Biped Patrol

Task 3.3: Think & Answer

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Date	January 15, 2020

Question No.	Max. Marks	Marks Scored
Q1	10	
Q2	20	
Q3	5	
Q4	5	
Q5	5	
Q6	10	
Q7	15	
Q8	8	
Q9	4	
Q10	8	
Q11	10	
Total	100	

Biped Patrol

Task 3.3: Think & Answer

Instructions:

- There are no negative marks.
- Unnecessary explanation will lead to less marks even if answer is correct.
- If required, draw the image in a paper with proper explanation and add the snapshot in your corresponding answer.

Q 1. Describe hardware design for the Medbot, your team is constructing. Describe various parts with well labeled image. Give reasons for selection of design. [10]

A 1. Multi-layer design will be used by our team for the construction of our Medbot which will have 3 layer. First layer or the bottom layer will contain both the motors along with L298n motor driver. The second layer or the middle layer will contain xbee and ardunio mega along with buzzer and will be attached to frame which will hold the electromagnet which will be pointing downward direction so that it can pick the boxes. This design will be easy to control through LQR controller. We will place the battery on the top layer along with led to signal when required. The reason to place battery there is it will provide more weight at a height and this will increase the moment of inertia which will provide stability whenever there is torque. So, our robot design should be selected.

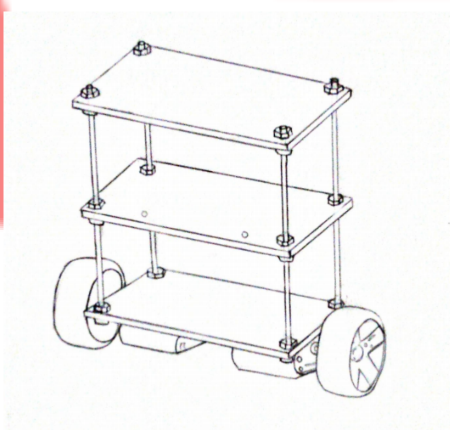

Figure 1: Robot Design

Q 2. In Task 1.2, you were asked to model different systems such as Simple Pulley, Complex Pulley, Inverted Pendulum with and without input and stabilizing the unstable equilibrium point using Pole Placement and LQR control techniques. There you had to choose the states; Derive the equations (usually non-linear), find equilibrium points and then linearize around the equilibrium points. You were asked to find out the linear system represented in the form

$$\dot{X}(t) = AX(t) + BU(t) \tag{1}$$

Where $X(t)$ is a vector of all the state,i.e., $X(t) = [x_1(t), x_2(t), \ldots, x_n(t)]^T$, and $U(t)$ is the vector of input to the system, i.e. $U(t) = [u_1(t), u_2(t), \ldots, u_m(t)]^T$. A is the State Matrix & B is the Input Matrix.
In this question, you have to choose the states for the Medbot you are going to design. Model the system by finding out the equations governing the dynamics of the system using Euler-Lagrange Mechanics. Linearize the system via Jacobians around the equilibrium points representing your physical model in the form given in equation 1.
Note: You may choose symbolic representation such as M_w for Mass of wheel, etc. [20]

A 2. We can find the equation of motion governing the system using the Euler-Lagrange method $\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) - \frac{\partial L}{\partial x} = 0$, here $L = K.E. - P.E.$

So L is given by

$$L = \left[\frac{M_b}{2} + M_w + \frac{I_a}{R^2}\right]\dot{x}^2 + \left[M_b d^2 + \frac{1}{2}I_x\right]\dot{\phi}^2 + \left[\left(M_w + \frac{I_a}{R^2}\right)L^2 + \frac{1}{2}\left(I_z cos^2\phi + I_y sin^2\phi + M_b d sin^2\phi\right)\right]\dot{\psi}^2 + M_b d cos\phi \dot{x}\dot{\phi} - \left[M_b g d cos\phi + M_b g R\right]$$

So the final variables are

$$\ddot{x} = -\frac{M_b^2 d^2 g R^2}{(M_b d^2 + I_x)(M_b R^2 + 2M_w R^2 + 2I_a) - (M_b d R)^2}\phi + \frac{R\left(M_b d^2 + I_x + M_b d R\right)}{(M_b d^2 + I_x)(M_b R^2 + 2M_w R^2 + 2I_a) - (M_b d R)^2}(\tau_1 + \tau_2)$$

$$\ddot{\phi} = \frac{\left(M_b R^2 + 2M_w R^2 + 2I_a\right)M_b g d}{[(M_b + 2M_w)R^2 + 2I_a]I_x + 2M_b d^2(M_w R^2 + I_a)}\phi - \frac{\left(M_b R^2 + 2M_w R^2 + 2I_a\right) + M_b d R}{[(M_b + 2M_w)R^2 + 2I_a]I_x + 2M_b d^2(M_w R^2 + I_a)}(\tau_1 + \tau_2)$$

$$\ddot{\psi} = \frac{L}{R\left[2\left(M_w + \frac{I_a}{R^2}\right)L^2 + I_z\right]}(\tau_1 - \tau_2)$$

now considering $x(t) = \begin{bmatrix} x & \dot{x} & \phi & \dot{\phi} & \psi & \dot{\psi} \end{bmatrix}$

In state-space form: $A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\frac{M_b^2 d^2 g R^2}{(M_b d^2 + I_x)(M_b R^2 + 2M_w R^2 + 2I_a) - (M_b d R)^2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \frac{\left(M_b R^2 + 2M_w R^2 + 2I_a\right)M_b g d}{[(M_b + 2M_w)R^2 + 2I_a]I_x + 2M_b d^2(M_w R^2 + I_a)} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$

$$B = \begin{bmatrix} 0 & 0 \\ \frac{R\left(M_b d^2+I_x+M_b dR\right)}{(M_b d^2+I_x)(M_b R^2+2M_w R^2+2I_a)-(M_b dR)^2} & \frac{R\left(M_b d^2+I_x+M_b dR\right)}{(M_b d^2+I_x)(M_b R^2+2M_w R^2+2I_a)-(M_b dR)^2} \\ 0 & 0 \\ -\frac{\left(M_b R^2+2M_w R^2+2I_a\right)+M_b dR}{[(M_b+2M_w)R^2+2I_a]I_x+2M_b d^2(M_w R^2+I_a)} & -\frac{\left(M_b R^2+2M_w R^2+2I_a\right)+M_b dR}{[(M_b+2M_w)R^2+2I_a]I_x+2M_b d^2(M_w R^2+I_a)} \\ 0 & 0 \\ \frac{L}{R\left[2\left(M_w+\frac{I_a}{R^2}\right)L^2+I_z\right]} & -\frac{L}{R\left[2\left(M_w+\frac{I_a}{R^2}\right)L^2+I_z\right]} \end{bmatrix}$$

PARAMETER	Symbol
Mass of main body	M_b
Mass of each wheel	M_w
Center of mass from base	d
Diameter of wheel	R
Distance between the wheels	L
Moment of inertia wrt x-axis	I_x
Moment of inertia wrt y-axis	I_y
Moment of inertia wrt z-axis	I_z
Moment of inertia of wheel about the center	I_a
Acceleration due to gravity	g

Table 1: Parameter and symbols

Q 3. Equation 1 represents a continuous-time system. The equivalent discrete time system is represented as:

$$X(k+1) = A_d X(k) + B_d U(k) \tag{2}$$

Where $X(k)$ is a measure of the states at k_{th} sampling instant,i.e., $X(k) = [x_1(k), x_2(k), \ldots, x_n(k)]^T$, and $U(k)$ is the vector of input to the system at k_{th} sampling instant, i.e. $U(k) = [u_1(k), u_2(k), \ldots, u_m(k)]^T$.
A_d is the Discrete State Matrix & B_d is the Discrete Input Matrix.
What should be the position of eigen values of A_d for system to be stable. **Hint:** In frequency domain, continuous-time system is represented with Laplace transform and discrete-time system is represented with Z transform. [5]

A 3. The eigen values of A_d for system to be stable, there real part should lie on the negative size of the complex plane. The solution to the equation $\dot{X}(t) = AX(t)$ is of the form $X(t) = e^{AX(T)}$. So when the eigen value of the A negative which means the scaling factor of the eigen vectors is negative thus providing a negative magnitude to the exponential function which decays to zero in an infinite time and in our case the impulse response will be of 10 milliseconds so even a second will be quite enough to stabilize the system. Obviously the value will not be negative and so there is need of a input matrix B_d which will control the actuators.

Q 4. Will LQR control always works? If No, then why not? and if Yes, Justify your answer.
Hint: Take a look at definition of Controllable System. What is controllability? [5]

A 4. LQR control works on system which is both controllable and observable.
The system is controllable if its state value can be changed using a suitable input. Mathematically from 1 if we find R such that $R = \begin{bmatrix} B & AB & A^2B & \cdots & A^nB \end{bmatrix}$ and that R has a rank of n than the system is controllable.
Apart from the system to be controllable the system needs to be observable. The system is observable if the state and the control input is able to determine the current state of the system.
Mathematically if we find O such that $O = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^n \end{bmatrix}$ and O has a rank of n than the system is observable.

Q 5. For balancing robot on two wheel i.e. as inverted pendulum, the center of mass should be made high or low? Justify your answer. [5]

A 5. The center of mass should be high to increase the moment of inertia. This is necessary as it will require more torque to tilt the upper part of the robot providing a stability to the whole system. When moment of inertia increases the angular velocity decreases. So eventually it will try to keep the system to tilt less.

Q 6. Why do we require filter? Do we require both the gyroscope and the accelerometer for measuring the tilt angle of the robot? Why? [10]

A 6. The Accelerometer produces high frequency noise. The useful information than need to be obtained from the accelerometer data is the low frequency values which can be obtained by passing the data to a low-pass filter.
The Gyrosope produces low frequency noise. The useful information that need to be obtained from the gyroscope data is the high frequency value which can be obtained by passing the data to a high-pass filter.
Yes, we require both the gyroscope and accelerometer data for measuring the tilt angle of the robot because tilt angle calculated from the accelerometer data has slow response time whereas tilt calculated from gyroscope data has drift over a period of time meaning that accelerometer data is useful for a long term and the gyroscope data is useful in short term. So a complimentary filter is required that combines the slow moving signals of accelerometer and fast moving signals of gyroscope.

Q 7. What is Perpendicular and Parallel axis theorem for calculation of Moment of Inertia? Do you require this theorem for modelling the Medbot?Explain Mathematically. [15]

A 7. Perpendicular Axis Theorem: This theorem is applicable only to the planar bodies. Bodies which are flat with very less or negligible thickness. This theorem states that the

moment of inertia of a planar body about an axis perpendicular to its plane is equal to the sum of its moments of inertia about two perpendicular axes concurrent with the perpendicular axis and lying in the plane of the body. $I_z = I_x + I_y$
Parallel Axis Theorem: Parallel axis theorem is applicable to bodies of any shape. The theorem of parallel axis states that the moment of inertia of a body about an axis parallel to an axis passing through the centre of mass is equal to the sum of the moment of inertia of body about an axis passing through centre of mass and product of mass and square of the distance between the two axes. $I_Z = I_z + M\alpha^2$ where, α is the distance between two axes.

We require both the theorem to find the moment of inertia in the X-axis, Y-axis and Z-axis. To calculate the moment of inertia in X-axis we use perpendicular axis theorem. For Y and Z we use parallel axis theorem to find the moment of inertia.

Q 8. What will happen in the following situations:

(a) Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit falls inside the store. Will there be any penalty imposed, points awarded? Will the First-Aid Kit be repositioned? [2]

(b) Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit falls outside the store. Will there be any penalty imposed, points awarded? Will the First-Aid Kit be repositioned? [2]

(c) Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit and the Medbot both fall inside the store. Will there be any penalty imposed, points awarded? Will the First-Aid Kit be repositioned? [2]

(d) Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit and the Medbot both fall outside the store. Will there be any penalty imposed, points awarded? Will the First-Aid Kit be repositioned? [2]

A 8.

(a) There will be no penalty imposed when the Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit falls inside the store. However no points will be awarded.

(b) There will be no penalty imposed when the Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit falls outside the store. Points will be awarded when the First Aid Kit is taken out of the Medical Store.

(c) There will be penalty imposed when the Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit and the Medbot both fall inside the store. However no points will be awarded. Yes, the First-Aid Kit will be repositioned.

(d) There will be penalty imposed when the Medbot picks a First-Aid Kit from the shelf of Medical Store but the First-Aid Kit and the Medbot both fall outside the store. Points will be awarded when the First Aid Kit is taken out of the Medical Store.Yes, the First-Aid Kit will be repositioned.

Q 9. What will be the points awarded if Medbot picks only one of the item from the medical store and repeatedly moves back and forth around the gravel pathway or the bridge for the entire run. [4]

A 9. For each item the Medbot carries, the count will be done only once. So if the Medbot moves back and forth it will be loosing time and will not be gaining any points for that whether it is carrying a box or not.

Q 10. What are the different communication protocols you'll be using? Name the hardware interfaced related to each of the communication protocols. Explain how these communication protocols works and what are the differences between them. [8]

A 10. We will be using 802.15.4 protocol based on IEEE 802.15.4 which is a technical standard defined for operation for low-rate wireless personal area network. Apart from this we can also use the Zigbee protocol which is also based on IEEE 802.15.4. We will be using Xbee hardware to achieve this communication.
The 802.15.4 standard defines communication layer at level 2 of OSI model and was created by IEEE. The Zigbee standard defines communication layer at level 3 of OSI model and was created by a set of companies which form the ZigBee Alliance.

Q 11. Why do we require IRF540N? Provide circuit diagram for interfacing IRF540N with the microcontroller. [5+5]

A 11. The power supply that can be provided by the microcontroller is 5V and the electromagnet need a 12V supply but was still needed to be controlled by the microcontroller. So we use IRF540N which on getting a signal from the microcontroller completes the circuit for the electromagnet hence acting as a switch.

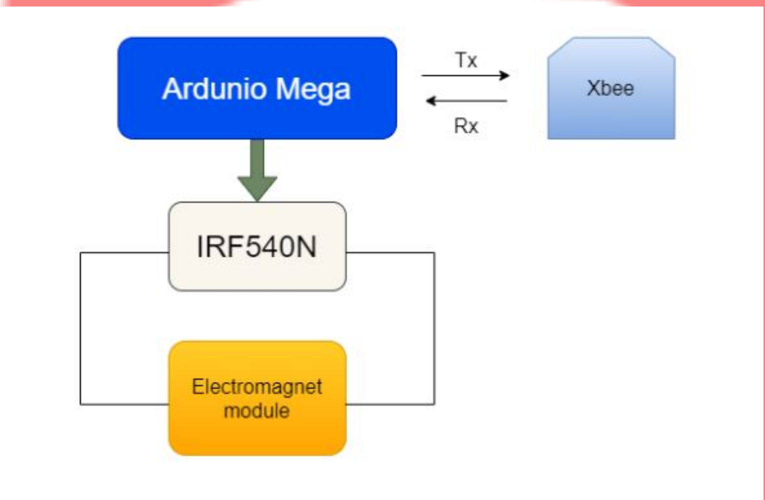

Figure 2: IRF540N Interfcing