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	

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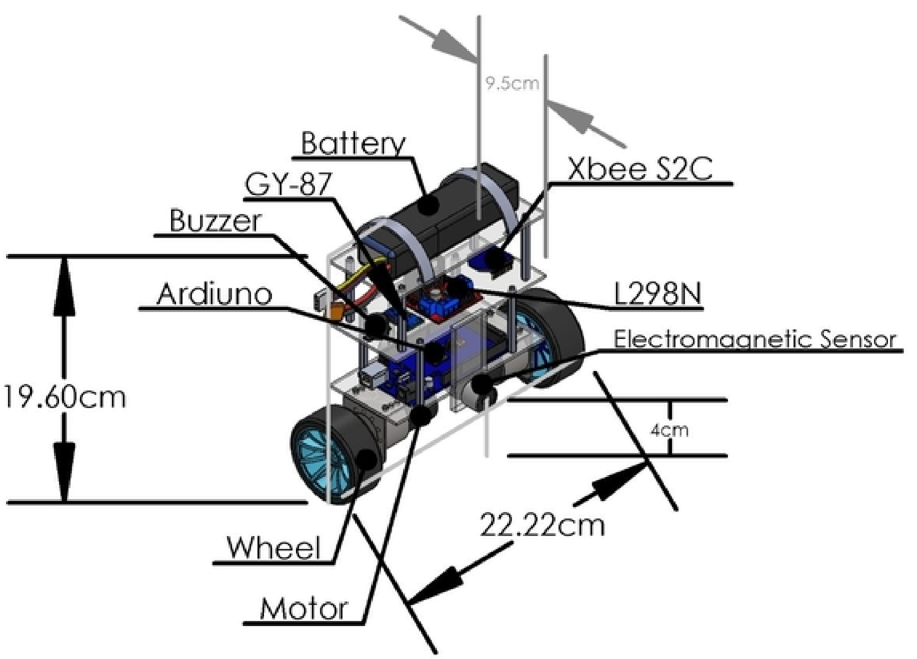
Task 3.3: Think & Answer

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.

Fig.CAD model of medbot

We have decided to put maximum weight on the top of the medbot because,it can be better if centre of mass is higher relative to the wheel axes and higher centre of mass means higher

moment of inertia which means lower the angular acceleration i.e.medbot requires less rpm to stabilize the entire system. So, Maximum weight is placed at top of the medbot.
As Shown in fig.,sections(slots) are made to place components in a better optimized way as well as to maintain the Centre of gravity (CG) of the medbot.Placing of Electromagnetic module is infront as well as behind the medbot so,it would be convenient to pick-up the supply items.Also,Electromagnetic sensor is mounted in such a way that supply items placed in medical racks is easily accessible.

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]

Let, r_w = radius of wheel
m_w = mass of wheel
l_b = position of centre of mass of bot
m_b = mass of body
T_w = wheel torque
θ = tilt angle
V_{com} = velocity of centre of mass
R = Resistance of motor
K = motor constant
I_m = moment of Inertia of motor
I_w = moment of Inertia of wheel
I_b = moment of Inertia of body.
n = gear ratio (30)
V_s = Input voltage to the System.

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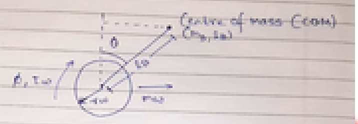
A 2.

A-2



$x = r\phi$ .... (displacement due to wheel)

$x_{com} = x + l\sin\theta$
$y_{com} = l_b\cos\theta$ — (centre of mass)

$V_{com} = \sqrt{\dot{x}_{com}^2 + \dot{y}_{com}^2}$ ... [velocity of centre of mass]

$E_{KB} = \frac{1}{2} m_b V_{com}^2$ ..... [kinetic energy due to motion]
$+ \frac{1}{2} I_b \dot{\theta}^2$
$= \frac{1}{2} m_b (\dot{x}^2 + 2\dot{x} l \cos\theta . \dot{\theta} + l^2 \dot{\theta}^2)$
$+ \frac{1}{2} I_b \dot{\theta}^2$

Kinetic Energy of wheels,

$E_{PB} = m_b g l \cos\theta$

Potential of wheel = 0
$E_{PW} = 0$

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$L = E_{KB} - E_{PB}$ ----- [Lagrangian]

$= E_{KB} + 2E_{KW} - E_{PB} - 2E_{PB}$ --- [since mediums of 2 wheels]

- Input to the system is torque from wheels.

$$\frac{\partial}{\partial t}\left(\frac{\partial L}{\partial \dot{x}}\right) - \frac{\partial L}{\partial x} = 2T_w$$

for x,

$$\left(m_b + 2m_w + \frac{2I_w}{r^2}\right)\ddot{x} + m_b l \cos\theta\,\ddot{\theta} - m_b l \sin\theta\,\dot{\theta}^2 = \frac{2T_w}{r} \quad (1)$$

for θ,

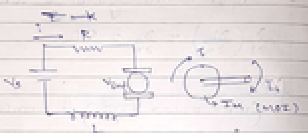
$$m_b l \cos\theta\,\ddot{x} + (m_b l^2 + I_B)\ddot{\theta} - m_b g l \sin\theta = -2T_w \quad (2)$$

Assume $\cos\theta = 1$, $\sin\theta = \theta$, $\dot{\theta}^2 = 0$.

$$\left(m_b + 2m_w + \frac{2I_w}{r^2}\right)\ddot{x} + m_b l\ddot{\theta} = \frac{2T_w}{r} \quad (3)$$

$$m_b l\ddot{x} + (m_b l^2 + I_B)\ddot{\theta} = -2T_w \quad (4)$$

The input of the system will be voltage provided by our controller. Hence, we need establish relationship between input voltage (V_s) and torque (T_w) of the motor.



$T = ki$, $V_{emf} = k\dot{\phi}_m$

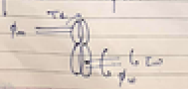
Applying KVL,

$$V_s - iR - V_{emf} - L\frac{di}{dt} = 0$$

$$I_m\ddot{\phi}_m + b_m\dot{\phi}_m + T_L = T$$

$$I_m\ddot{\phi}_m + \left(b_m + \frac{k^2}{R}\right)\dot{\phi}_m + T_L = \left(\frac{k}{R}\right)V_s \quad (5)$$

Required torque is T_w. Hence, we need to use gear reduction in order to achieve required torque.



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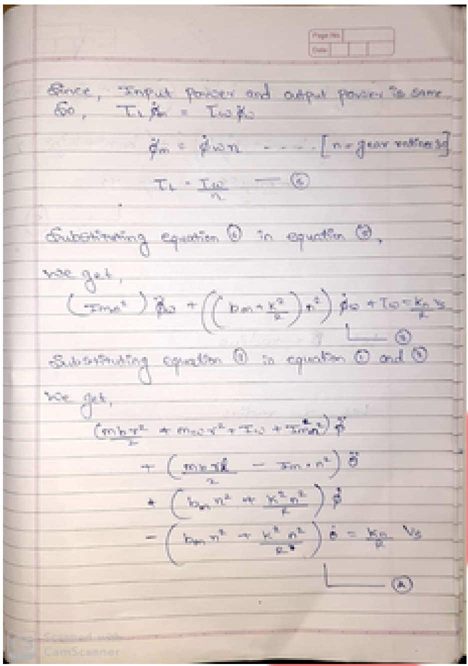


Since, Input power and output power is same
So, $T_L \dot{\phi}_m = T_w \dot{\phi}_w$

$\dot{\phi}_m = \dot{\phi}_w n$ ..... [n = gear ratio]

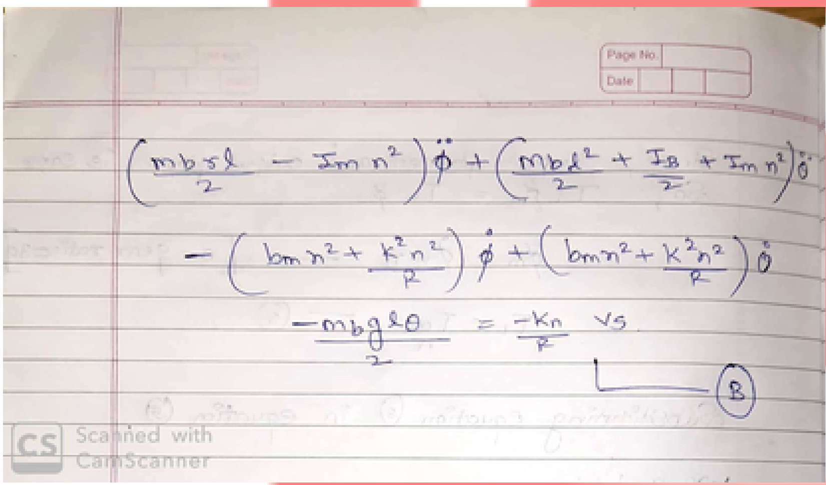
$T_L = \frac{T_w}{n}$ —— ④

Substituting equation ④ in equation ③,
we get,

$\left(I_m n^2\right)\ddot{\phi}_w + \left(\left(b_m + \frac{K^2}{R}\right)n^2\right)\dot{\phi}_w + T_w = \frac{K_n V_s}{R}$ —— ⑤

Substituting equation ⑤ in equation ① and ②
we get,

$\left(\frac{m_b r^2}{2} + m_w r^2 + I_w + I_m n^2\right)\ddot{\phi}$
$+ \left(\frac{m_b r l}{2} - I_m n^2\right)\ddot{\theta}$
$+ \left(b_m n^2 + \frac{K^2 n^2}{R}\right)\dot{\phi}$
$- \left(b_m n^2 + \frac{K^2 n^2}{R}\right)\dot{\theta} = \frac{K_n}{R} V_s$ —— Ⓐ



$\left(\frac{m_b r l}{2} - I_m n^2\right)\ddot{\phi} + \left(\frac{m_b l^2}{2} + \frac{I_B}{2} + I_m n^2\right)\ddot{\theta}$
$- \left(b_m n^2 + \frac{K^2 n^2}{R}\right)\dot{\phi} + \left(b_m n^2 + \frac{K^2 n^2}{R}\right)\dot{\theta}$
$- \frac{m_b g l \theta}{2} = \frac{-K_n}{R} V_s$ —— Ⓑ

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. Ad matrix must be real-valued and distinct.

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 will not work always.
Reason : The solution to a particular LQR problem is obtained under the implicit assumption that the desired final state is reachable from the given initial state. If this is not possible, then you can not construct any u(t) input. Concept of controllability also denotes the same thing i.e. the ability to move a system around in its entire configuration space using only certain admissible manipulations.

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. It can be better if centre of mass is higher relative to the wheel axes. A higher centre of mass means higher moment of inertia which means lower the angular acceleration.
Example : Stick with longer length(higher centre of mass) can be better balancing than stick with shorter length(lower centre of mass).

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. Both gyroscope and accelerometer has their own strengths and weaknesses. The calculated tilt angle from the accelerometer data has slow response time, while the integrated tilt angle from the gyro data is subjected to drift over a period of time. In other words, we can say that the accelerometer data is useful for long term while the gyro data is useful for short term.Filter is to take slow moving signals from accelerometer and fast moving signals from a gyroscope and combine them.
Basically,the purpose of designing the filter is to overcome the weakness of the one sensor using strength of other sensor.
Yes,We require both gyroscope and accelerometer.Because,both gyroscope and accelerometer gives varying reading independently and we need precise readings, so fusion of both reading is required which can be done by using filter.

Q 7. What is Perpendicular and Parallel axis theorem for calculation of Moment of Inertia?

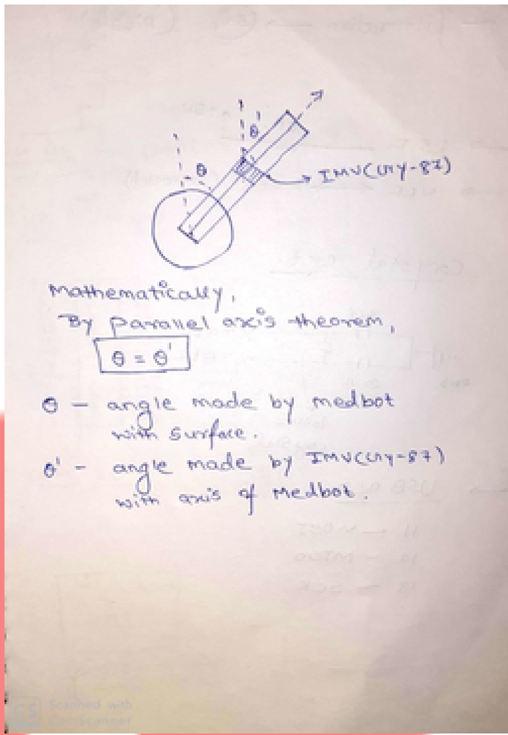
Do you require this theorem for modelling the Medbot?Explain Mathematically. [15]

A 7. Perpendicular axis theorem : The perpendicular axis theorem states that the moment of inertia of a plane lamina about an axis perpendicular to the plane of the lamina is equal to the sum of the moments of inertia of the lamina about the two axes at right angles to each other, in its own plane intersecting each other at the point where the perpendicular axis passes through it. Let Ix, Iy and Iz be moments of inertia about axis x, y, z respectively, the perpendicular axis theorem states that :
$Iz=Ix+Iy$.

Parallel axis theorem : 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.

Suppose a body of mass m is rotated about an axis z passing through the body's centre of gravity. The body has a moment of inertia Icm with respect to this axis. If this body rotates about new axis z' which is parallel to axis z and displaced by distance d from it,then moment of inertia I about new axis is given by :
$I=I_{cm} + md^2$.

Yes,we require parallel axis theorem for the modelling of the bot since, we need to estimate the angle of inclination of the medbot with respect to vertical axis from the centre of the medbot.The IMU(GY-87) would be placed in such a way that it would be parallel to the surface of the bot.By using parallel axis theorem, we can say that angle indicated by IMU(GY-87) is the tilt angle of bot also.



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 inside the store. Will there be any penalty imposed, points awarded? Will the First-Aid Kit be repositioned? [2]

A 8. (a)In this situation, First-aid kit will be repositioned i.e. the first-aid kit will be placed back to the initial position and there will be no penalty imposed on team.

(b)In this situation, First-aid kit will be repositioned i.e. the first-aid kit will be placed back to the initial position and there will be no penalty imposed on team.

(c)In this situation, First-aid kit will be repositioned i.e. the first-aid kit will be placed back to the initial position and there will be penalty of 50 points on each fall count and Medbot will be placed at Parking Area.

(d)In this situation, First-aid kit will be repositioned i.e. the first-aid kit will be placed back to the initial position and there will be penalty of 50 points on each fall count and Medbot will be placed at Parking Area.

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. In this situation, points will be awarded for the picking up the item once and points will be awarded for traversing the gravel pathway or the bridge for once only(MG and MB).
No points will be awarded when medbot moves back and forth around the gravel pathway or the bridge.

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. The different communication protocols we will be using are I2C,UART,SPI.

Hardware	Protocols	
XBEE S2C	UART	SPI
GY87/HW-290	I2C	SPI

<u>I2C</u> : I2C stands for Inter-integrated circuits. I2C is a serial communication protocol, so data is transferred bit by bit along a single wire (the SDA line). Like SPI, I2C is synchronous, so the output of bits is synchronized to the sampling of bits by a clock signal shared between the master and the slave. The clock signal is always controlled by the master.

<u>UART</u> : UART stands for universal asynchronous receiver-transmitter. In UART communication, two devices serially communicate with each other over a single channel on same frequency. Parameters such as total no.of bits, start and stop bits are defined so that communication can be established. The transmitter starts by sending a start pulse, followed by 8 bits of data, followed by an end pulse indicating transmission completed.

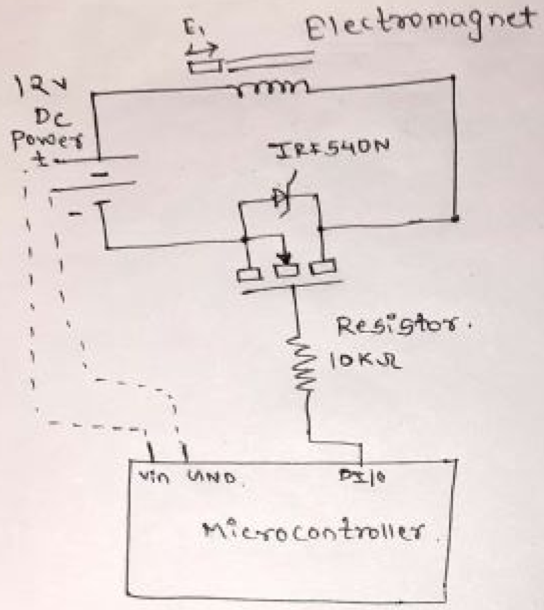
<u>SPI</u> : SPI stands for Serial Peripheral Interface. SPI is a "synchronous" data bus, which means that it uses separate lines for "data" and a "clock" that keeps both sides in perfect sync. The clock is an oscillating signal that tells the receiver exactly when to sample the bits on the data

line.SPI is a common communication protocol used by many different devices. For example, 2.4 GHz wireless transmitter/receivers all use SPI to communicate with microcontrollers. One unique benefit of SPI is the fact that data can be transferred without interruption.
The difference between I2C,UART and SPI are as follows :

Protocols	I2C	UART	SPI
Full-Form	Inter-integrated Circuit	Universal Asynchronous Receiver-Transmitter	Serial Peripheral Interface
Type of Communication	Synchronous	Asynchronous	Synchronous
Pin Designation	Uses two lines SDA : Serial Data SCL : Serial Clock	Uses two lines Tx : Transmit Data Rx : Receive Data	Uses four lines SCLK : Serial Clock MOSI : Master Output, Slave Input MISO : Master Input, Slave Output SS : Slave Select
Clock	Common Clock signal between multiple masters and multiple slaves	No Common Clock signal is used.	one common serial clock signal between master and slave devices.
Duplex	Half Duplex	Full Duplex	Full Duplex
No. of masters and slaves	Supports multiple masters and slaves	No multiple masters and slaves	Only 1 master but can have multiple slaves

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

A 11. IRF540N is a N-channel mosfet,basically used for switching operations as well as for amplification process.We are using IRF540N as a switch which is actuated using digital signals from Arduino. The voltage requirement of Electromagnet module is 12v which cannot be provided by Arduino(Max. 5v) directly hence we rely on switching using IRF540N.



→ DI/O is Digital Input-output pin of microcontroller.

fig. Interfacing of IRF540N with Microcontroller.

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