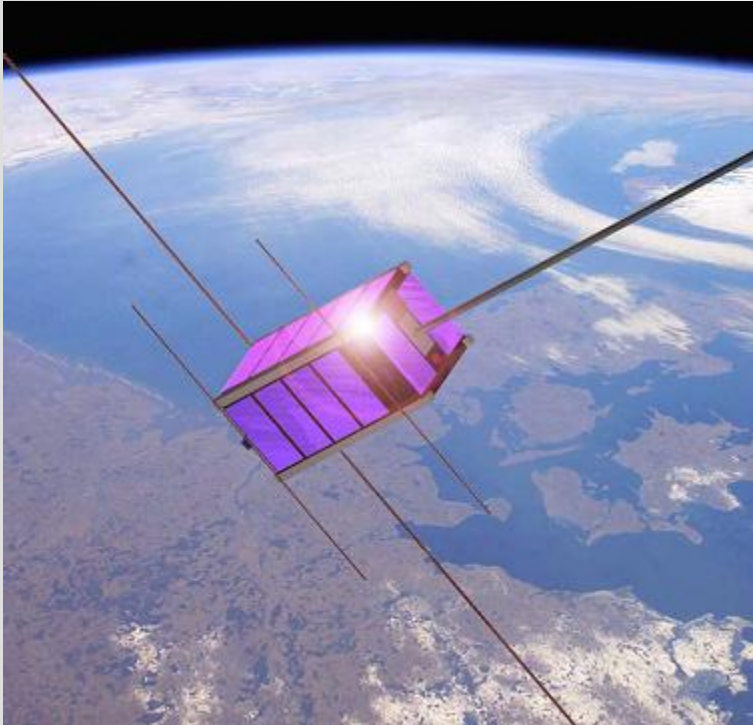
- Double cubesat
- Launch planned in 2014
- 10-15 master students at NTNU
- Infrared camera payload for observation of gravity waves

Outline:

- Quaternions
- QUEST and EQUEST
- Developed EQUEST
- Simulations
- EKF vs EQUEST



Attitude determination



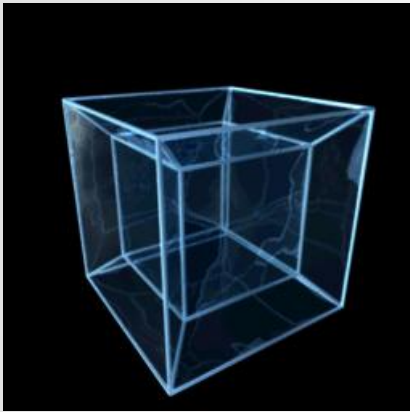
Attitude:

- Orientation control
- Determine attitude

Estimation methods:

- Kalman filter
- Quaternion estimator
- Developed extended quaternion estimator

Quaternions



Quaternions:

- Avoid singularities
- Represent rotations
- A quaternion product gives a new attitude quaternion

QUEST- quaternion estimation

QUEST method cost function:

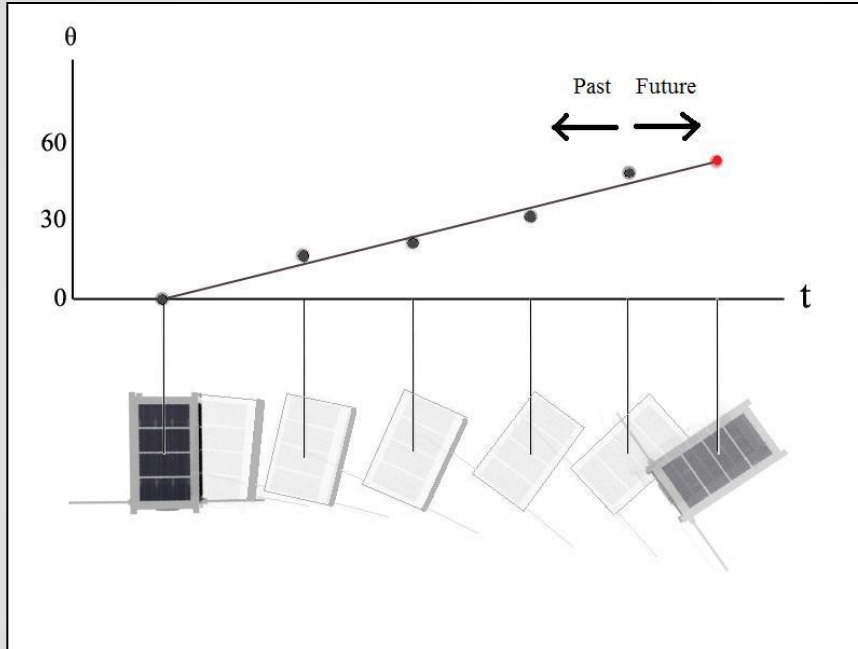
$$J(q) = \frac{1}{2} \sum_{j=1}^n \frac{1}{\sigma_j^2} (b_j - R_b^i(q)r_j)^T (b_j - R_b^i(q)r_j)$$

Parameters:

- b - measured direction values in spacecraft coordinates
- r - known direction values in inertial coordinates
- σ - standard deviation of measurement error



EQUEST- extended quaternion estimation



Motivation:

- Include terms for gyroscope measurements and linear attitude prediction

EQUEST- extended quaternion estimation

Extended QUEST method cost function:

$$J(q) = \frac{1}{2} \sum_{j=1}^n \left\{ \frac{1}{\sigma_j^2} (b_j - R_b^i(q)r_j)^T (b_j - R_b^i(q)r_j) \right\} + \frac{1}{2} (q - \hat{q}_{gyro})^T D (q - \hat{q}_{gyro}) + \frac{1}{2} (q - \hat{q}_{pre})^T S (q - \hat{q}_{pre})$$



Developed EQUEST

Developed EQUEST method cost function:

$$J(q) = \frac{1}{2} \sum_{j=1}^n \left\{ \frac{1}{\sigma_j^2} (b_j - R_b^i(q)r_j)^T (b_j - R_b^i(q)r_j) \right\} +$$
$$\frac{1}{2} (\hat{q}_{gyro}^* \otimes q)^T D (\hat{q}_{gyro}^* \otimes q) + \frac{1}{2} (\hat{q}_{pre}^* \otimes q)^T S (\hat{q}_{pre}^* \otimes q)$$

- Subtraction terms replaced with quaternion products



Developed EQUEST

Developed EQUEST method cost function:

$$J(q) = \frac{1}{2} \sum_{j=1}^n \left\{ \frac{1}{\sigma_j^2} (b_j - R_b^i(q)r_j)^T (b_j - R_b^i(q)r_j) \right\} + \frac{1}{2} (\hat{Q}_{gyro}^* q)^T D (\hat{Q}_{gyro}^* q) + \frac{1}{2} (\hat{Q}_{pre}^* q)^T S (\hat{Q}_{pre}^* q)$$

- Quaternions replaced with matrix representation



Developed EQUEST

Developed EQUEST method cost function:

$$J(q) = \frac{1}{2} \sum_{j=1}^n \left\{ \frac{1}{\sigma_j^2} (b_j - R_b^i(q)r_j)^T (b_j - R_b^i(q)r_j) \right\} + \frac{1}{2} q^T (\hat{Q}_{gyro}^{*T} D \hat{Q}_{gyro}^*) q + \frac{1}{2} q^T (\hat{Q}_{pre}^{*T} S \hat{Q}_{pre}^*) q$$

- Rearranging of terms and matrix multiplication



Developed EQUEST

Developed EQUEST method cost function:

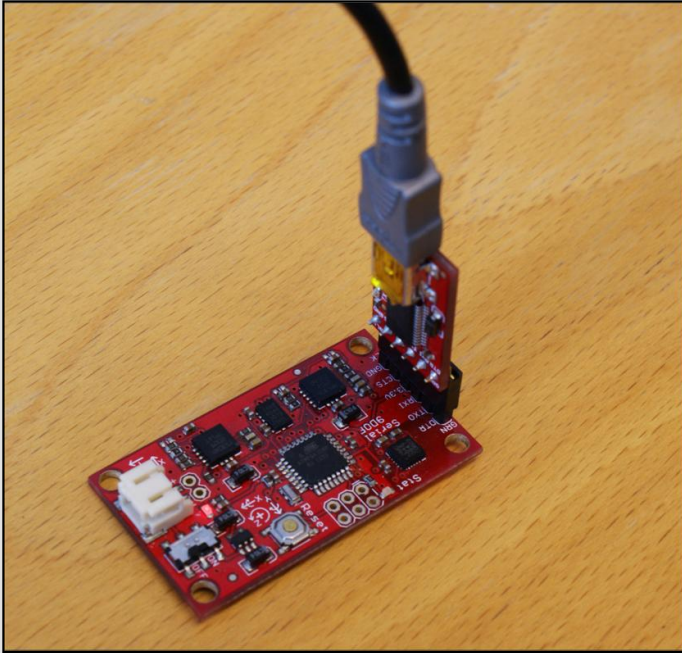
$$J(q) = \frac{1}{2} \sum_{j=1}^n \left\{ \frac{1}{\sigma_j^2} (b_j - R_b^i(q)r_j)^T (b_j - R_b^i(q)r_j) \right\} + \frac{1}{2} q^T N_d q + \frac{1}{2} q^T N_s q$$

$$N_d = \hat{Q}_{gyro}^{*T} D \hat{Q}_{gyro}^*$$

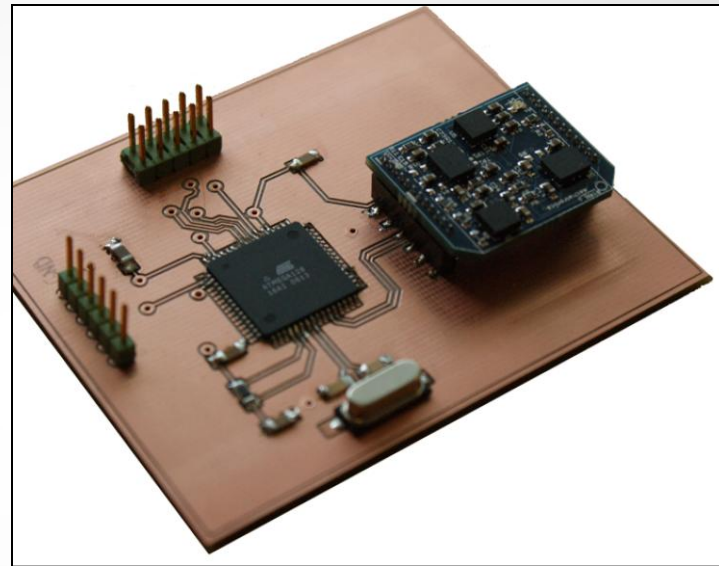
$$N_s = \hat{Q}_{pre}^{*T} S \hat{Q}_{pre}^*$$



Implementation

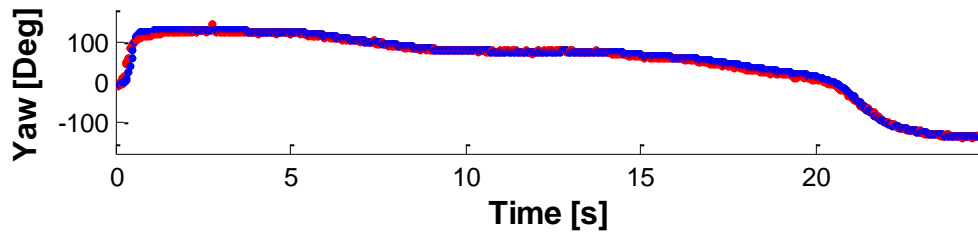
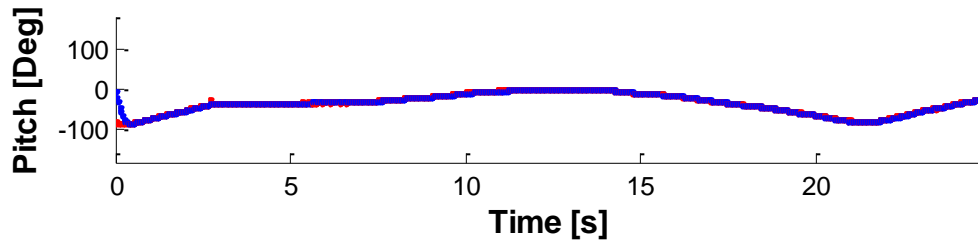
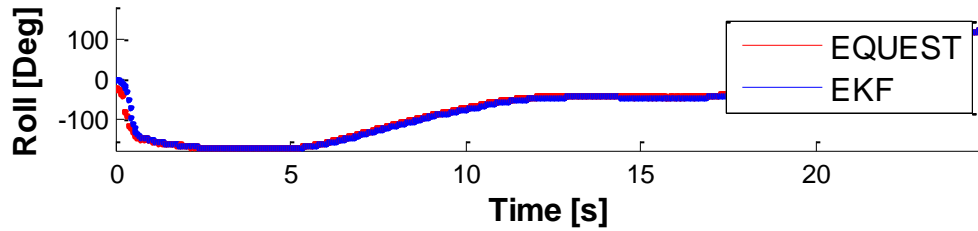


9- DOF IMU

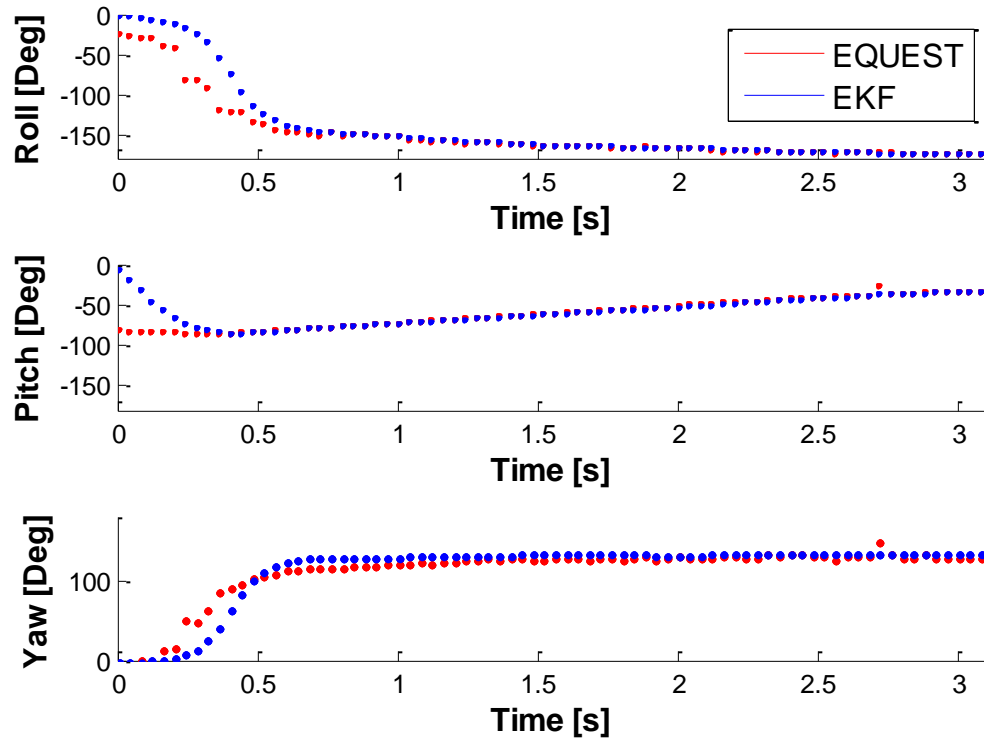


Prototype

EKF vs developed EQUEST



EKF vs developed EQUEST



EKF vs developed EQUEST

EKF:

- Well known
- Estimates sensor bias
- Good filtering effect
- Requires about 4000 arithmetic operations

Developed EQUEST:

- Finds solution in one operation
- Requires about 3200 arithmetic operations
- About 5 times faster than implemented EKF
- More intuitive tuning parameters



QUESTIONS?

Sponsors:



Kongsberg Seatex,
supporting the trip to
this conference

