Design Architecture of Attitude Determination and Control System of ICUBE

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Scope

- IST- CUBESAT- ICUBE
- Attitude Determination (AD)
- Design Architecture
- Attitude Sensors and Representation
- AD Algorithms –Actuators - Disturbances
- Orbit Design – AD – AC SIMULATION
- ADCS Flow Diagram
- Conclusion - Recommendations - References

Institute of Space Technology, Islamabad, Pakistan

- Institute of Space Technology (IST)[1], Islamabad, Pakistan is a Public sector University offering BS and MS degrees in Aerospace, Electrical and Materials Engineering

- IST initiated the CUBESAT project in 2009 with the aim to train its undergraduate and graduate students for the satellite technology and to develop and acquire the hands-on experience for the development, integration and launch of CubeSat.

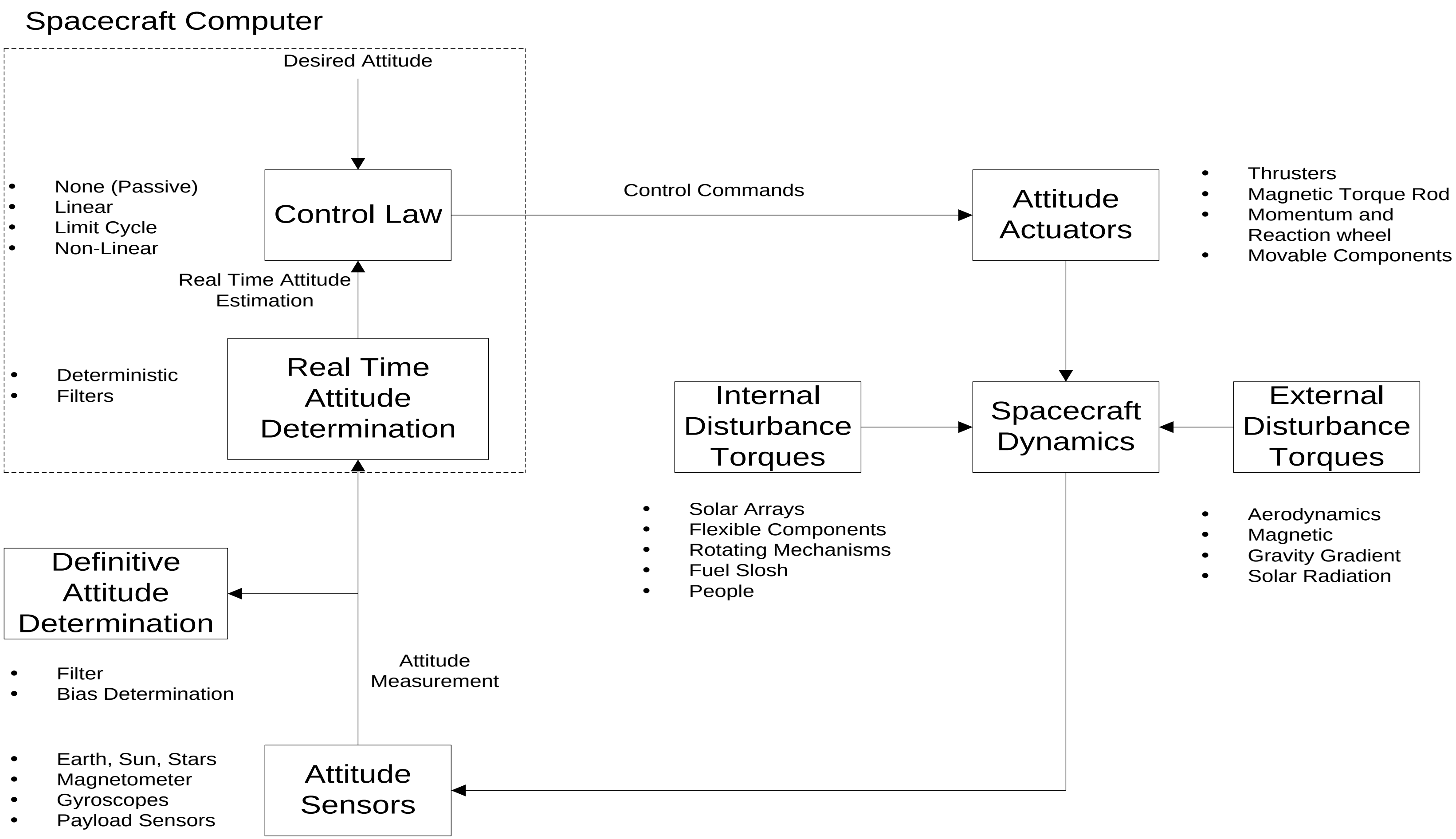
CUBESAT- ICUBE-1

- ICUBE-1 is the first experimental CUBESAT of this series that is planned to be launched in 2013 in LEO orbit at the height of 650 KM with an inclination of 98.8 degrees in the Sun synchronous orbit for a period of one and a half year.
- The 1U CubeSat structure of dimension 10cm cube with a maximum mass of 1 kg is used for the ICUBE-1.
- An imaging payload consisting of a small, low resolution CMOS camera will be used for capturing photographs.
- Commercial off-the Shelf (COTS) components and modules already flown in space will be used for this first satellite. The detailed subsystem overview and system engineering analysis is given at [2].

ATTITUDE DETERMINATION

The Attitude of a spacecraft is its orientation in space with respect to a given coordinate system. Attitude determination and control system (ADCS) involves defining of coordinate system, selecting attitude representation parameters, designing orbit propagator, selection of attitude determination sensors and algorithms, mathematical modeling of kinematics, dynamics, disturbance torques and sensors, and finally the selection of control schemes and actuators along with the appropriate control and stabilization schemes[3].

Attitude Determination Overview



DESIGN ARCHITECTURE

Mission: Student Satellite

Size : NanoSatellite - 1U-10 cm cube

Mass : Less than 1Kg

Orbit : LEO Sun Synchronous Orbit

Height: 650 km

Sensor : Magnetometer

Actuator : Magneto-Torquer rods / Coils

Mission Endurance: 12 -18 Months

AD SENSORS CHOICE

Sensor	**Accuracy (Degrees)**	**Pros**	**Cons**
Sun Sensor	0.1	Reliable, Simple, Cheap	No measurement in eclipse
Horizon Scanner	0.03	Expensive	Orbit dependent, Poor in yaw
Magnetometer	***1***	***Cheap– Continuous Coverage***	***Low Altitude only***
Star Tracker	0.001	Very Accurate	Expensive-Heavy-Complex
Gyroscope	0.01 per hour	High Band Width	Expensive-Drifts with time

AD REPRESENTATION PARAMETER CHOICE

Representation	Par.	Characteristics	Applications
Rotation matrix (Direction cosine matrix)	9	Inherently Nonsingular Intuitive Representation Difficult to maintain orthogonality Expensive to store Six redundant Parameters	Analytical studies and transformation of vectors
Euler angles	3	Minimal set Clear physical interpretation. Trigonometric functions in rotation matrix and kinematic relation No convenient product rule Singular for certain rotations	Theoretical physics, Spinning Spacecraft Attitude Maneuvers. Used in analytical studies.
Axis-azimuth	3	Minimal set Clear physical interpretation. Often computed directly from observations. No convenient product rule. Computation of rotation matrix difficult. Singular for certain rotations. Trigonometric functions in kinematic relation.	Primarily Spinning Spacecraft.
Rodriguez (Gibbs vector)	3	Minimal set Singular for rotations near $\theta = \pm \pi$. Simple kinematic relation	Analytic Studies.
Quaternions (Euler symmetric parameters	***4***	***Easy orthogonality of rotation matrix.*** ***Not singular at any rotation.*** ***Linear simple kinematic equations.*** ***No clear physical interpretation.*** ***One redundant parameter.***	***Preferred Attitude representation for attitude control systems***

AD ALGORITHMS CHOICE

Recursive AD Algorithm/ Method
RE-QUEST , *Bar-Itzhack [4]*
Optimal REQUEST, *Choukroun et al. [5]*
Minimum Model Error (MME),*Crassidis et al. [6]*
Euler-q,*Mortari [7]*
Kalman Filtering,Lefferts et al. [8],Psiaki et al. [9]
Particle Filters, *Crassidis et al. [10]*
Point-To-Point AD Algorithm/ Method
Wahba problem -*Grace Wahba [11]*
Q Method -*Davenport [12]*
QUEST Method-*Shuster [13]*
SVD-*Markley [14]*
FOAM-*Markely [15]*
Triad-*Lerner [3]*

DISTURBANCE TORQUES IMPLEMENTED

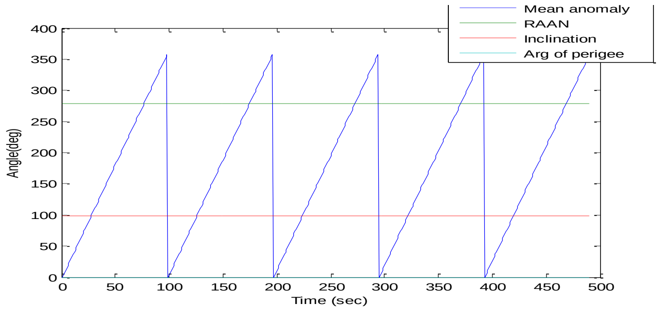
Type/Sources of Torques	Remarks
Gravity-Gradient	Varies inversely with distance from the Earth Centre
Solar Radiation Pressure	Effects geostationary spacecrafts
Earth's Magnetic Field	**Used for passive Attitude Control of small spacecrafts**
Aerodynamic Forces	**Effective for altitudes up to 800 km (LEO)**
Flexible Structures	Effective for big flexible structures
Internal Magnetic Torques	Due to residual permanent magnetism, Closed loop currents in instrumentation and eddy currents.
Earth's albedo - reflected radiations - micrometeorite impacts -cosmic dust	Less significant sources of torques for small LEO missions

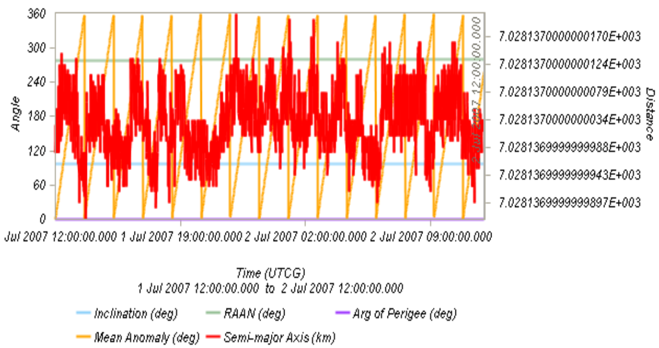
ATTITUDE CONTROL SENSORS CHOICE

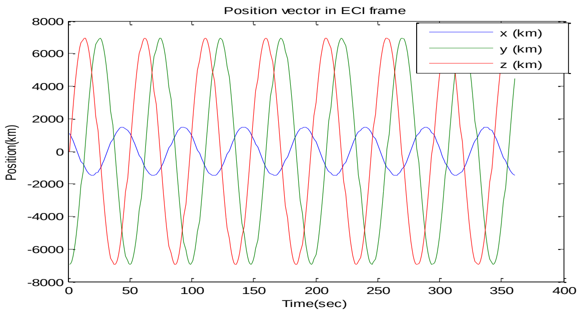
Method	**Accuracy (Degrees)**	**Pros**	**Cons**
Spin Stabilization	0.1-1.0	Passive, Simple, Cheap	Inertially Oriented
Gravity Gradient	1-5	Passive, Simple, Cheap	Central Body Oriented
RCS	0.01 - 1	Quick Response	Consumables
Magnetic Torquers	***1- 2***	***Cheap***	***Slow, Lightweight, LEO only***
Reaction Wheels	0.001 - 1	Expensive – Precise – Faster Slew	Weight

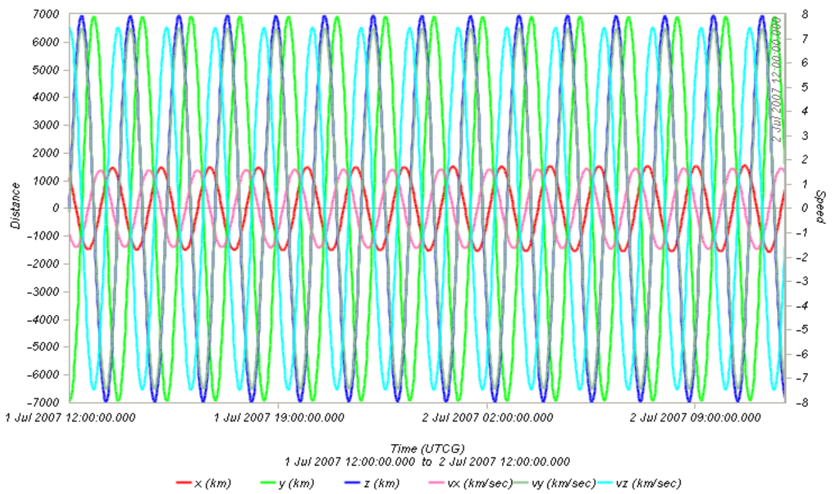
Orbit Design and Propagator

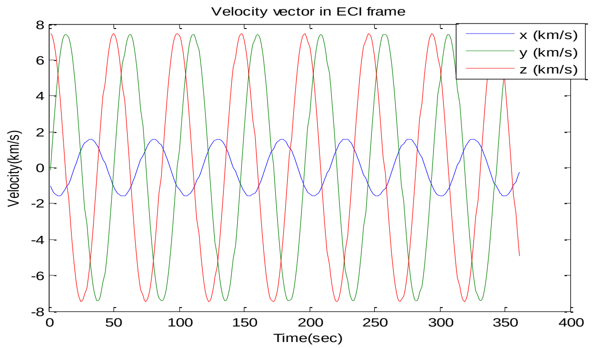
MATLAB – STK Comparison (Keplarians-Position-Velocity)



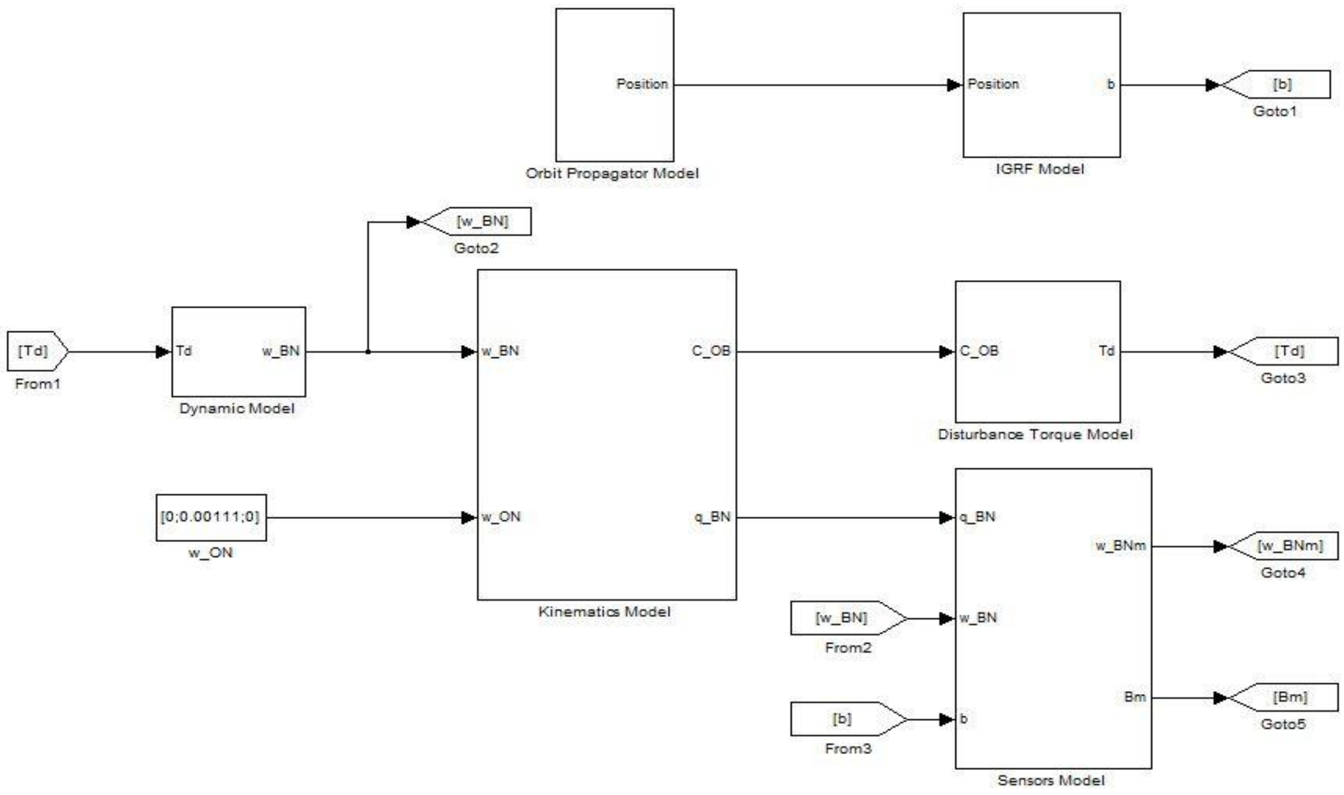






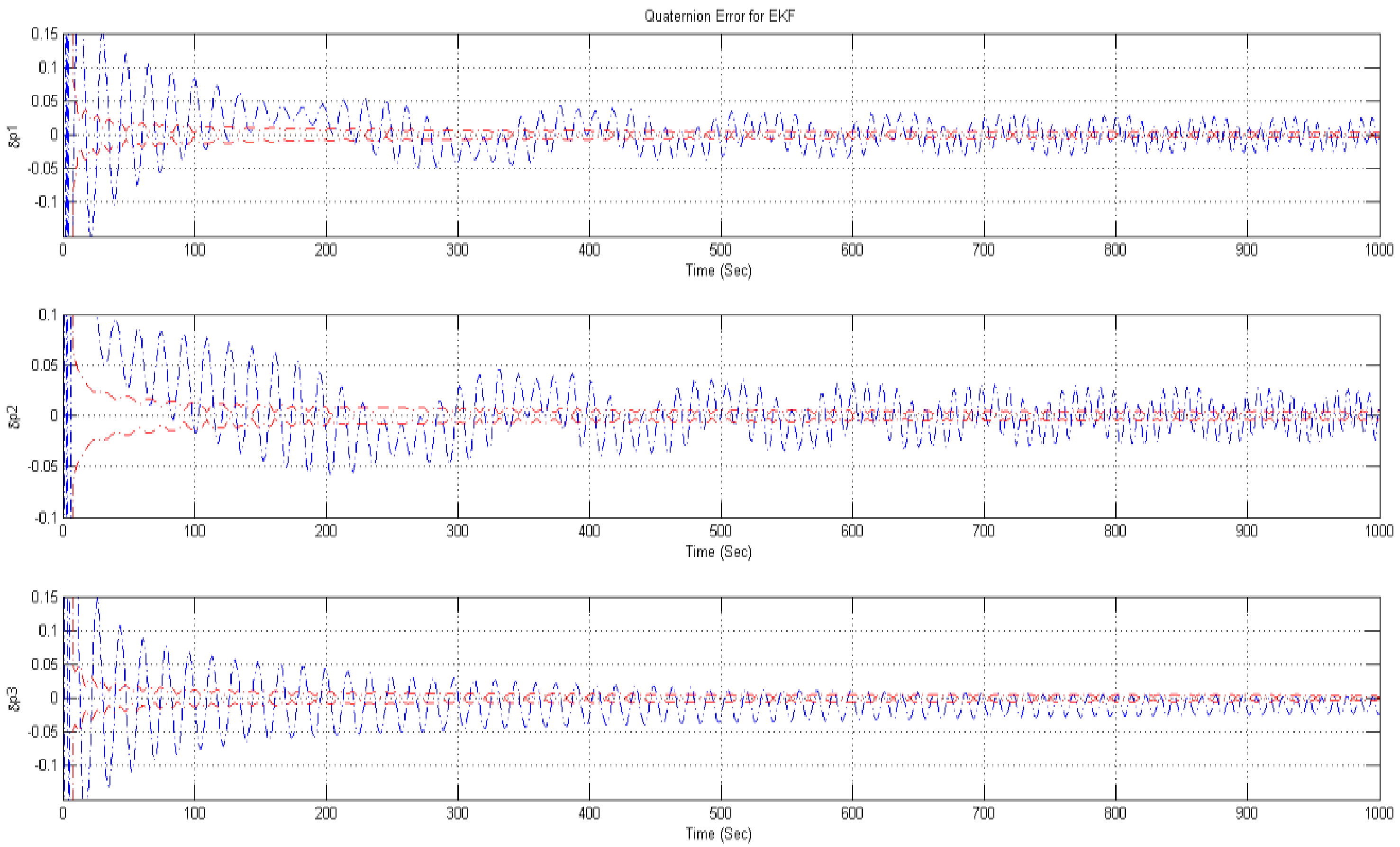


ICUBE-1 SIMULINK MODEL



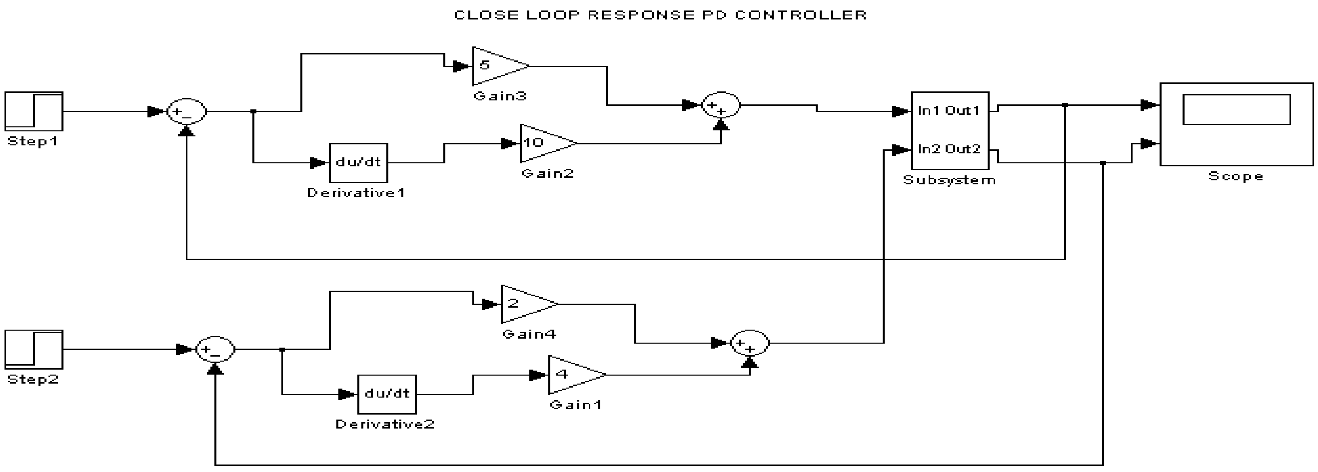
AD SIMULATION

Extended Kalman Filter

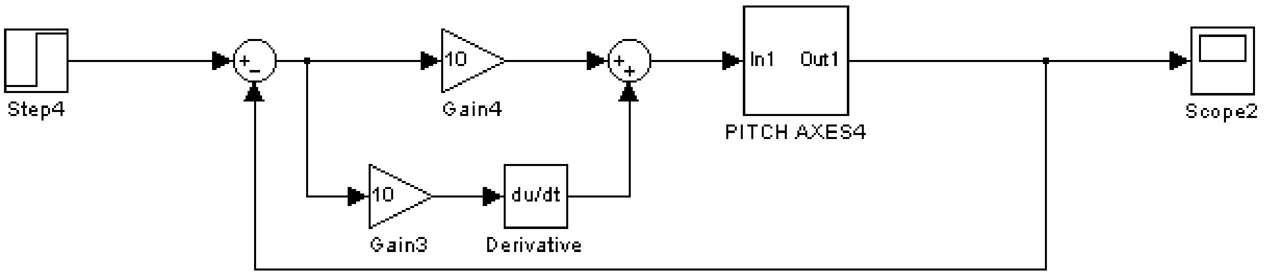


ATTITUDE CONROL SCHEME

Simulink Model



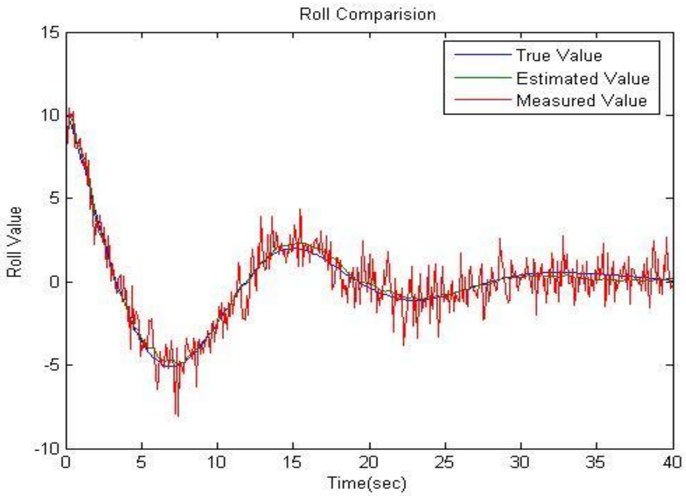
Roll and Yaw control using PD Controller



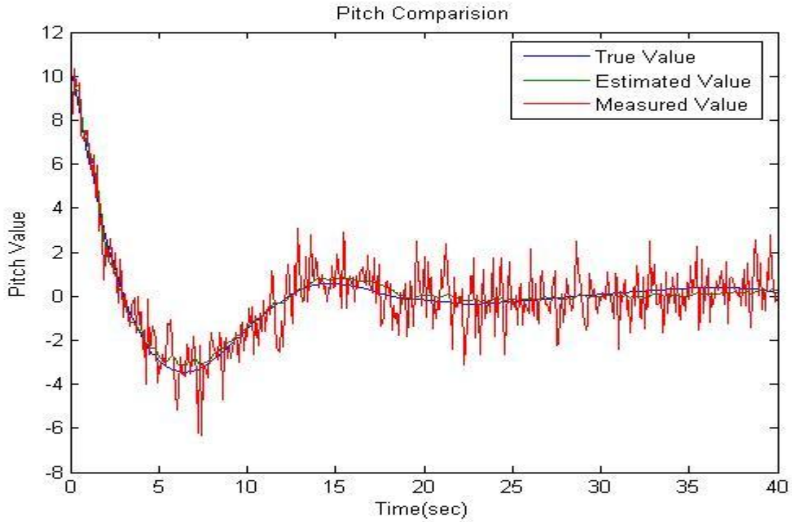
Pitch control using PD Controller

ATTITUDE CONROL SIMULATION

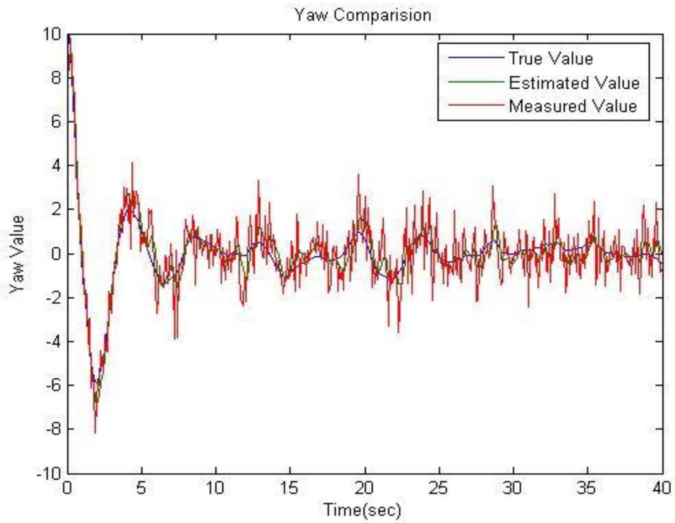
Roll – Pitch –Yaw Comparison



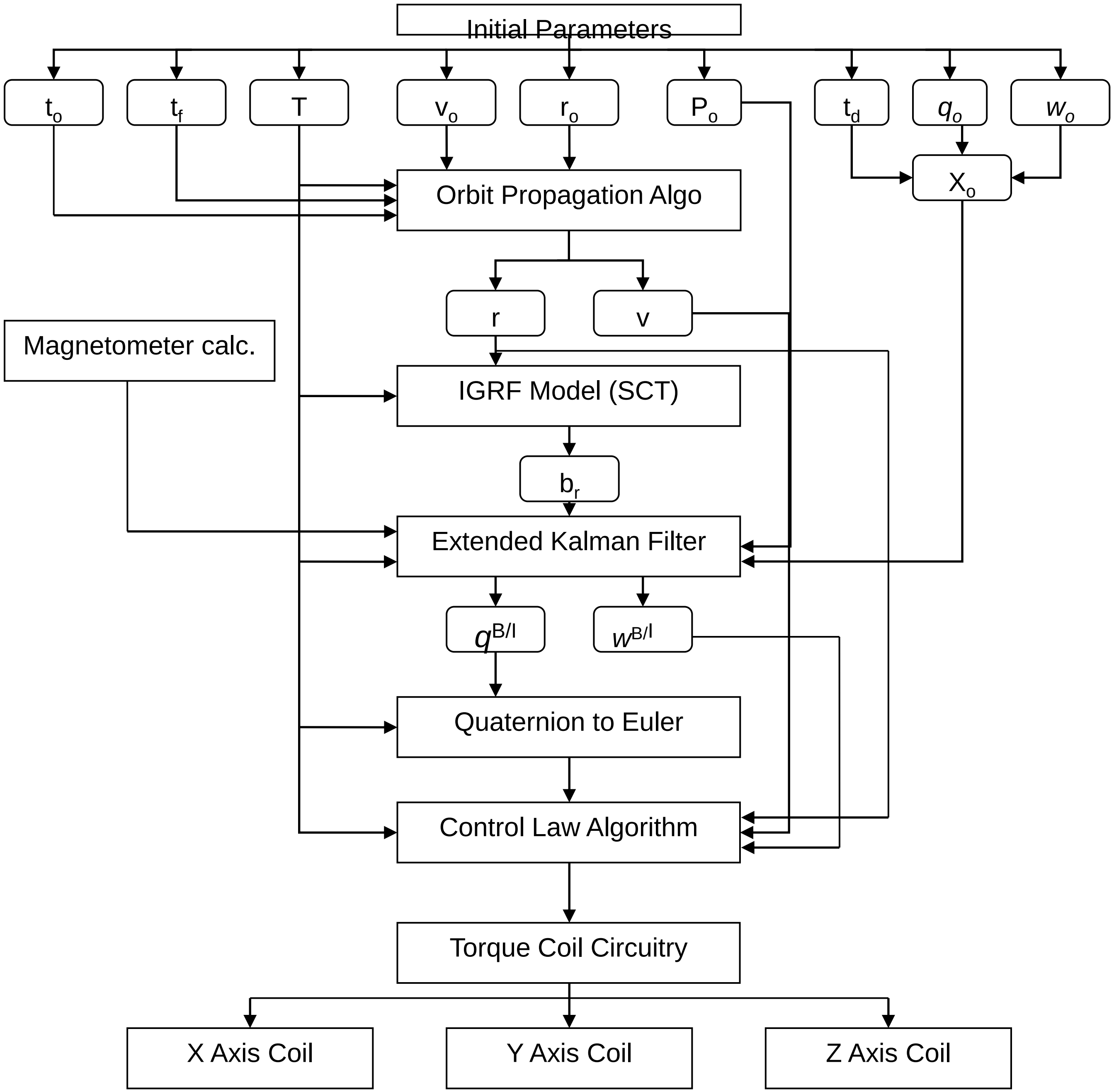
Roll Comparison



Pitch Comparison



Yaw Comparison



ADCS FLOW DIAGRAM

CONCLUSION AND RECOMMENDATIONS

- ADCS of ICUBE-1 is designed and simulated
- Magnetometer is used as sensor and Magnetic coils are used as actuators
- EKF is used as Attitude Determination algorithm while PD Controller is used for Attitude Control
- ADCS along with Orbit propagator is simulated in MATLAB/Simulink
- **This ADCS Design Architecture is one option for ICUBE-1, other options are also under research and most feasible one will be used for the final design**

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