# Task 3B : Theme & Rulebook Questionnaire

| | |
|---|---|
| **Team ID** | LS_3083 |
| **College** | MBM ENGINEERING COLLEGE |
| **Team Leader** | AJEET JAIN |
| **e-mail** | jainajeet29@gmail.com |
| **Date** | 29 NOVEMBER 2023 |

| Question No. | Max. Marks | Marks Scored |
|---|---|---|
| Q1 | 5 | |
| Q2 | 10 | |
| Q3 | 5 | |
| Q4 | 5 | |
| Q5 | 10 | |
| Q6 | 5 | |
| Q7 | 10 | |
| Q8 | 15 | |
| Q9 | 5 | |
| Q10 | 5 | |
| Q11 | 10 | |
| Q12 | 5 | |
| Q13 | 10 | |
| **Total** | 100 | |

**Q1.** Briefly describe your experience in building the Lunar Scout bike.

**A1. When we started working on task 1 to balance the inverted pendulum, at first, it seemed difficult, but as we went solving, things got better and we got clarity on how to proceed. Then I started writing code in the CoppeliaSim software and got some positive output. I believed that my K matrix was perfect because I followed every step correctly and calculated the Lagrangian equation multiple times. After finding input torque using K matrix and error, we found that the pendulum is balancing and used all the permutations of signs in the formula, changed the gain of errors and after a lot of tuning, got a perfect solution for the task. By this time, we had got a lot of knowledge about the rotary inverted pendulums and LQR Control System.**

**Then we started working on task 2, which was really engaging as we had to design our own bike for the task, keeping in mind the proper mass distribution. There, we added our knowledge of task 1 and finally succeeded in task 2 and also got ranked first on the leader board, which immensely boosted up our confidence.**

**Whenever we got stuck, we discussed among the team members and also got a lot of help and support from the QnA section on the portal.**

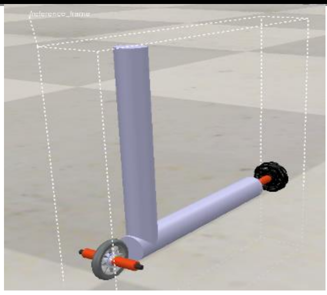
**Overall, it has been a wonderful journey till now.**

---

**Q2.** In task 1, you were introduced to LQR controller design for a simple pendulum and asked to do mathematical modelling and LQR controller design for Rotary Inverted Pendulum. In that, you were asked to derive the equations, linearize around the equilibrium point and find the A & B matrix using the Jacobian function.

In this question, you have to choose the states for your Lunar Scout bike that you are going to design. Model the system using Euler-Lagrangian Mechanics that you learned in task 1. Linearize the system using jacobians around the equilibrium points representing your physical system. Use mathematical expressions for derivations and proper diagrams where necessary.

**A2.**



**Above is the bike which we have designed and below is the attached PDF file, containing the derivations using mathematical expressions.**

[**PDF LINK**]

$$\ddot{\alpha} = \frac{-T\cdot k_1\cdot\cos(\theta)-k_1^2\cdot\dot{\theta}^2\cdot\sin(\theta)\cdot\cos(\theta)+2\cdot k_1\cdot k_6\cdot\dot{\alpha}\cdot\dot{\theta}\cdot\sin(\theta)-k_5\cdot k_6\cdot\sin(\theta)-\dot{\alpha}\cdot\dot{\theta}\cdot k_6\cdot\sin(\theta)}{-k_1^2\cdot\cos(\theta)^2-k_6\cdot k_7}$$

$$\ddot{\theta} = \frac{\cos(\theta)\cdot\sin(\theta)\cdot((k_1\cdot\dot{\alpha}\cdot\dot{\theta})-(2\cdot k_1^2\cdot\dot{\alpha}\cdot\dot{\theta})+(k_1\cdot k_5))-(k_7\cdot T)-(k_1\cdot k_7\cdot\dot{\theta}^2\cdot\sin(\theta))}{k_1^2\cdot\cos(\theta)^2-k_7\cdot k_6}$$

$$k_1 = 2 \cdot M_p \cdot l \cdot R_p$$

$$k_2 = 2 \cdot M_p \cdot l$$

$$k_3 = M_p \cdot R_p^2$$

$$k_4 = M_p \cdot l^2$$

$$k_5 = 2 \cdot g \cdot M_p \cdot l$$

$$k_6 = I_{\text{arm}} + k_3$$

$$k_7 = I_{\text{pendulum\_theta}} + 4 \cdot k_4$$

$$T = u$$

$$I_{\text{pendulum\_theta}} = \frac{1}{4} \cdot M_p \cdot r_p^2 + \frac{1}{3} \cdot M_p \cdot l^2 \cdot 4$$

$$I_{\text{arm}} = \frac{1}{4} \cdot M_a \cdot r_a^2 + \frac{1}{3} \cdot M_a \cdot R_p^2$$

**Then, we used jacobian() and subs() functions in Octave, to find A and B matrices at equilibrium point {alpha_dot,alpha,theta_dot,theta}= {0,0,0,pi}**

---

**Q3.** Which is the most optimal controller between PID and LQR. Justify your answer.

**A3. As such, it totally depends on our requirement, as both the controllers have their own strengths and weaknesses. LQR control gives good performance but it is more complex while PID can be easily implemented, but is less efficient and requires a lot of tuning for good performance. PID control is a good choice for simple applications, but for complex and non-linear behaviour, LQR is an optimal controller and hence, LQR best suited for our tasks.**

**LQR gives all calculated values and does not require more tuning of our system after calculation, as we only need to change gains according to our needs to make the perfect model.**

---

**Q4.** What is the significance of finding Controllability and Observability of a system in state space approach?

**A4. Controllability refers to the ability to control the system's state using inputs. The significance of finding controllability is that it shows how we can control the system's states at desired point in a finite time and also confirms that our system is controllable by inputs. Controllability is essential for ensuring that the system can be guided to achieve desired performance or behavior.**

**Observability is the ability to find out what's happing inside the system .**

**If we want to know the current states by examining its output, then observability plays a significant role.**

---

**Q5.** Briefly explain your opinion on having the centre of mass of the bike low or high. Use diagrams/calculations/examples to support your argument.

**A5. Lower centre of mass makes it more difficult to move away from the equilibrium point of bike and makes it more stable, less responsive and on the other hand, higher centre of mass makes it less stable and more responsive.**

**During our task 2b, we worked on mass distribution and tried every location of centre of mass and thereafter, concluded that when we put COM higher, the bike goes immediately to yaw setpoint but then it is getting unbalanced and starts vibrating. But when we put COM lowest, the bike remains stable but less responsive and it takes more time to reach the desired yaw point.**

**Therefore, after lots of experimentations, we got a perfect location of COM which was not much lower and not much higher either. It was somewhere in the middle of both of these positions and we believe that it is due to the 'gravity torque'.**

**Let us understand this with a simple example of a truck (transport vehicle) which we can take it as an inverted pendulum. We know that on a banked turn, there are higher chances of the fully loaded truck getting turned(crashed) because of its higher COM.**

**Similarly, for keeping up right position of bike, lower COM is good but for controlling bike while keeping it in upright position, the position of COM should be somewhere between higher and lower positions.**
**Example of truck was suitable for keeping the upright position stable.**
**But now, on the other side, balancing a stick on hand is second example to understand controlling as we know practically balancing a pen on hand is much harder than balancing a big heavy stick on hand.**
**So, we believe that the position of centre of mass should be suitably selected to make both balancing and controlling at the same time.**

---

**Q6.** In what cases will the run time be considered as the maximum time (Tmax = 300 seconds) according to the scoring formula and theme rules?
**A6. According to the theme rules and the scoring formula, the run time will be considered as the maximum time (Tmax = 300 seconds) in the following cases:**

1. **Invalid Run Completion:**
   **If the 5-second buzzer beep, indicating run completion, occurs without the bike reaching any of the three Start/Stop Locations (SL) or without covering all given Colony Sites (CS), the run time will be considered as the maximum time.**

2. **Exceeding Maximum Manual Interventions (MI):**
   **If a team exceeds the maximum allowed Manual Interventions (MI) during the run (more than 5 MIs), the run will end, and the time taken will be considered as the maximum time.**

**In both the cases, the run would be considered as incomplete or invalid, and the time taken is capped at the maximum time limit of 300 seconds (Tmax).**

---

**Q7.** Explain what you have understood from the Theme play in your own words.
**A7. According to theme description, each team will perform different tasks according to an undisclosed configuration table. Each team will go to the same colony sites but polarities of magnet will be different for each team**

**for the colony site. Polarities of magnet facing path will be considered to detect by bike. Obstacle configuration will be same for each team. There will be three locations S1 ,S2 and S3 . One of them will be start location and one of them will be stop location this will be disclosed in configuration table. There will be six colony sites and each site will have a permanent magnet placed with a random polarity. There will be maximum three obstacles on the path bike has to balance from passing by obstacles. At first bike will be placed at the start location according to given position in configuration table. Then one member will turn on the bike. It will start balancing at its position on two point of contact with ground. After starting bike a buzzer will beep for one second it will indicate the timer has been started the team will select a member before run to control the bike using remote made by them bike should be balanced all the time including the time of detection or indication while navigating through the arena track bike will stop at colony sites for at least three seconds halt and Generate one second bazaar beep twice with delay of one second along with indicating polarity of magnet for 3 seconds using led red colour for North polarity the (dmaged colony sites) green colour for South polarity (not damage colony sites). When all colony sites will be covered bike should reach to stop location and trigger the Bazar beep for 5 seconds and this will be considered as run completion time.**

---

**Q8.** What will be the SCORE in the following situation:
**Given Run Configuration:**
StartLocation : S1
ColonySites: 1, 2, 3, 5
Obstacle: O1, O3

In the given run there are four Colony Sites(**CS**). The bike started its journey from S1. It halted near the first CS, which has the north pole of the magnet facing the track. It indicated green LED and buzzer, then started its traversal.

- Now it has reached the second CS which has no magnet in it. It doesn't indicate any of the light and started its traversal.

- The bike crossed one obstacle and then indicated the first CS again with red led and buzzer with proper halt, then it continued forward.
- Now it reaches its final CS which is having a south pole facing towards the track and indicating green LED and buzzer beep while passing by the CS, but without halting near the CS.
- Bike then goes to the S2 position, stops and beeps the buzzer for 5 seconds. By this time 150 seconds have passed, from the start time. The bike did not have any MI/PP/HP during the run.

**A8. Start Location : S1**
**Colony Sites: 1, 2, 3, 5**
**Obstacle: O1, O3**
**According to given information**
**As run time is given so we assume that 1 second Buzzer beep produced by the bike at starting and a 5 second beep of run compilation.**
**It halted at first CS so first CV is counted. It indicated green LED for north pole it is WI . At next CS it does not given that bike did proper halt(if we consider bike halted then we need a conformation that is halted 3 secondor any proper time) so CV is not counted and according to rules and also WI is counting for detection without reaching/halting at the CS. Bike crossed one obstacle so OB is counted. It indicated first CS again with correct indication and proper halting so as per rules one CI is counted on second attempt . At last CS it indicates without halting so WI is counted and CV is not counted . in this run bike takes 150 seconds so T=150.**
**CV=1**
**WI = 3**
**CI = 1**
**OB = 1**
**T = 150**
**MI = 0**
**HP = 0**
**PP = 0**
**RB = 0**
**Total Score = (300-T) + CV *75 + CI*150 - WI*50 - MI*25 - HP*20 - PP*10 + OB*50 + RB*100 + DB**

**Total Score = (300-150) + 1 *75 + 1*150 - 3*50 - 0*25 - 0*20 - 0*10 + 1*50 + 0*100 + DB**
**Total Score = 275 + DB**

---

**Q9.** What is Parallel and Perpendicular axis theorem? Is it required for mathematical modelling? Justify your answer with respect to the lunar scout bike.

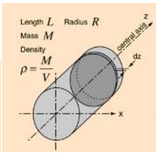
**A9. The Parallel Axis Theorem and the Perpendicular Axis Theorem are two related principles in physics and engineering, specifically in the context of rotational motion and the calculation of moments of inertia.**

**1. Parallel Axis Theorem:**
**- The Parallel Axis Theorem states that the moment of inertia of a rigid body about any axis parallel to an axis through its center of mass is the sum of the moment of inertia of the body about its center of mass and the product of its mass and the square of the distance between the two axes.**
**2. Perpendicular Axis Theorem:**
**- The Perpendicular Axis Theorem is a special case of the moment of inertia theorem and is applicable for planar objects (objects lying in a plane). It states that the sum of the moments of inertia of a planar object about any two perpendicular axes in the plane of the object is equal to the moment of inertia about an axis perpendicular to the plane and passing through the point of intersection of the two perpendicular axes.**

**These theorems are valuable tools in solving rotational motion problems, especially when dealing with complex shapes or objects with irregular geometries like lunar scout bike. They provide a way to calculate the moment of inertia about an axis that does not pass through the center of mass, making it easier to analyze and solve rotational motion equations.**

**Yes, it is required for mathematical modelling of lunar scout bike.**
**The moment of inertia about the end of the cylinder is**

$$I_x = \frac{1}{4}MR^2 + \frac{1}{3}ML^2$$



**The development of the expression for the moment of inertia of a cylinder about a diameter at its end (the x-axis in the diagram) makes use of both the parallel axis theorem and the perpendicular axis theorem.**
**As bike is working on concept of RIP (rotary inverted pendulum) and the arm is connected from its end to the pivot and it rotates with respect to end of cylinder so to find the moment of inertia of a cylinder about a diameter at its end we use both these theorem.**

**These images are from** 🔗

-----------------------------------------------------------------------------------------------

**Q10.** How will you check whether the system is stable or not in a state-space approach?

**A10. In state-space approach we can find system is stable or not at each of the equilibrium points by finding out the eigenvalues of the State matrix(A matrix). If any of the eigenvalues have a positive real part, the system will be unstable and if all real part of eigenvalues are negative then system will be stable.**

-----------------------------------------------------------------------------------------------

**Q11.** What will be happening in the following situation:

The bike wrongly indicated the LED colour for a colony site while in halt. When starting to move it crosses the dotted line and hits the colony sites and falls. So Manual intervention has taken place. How many penalties will be imposed and what are they?

**A11. There will be 2 penalties:-**
**1.Wrong Indication Penalty (WI):**
**The bike wrongly indicated the LED color for a Colony Site while in halt.**
**This incurs a Wrong Indication Penalty (WI).**
**2.Manual Intervention Penalty (MI):**
**The bike crosses the dotted line, hits the Colony Sites, and falls.**
**A Manual Intervention (MI) has high weightage so This incurs a Manual Intervention Penalty (MI).**

**Because In the case of an event incurring multiple penalties(any of MI/HP/PP), the penalty with highest weight among them will be considered for that particular event.**
**Here all three penalties happened (MI/HP/PP)but MI has high weightage so only MI will be counted.**

---

**Q12.** How many different type sensors does a 6-axis Inertial Measurement Unit(IMU) have? Explain what physical quantities they measure exactly?

**A12. There are two types of sensors does a 6-axis Inertial Measurement Unit(IMU)**

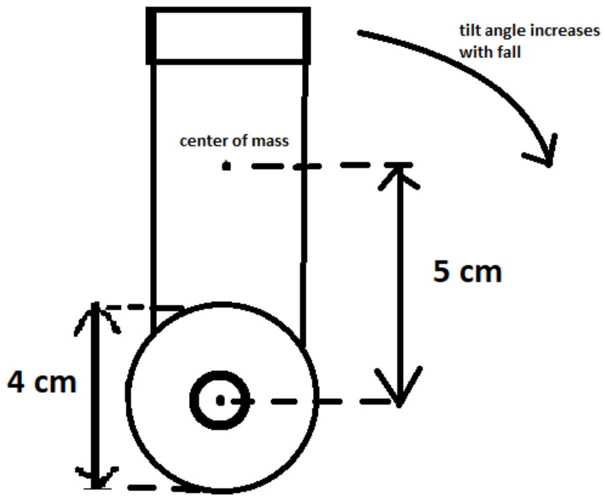
1. **Accelerometers (3-axis): These sensors measure linear acceleration along three perpendicular axes: X, Y, and Z. This allows the IMU to determine the translational motion of the object it is attached to, such as its acceleration, deceleration, and tilt.**
2. **Gyroscopes (3-axis): These sensors measure the angular velocity of the object, also known as its rotational motion around the three axes: pitch, roll, and yaw. This allows the IMU to determine the object's orientation and angular rate of change in its orientation.**
   **Therefore, 6-axis IMU measures a total of 6 physical quantities:**
   **3 linear accelerations: X, Y, and Z**
   **3 angular velocities: pitch, roll, and yaw**

**MPU6050 Accelerometer and Gyroscope Module, GY-87(3-axis Gyro+Acceleration) measures 6-axis Inertial Measurement Unit(IMU)**

---

**Q13.** Consider a wheeled inverted pendulum having a vertical body balanced using a DC geared motor. The center of mass of the body is at 5 cm height from the axle of the wheel and motor shaft. The diameter of the wheel is 4 cm.

- What is the torque required from the DC geared motor(max RPM = 300), to be able to balance this body of total mass 1.5 kg(consider wheel & motor massless), with max correctable angular tilt as +/- 5 degrees. (Mention steps for your calculation)




A13.

ANSWER PDF

DC motor have to apply the torque of equal in magnitude of body's applied torque and in opposite direction to balance the body vertical. Calculations are in provided pdf.

---