Attitude Determination and Controls Subsystem, Advitiy, IITBSSP

Mini Projects 2019

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Contents

1 Introduction

This document contains the descriptive problem statements for all the mini projects along with other information, viz., software/hardware required, contact details of mentors and co-mentors and references for the respective projects. Each subsection of the Sec 2 contains a detailed description of one of the mini projects, name of the candidate who is assigned that particular project and names of mentor and co-mentor. Contact details of mentors and co-mentors can be found in the table 1.

2 Projects

2.1 Attitude parameterization and Kinematics

Assigned to : Prathamesh More
Mentor : Ravit Anand **Co-Mentor :** Anant Joshi

Up until school we only studied planar motion of extended rigid bodies, i.e., the case when motion of any particle of the body is restricted to a plane and all such planes are parallel to each other. To describe such motion we only need three scalars, two to parameterize the motion of any one of the body's particle and another scalar to parameterize the rotation of the body. Now, to study general motion of rigid bodies for example like that of a satellite the above formulation is not enough and hence the need to learn how to parameterize the orientation of a rigid body in three dimensions, more epigrammatically the attitude. This project aims to provide a rigorous exposure to ideas of attitude parameterization and kinematics along with a numerical exercise which will require the implementation of the concepts learnt in a computer simulation. The following describes the general flow of the project:

1. Euler's rotation theorem; Rotation vector and Euler angles along with the discrepancies in these parameterizations. [1]
2. Rotation matrix and Quaternions along with discrepancies in them. [1]
3. Inter-conversions between these parameterizations. [1]
4. Attitude Kinematics in at least one of the attitude parameterizations [1]; Kinematics of frames rotating with respect to each other([1], [2]); Transport theorem [2].
5. Numerical Exercise:
   (a) Start by assuming some trajectory of attitude of a rigid body in any one of the parameterizations studied above.
   (b) Write a program to convert the attitude trajectory into other paramaterizations.
   (c) Calculate analytically the angular velocity of the body as a function of time.
   (d) Calculate the attitude trajectory in various parameterizations using the angular velocity calculated above by implementing numerical integration techniques [3] like R-K4.

(e) Compare the numerically generated trajectory with the assumed original trajectory.

2.2 Rigid Body Dynamics

Assigned to : Mayuresh Bhattu
Mentor : Anant Joshi **Co-Mentor :** Ravit Anand

In school we are taught rotational dynamics of planar rigid bodies. When we start thinking of rigid bodies in three dimensions the equations of motion undergo a significant change since motion along one axis affects motion along other axes. This mini project aims to provide a rigorous exposure of ideas to the candidate and closes with a numerical exercise where the candidate will implement the concepts learnt in a numerical simulation. The following describes the general flow of the project:

1. Rotational transformation between frames and of vectors ([4,5])
2. Time derivative with respect to a rotating frame, transport theorem, time derivatives of rotation matrices ([4,6])
3. Moment of inertia tensor for a system of particles ([2,4,6])
4. Angular momentum for a system of particles ([2,4,6])
5. Torque applied on a system of particles ([2,4,6])
6. Relation between rate of change of angular momentum between torque ([2,4,6])
7. Euler's equation of motion for rotational dynamics of a rigid body with respect to an inertial frame ([2,4,6])
8. Modification of Euler's equations for dynamics with respect to a rotating frame
9. Stability of torque free rigid body motion; spinning about major, intermediate and minor axes ([2])
10. Dynamics of a spinning top ([2])
11. Runge Kutta order 4 solver for ordinary differential equations ([3])
12. Numerical simulation of torque free rigid body

2.3 Linear State Space Systems

Assigned to : Swarada Bharadwaj
Mentor : Niket **Co-Mentor :** Ravit

For complex systems with multiple inputs and outputs, it becomes difficult to represent them with differential equations. State-space representation makes it simpler to model and analyse complex systems such as our satellite. In this mini project, the candidates will learn state space representation of linear systems and consequently understand the controllability and observability of linear state space systems. They will also be exposed to internal stability and Lyapunov stability. The mini project will cover the following:

1. Basics of Control Systems
2. Modelling of systems
3. State space representation of linear systems
4. Internal stability
5. Lyapunov stability for linear systems
6. Controllability and Observability of systems
7. Python simulation of a given controller
8. General Lyapunov stability

2.4 Allan Variance

Assigned to : Yuktee Gupta
Mentor : Piyush

For simualation purposes, we need to create an environment just like the one that the satellite faces in space. For this, we need to model sensors, and gyroscope is one of them. The modelling of gyroscope is not as easy as other sensors and needs a special technique known as called Allan Variance. The flow of this mini project will be as shown below:

1. Working principle of a MEMS gyroscope and using a datasheet
2. Understanding various types of errors and noises in a gyroscope
3. Study Allan Variance
4. Interfacing arduino with gyro and obtaining data
5. Code Allan variance in Python
6. Model the gyroscope and compare the model with its datasheet ([7])

2.5 Multi variate statistics and weighted least square estimation

Assigned to : Latika Patel
Mentor : Piyush **Co-Mentor :** Sanskriti

In a satellite, there is no equipment that directly measures attitude. Instead, what we are required to do is to use measurements from multiple sensors to get measured vector quantities in the body frame of satellite. These quantities are compared with their calculated values from scientific models in the reference frame (represents the required orientation of the coordinate axes of the satellite at a point in space) and these are collectively used to 'estimate' the attitude. Attitude estimation algorithms have to be used to find an optimal answer in the presence of unavoidable errors from sensor measurements. To begin with the estimation techniques, one needs to have a clear idea of multivariate statistics. This and other basic estimation techniques will be introduced in this project.

1. Multivariate random variable
2. Least square estimation
3. Weighted Least square estimation
4. Batch estimation and recursive estimation
5. Implementation of BWLSE
6. Implementation of RWLSE ([8])

2.6 Single-point estimator

Assigned to : Rushi Gadekar
Mentor : Sanskriti

In a satellite, there is no equipment that directly measures attitude. Instead, what we are required to do is to use measurements from multiple sensors to get measured vector quantities in the body frame of satellite.These quantities are compared with their calculated values from scientific models in the reference frame (represents the required orientation of the coordinate axes of the satellite at a point in space) and these are collectively used to 'estimate' the attitude. Attitude estimation algorithms have to be used to find an optimal answer in the presence of unavoidable errors from sensor measurements. QuEST is an algorithm for quaternion estimation. We will use Quest only to find initial quaternion for MEKF.

1. Basics of rotation matrices and quaternions and its properties; some background of rotation matrices
2. Triad method
3. Wahba's problem; Q-Method; its reduction to quadratic form using quaternions
4. Study QuEST
5. Study optimal QuEST (used in Pratham) and suboptimal QuEST
6. Code Optimal QuEST

2.7 Kalman Filtering

Assigned to : Millen Kanabar
Mentor : Sanskriti **Co-Mentor :** Anant Joshi

In a satellite, there is no equipment that directly measures attitude. Instead, what we are required to do is to use measurements from multiple sensors to get measured vector quantities in the body frame of satellite. These quantities are compared with their calculated values from scientific models in the reference frame (represents the required orientation of the coordinate axes of the satellite at a point in space) and these are collectively used to 'estimate' the attitude. Attitude estimation algorithms have to be used to find an optimal answer in the presence of unavoidable errors from sensor measurements. Multiplicative Extended Kalman Filter will be used to estimate the state, because it uses previous data and can estimate in eclipse region also. this project is to make the person familiar with Kalman filtering and its variants.

1. Basics of multi-variate random variables and least square estimation
2. MVUE and BLUE leading to kalman filter
3. Moving Horizon Estimation
4. Non-linear discrete time model
5. Extended Kalman Filter
6. Basic understanding of MEKF

2.8 Propagator

Assigned to : K T Prajwal Prathiksh
Mentor : Riya **Co-Mentor :** Anmol Sikka

To control a satellite, we use various algorithms for estimation of attitude and deciding the torque to be applied. Whether these algorithms will work for our case or not can't be found out using analytical methods. So, we simulate the attitude dynamics of satellite. To generate the orbit of satellite (i.e. to find the position and the velocity of satellite), we use mathematical models. In orbit, we use J2 model due to its simplicity which takes into account the oblateness of earth. But it does not take into account drag effect and higher order gravitational effects. SGP is an option which can be used for ground simulation but it is again an approximate model only. So, we are planning to use GMAT software for generation of orbit which is mostly used by the satellites for orbit generation. The aim of this mini-project is to understand the propagator and start the propagator design task.

3 Contact details

Name	Contact No.	Email address
Anant Joshi	+91 98205 02797	anantjoshi97.iitb@gmail.com
Anmol Sikka	+91 95012 03963	anmolsikka09@gmail.com
Niket Parikh	+91 91829 80055	npnike@gmail.com
Piyush Jirwankar	+91 75065 94848	piyushjirwankar31@gmail.com
Ravit Anand	+91 88791 79194	ravitanand2014@gmail.com
Riya	+91 84549 30220	rsriya383@gmail.com
Sanskriti Bhansali	+91 94135 31098	sanskritibhansali@gmail.com
Lab	022 2576 4147	

Table 1: Mentors' contact details

References

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[7] "Resources for allan variance," https://drive.google.com/open?id=1yqo0irymGye8f8YQgKz-MuE3OmOAZwRk.

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