Biped Patrol

Task 3.3: Think & Answer

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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]

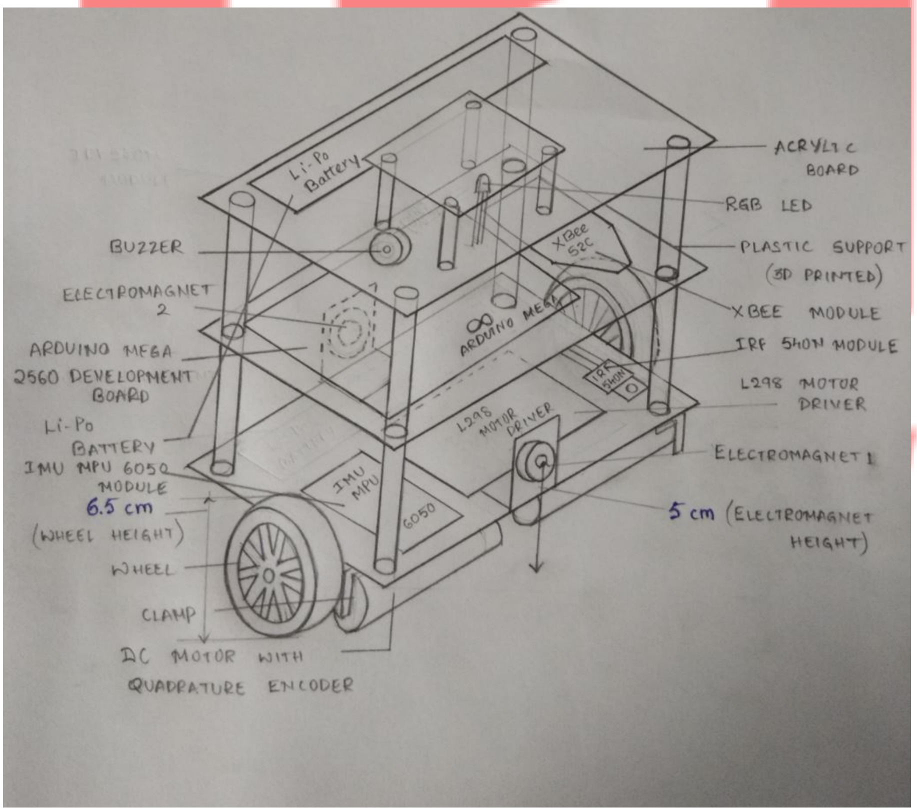

Figure 1: MedBot design : Isometric view

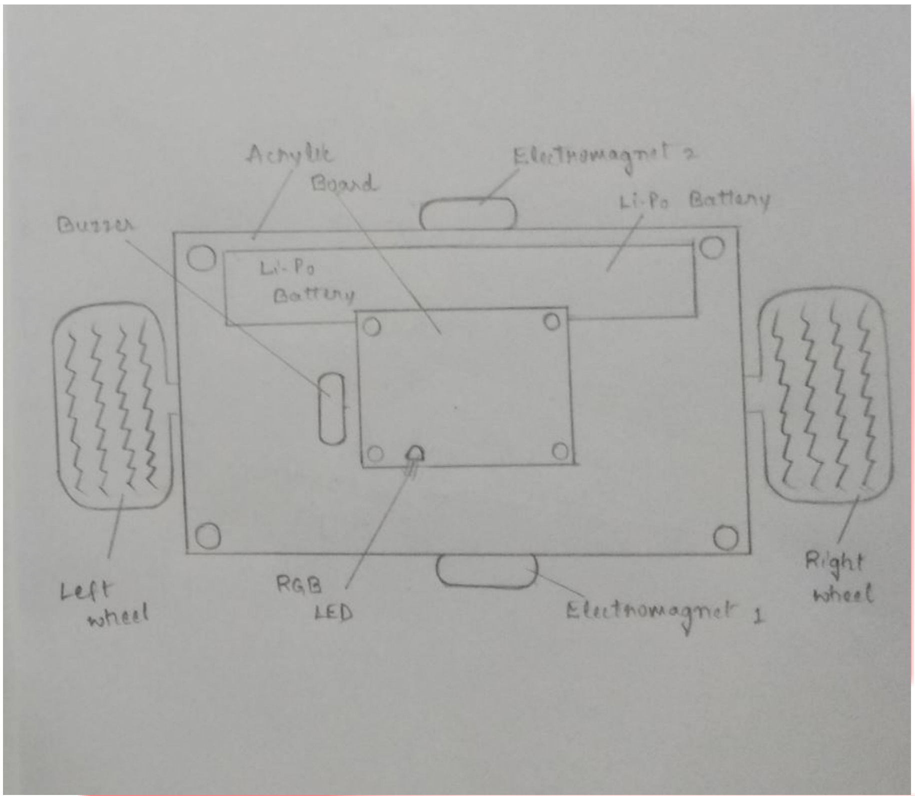

Figure 2: MedBot design : Top view

A 1. Mainly there are two types of designs:

- Vertical design
- Stackable design.

Reasons for the selection of the design :

- We have chosen stackable design, as it is more feasible to construct and components can be mounted and removed easily, without having to worry much about the shift in center of gravity.
- The mass moment of inertia of the robot must be high so that it tilts more slowly when external torque is applied. In our design the mass is distributed as different compartments. Hence height of the robot can be adjusted in order to shift the center of gravity as required.
- The IMU MPU6050 is placed at the bottom most compartment as it is advised to keep it near the axis of the motors because as the distance from the ground increases, linear acceleration and vibrations, measured at higher points, increases. This could lead to false readings of the accelerometer. However, the angular rate measured by the gyroscope is not affected by the placement of the sensor, as it will vary by the same amount at all points on the robot.
- The two electromagnets are placed on the first compartment to carry the boxes.
- If we want the robot to carry some load, it can be easily done using this design as we can add another layer and put load on it.

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 .

Note: You may choose symbolic representation such as M_w for Mass of wheel, etc. [20]

A 2. Analysing wheels and body separately and later combining both of them. Let's analyse.

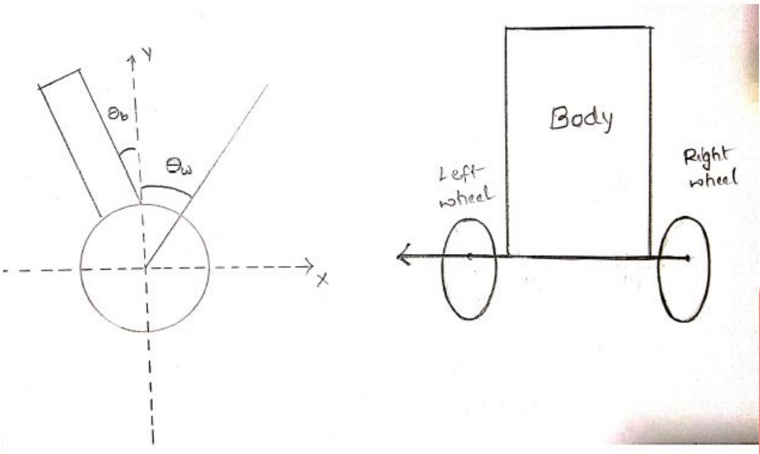

Figure 3: Diagram

Assuming mass of wheel concentrated at centre mass.
We have

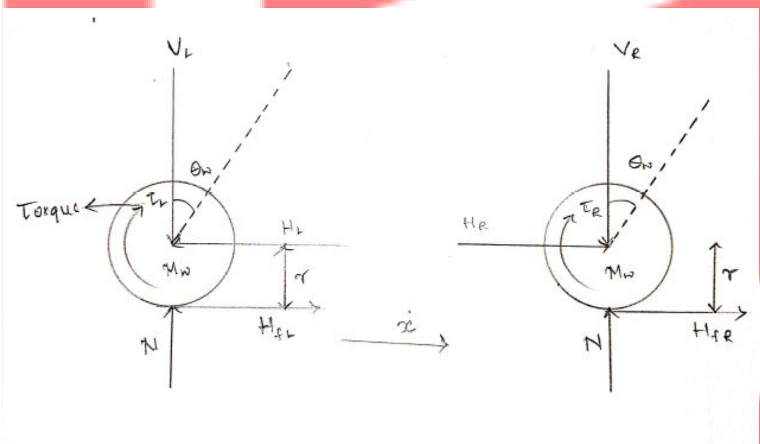

Figure 4: Wheels

H_R,H_L $\Rightarrow$ *Force exerted by right and left wheel*
H_{fL} $\Rightarrow$ *Frictional force*
r $\Rightarrow$ *Radius*
M_w $\Rightarrow$ *Mass of wheel*
I_w $\Rightarrow$ *Moment of inertia of wheel*

Considering wheel:
$PotentialEnergy = M_w g r$

$$KineticEnergy = (\frac{1}{2})M_w\dot{x}^2 + (\frac{1}{2})I_w W^2$$

$$KineticEnergy = (\frac{1}{2})M_w\dot{x}^2 + (\frac{1}{2})I_w \theta^2$$

By Euler-Lagrange method

$$\frac{d}{dt}(\frac{\partial L}{\partial x}) - \frac{\partial L}{\partial x} = F_{net}$$

Considering left wheel

$$L \Rightarrow [K.E - P.E]$$

$$L = (\frac{1}{2})M_w\dot{x}^2 + (\frac{1}{2})I_w\theta^2 - M_w gh$$

$$\frac{\partial L}{\partial \dot{x}} = M_w\dot{x}$$

$$\frac{d}{dt}(\frac{\partial L}{\partial x}) = M_w\ddot{x}$$

$$\frac{\partial L}{\partial x} = 0$$

$$F_{net} = H_{fL} - H_L$$

$$M_w\ddot{x} = H_{fL} - H_L$$

$$\frac{d}{dt}(\frac{\partial L}{\dot{\theta}}) - \frac{\partial L}{\theta} = \tau_{net}$$

$$I_w\ddot{\theta}_w = \tau_L - H_{fL}r$$

Similarly right wheel

$$M_w\ddot{x} = H_{fR} - H_R$$

$$I_w\ddot{\theta}_w = \tau_R - H_{fR}(r)$$

Solving (1)(2)(3)(4)
Assuming H_{fL}=H_{fR}
we get,

$$2(M_w + \frac{I_w}{r^2})\ddot{x} = \frac{\tau_R + \tau_L}{r} - (H_R + H_L)$$

$$\tau_R \Rightarrow \quad Right \;\; wheel \;\; torque$$
$$\tau_L \Rightarrow \quad Left \;\; wheel \;\; torque$$

Now considering body of the bot

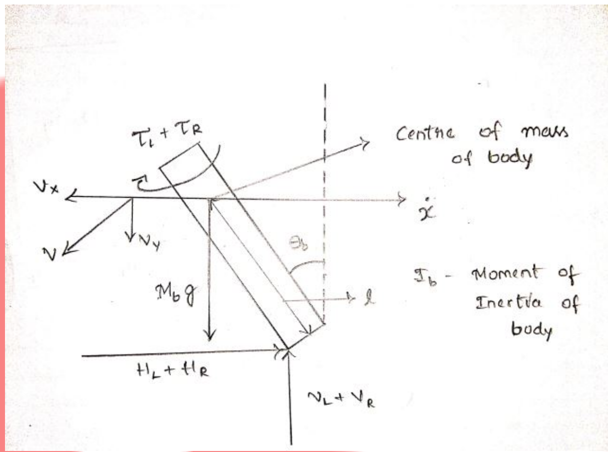

Figure 5: Diagram

I_b->moment of inertia of body
Vertical forces are balanced i.e $\sum F_V = 0$
Kinetic Energy of the body

$$= (1/2)M_b(\dot{x} - l\theta_b cos\theta_b)^2 + (1/2)M_b(l\dot{\theta}_b sin\theta_b)$$
$$= (1/2)M_b(\dot{x^2} + l^2\dot{\theta} cos^2\theta_b - 2\dot{x}l\dot{\theta}_b cos\theta_b) + (1/2)M_b(l^2\theta_b^2 sin^2\theta_b) + (1/2)I_b\dot{\theta_b^2}$$
$$= (1/2)M_b(\dot{x^2} + l^2\theta_b(cos^2\theta_b + sin^2\theta_b) - 2\dot{x}l\dot{\theta}_b cos\theta_b) + (1/2I_b\dot{\theta_b^2})$$
$$= (1/2)M_b(\dot{x^2} + l^2\theta_b - 2\dot{x}l\dot{\theta}_b cos\theta_b) + (1/2I_b\dot{\theta_b^2})$$

consider P.E of body

$$M_b g l cos\theta_b$$
$$L = K.E - P.E$$
$$\frac{d}{dt}(\frac{\partial L}{\partial \dot{x}}) - \frac{\partial L}{\partial x} = F_{net}$$
$$\frac{\partial L}{\partial x} = 0$$

$$M_b\ddot{x} - M_bl\ddot{\theta}_bcos\theta_b + M_bl\dot{\theta}_b^2sin\theta_b = H_L + H_R$$
$$\dot{\theta}_b^2 \simeq= 0$$
$$M_b\ddot{x} - M_bl\ddot{\theta}_bcos\theta_b = H_L + H_R \quad (6)$$

consider

$$\frac{d}{dt}(\frac{\partial L}{\partial \dot{\theta}}) - \frac{\partial L}{\partial \theta} = \tau_{net}$$
$$\frac{\partial L}{\partial \theta} = 0$$
$$I_b\ddot{\theta}_b + M_bl^2\ddot{\theta}_b - M - bl\ddot{x}cos\theta_b - M_blgsin\theta_b = -(\tau_R + \tau_L)$$
$$\ddot{\theta}_b(I_b + M_bl^2) - M_bl\ddot{x}cos\theta_b - M_blgsin\theta_b = -(\tau_R + \tau_L) \quad (7)$$

combining
comparing (5)(6) and eliminating $(H_R + H_L)$

$$2(M_w + \frac{I_w}{r^2})\ddot{x} = \frac{\tau_R + \tau_L}{r} - (M_b\ddot{x} - M_bl\ddot{\theta}_bcos\theta_b)$$
$$(M_b + 2M_w + \frac{2I_w}{r^2})\ddot{x} = \frac{\tau_R + \tau_L}{r} + M_bl\ddot{\theta}_bcos\theta_b$$

consider

$$(M_b + 2M_w + \frac{2I_w}{r^2}) = A_1$$
$$\ddot{x} = \frac{\tau_R + \tau_L}{r(A_1)} + \frac{M_bl\ddot{\theta}_bcos\theta_b}{A_1} \quad (8)$$

from 7 (Rearranging terms)

$$\ddot{\theta}_b = \frac{M_bl\ddot{x}cos\theta_b + M_blgsin\theta_b - \tau_R - \tau_L}{(I_b + M_bl^2)} \quad (9)$$

Solving eq (8) and (9) we get

$$\ddot{x} = \frac{(I_b + M_bl^2 - M_bcos_{\theta b}lr)(\tau_R + \tau_L) + M_b^2cos\theta_bsin\theta_bgl^2r}{r(A_1(I_b + M_bl^2) - M_b^2cos^2\theta_bl^2)}$$

$$\ddot{\theta} = \frac{(-A_1r + M_bcos\theta_bl)(\tau_L + \tau_R) + A_1M_bglrsin\theta_b}{r(A_1(M_bl^2 + I_b) - M_b^2cos^2\theta_bl^2)}$$
$$cos(\theta_b) \simeq 1(at\theta_b = 0)$$
$$sin\theta_b \simeq \theta_b$$
$$\ddot{x} = \frac{(I_b + M_bl^2 - M_blr)(\tau_R + \tau_L) + M_b^2\theta_bgl^2r}{r(A_1(I_b) + A_1M_bl^2 - M_b^2l^2)}$$

$$A_1 = M_b + 2M_w + \frac{2I_w}{r^2}$$

after substituting we get

$$\ddot{x} = \frac{(I_b + M_b l^2 - M_b l r)(\tau_R + \tau_L) + M_b^2 \theta_b g l^2 r}{r(A_1 I_b + M_b l^2 + 2M_b l^2 (M_w \frac{I_w}{r^2}) - M_b l^2)}$$

$$\ddot{x} = \frac{(I_b + M_b l^2 - M_b l r)(\tau_R + \tau_L) + M_b^2 \theta_b g l^2 r}{r(A_1 I_b + 2M_b l^2 (M_w \frac{I_w}{r^2})}$$

$$B_1 = A_1 I_b + 2M_b l^2 (M_w + \frac{I_w}{r^2})$$

Hence

$$\ddot{x} = \frac{(I_b + M_b l^2 - M_b l r)(\tau_L + \tau_R) + M_b^2 \theta_b g l^2 r}{r B_1} \tag{10}$$

Relationship between applied voltage and torque produced by the motor
k_m–> Torque Constant
k_e–> Back emf constant
R–> Nominal terminal resistance
V_a –> Input Voltage

$$\tau_L = \frac{-k_m k_e}{Rr}\dot{x} + \frac{k_m V_a}{R}$$

$$\tau_R = \frac{-k_m k_e}{Rr}\dot{x} + \frac{k_m V_a}{R}$$

Assuming Voltage to be same

$$\tau_L + \tau_R = \frac{-2k_m k_e}{Rr}\dot{x} + \frac{2k_m V_a}{R}$$

Substituting in (10)

$$\ddot{x} = \frac{(I_b + M_b l^2 - M_b l r)(\frac{-2k_m k_e}{Rr}\dot{x} + \frac{2k_m V_a}{R}) + M_b^2 \theta_b g l^2 r}{r B_1}$$

$$\ddot{\theta} = \frac{(M_b l - A_1 r)(\frac{-2k_m k_e}{Rr}\dot{x} + \frac{2k_m V_a}{R}) + A_1 M_b g l r \theta_b}{r B_1} \tag{11}$$

$$\dot{x_1} = x_2$$
$$\dot{x_2} = \frac{(I_b + M_b l^2 - M_b l r)(\frac{-2k_m k_e}{Rr}\dot{x} + \frac{2k_m V_a}{R}) + M_b \theta_b g l^2 r}{r B_1}$$
$$\dot{x_3} = x_4$$

$$\dot{x_4} = \frac{(M_b l - A_1 r)(\frac{-2k_m k_e}{Rr}\dot{x} + \frac{2k_m V_a}{R}) + A_1 M_b g l r \theta_b}{rB1}$$

By Jacobian A= $\begin{bmatrix} \frac{\partial \dot{x_1}}{\partial x_1} & \frac{\partial \dot{x_1}}{\partial x_2} & \frac{\partial \dot{x_1}}{\partial x_3} & \frac{\partial \dot{x_1}}{\partial x_4} \\ \frac{\partial \dot{x_2}}{\partial x_1} & \frac{\partial \dot{x_2}}{\partial x_2} & \frac{\partial \dot{x_2}}{\partial x_3} & \frac{\partial \dot{x_2}}{\partial x_4} \\ \frac{\partial \dot{x_3}}{\partial x_1} & \frac{\partial \dot{x_3}}{\partial x_2} & \frac{\partial \dot{x_3}}{\partial x_3} & \frac{\partial \dot{x_3}}{\partial x_4} \\ \frac{\partial \dot{x_4}}{\partial x_1} & \frac{\partial \dot{x_4}}{\partial x_2} & \frac{\partial \dot{x_4}}{\partial x_3} & \frac{\partial \dot{x_4}}{\partial x_4} \end{bmatrix}$

$$A_{matrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & X_1 & X_2 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & X_3 & X_4 & 0 \end{bmatrix}$$

$$B_{matrix} = \begin{bmatrix} \frac{\partial \dot{x_1}}{\partial V_a} \\ \frac{\partial \dot{x_2}}{\partial V_a} \\ \frac{\partial \dot{x_3}}{\partial V_a} \\ \frac{\partial \dot{x_4}}{\partial V_a} \end{bmatrix} = \begin{bmatrix} 0 \\ L_1 \\ 0 \\ L_2 \end{bmatrix}$$

where,

$$X_1 = \frac{2k_m k_e (M_b l r - I_b - M_b l^2)}{Rr^2 B_1}$$

$$X_2 = \frac{M_b^2 g l^2}{B1}$$

$$X_3 = \frac{2k_m k_e (rA_1 - M_b l)}{Rr62B_1}$$

$$X_4 = \frac{M_b g l A_1}{B1}$$

$$L_1 = \frac{2k_m (I_b + M_b l^2 - M_b l r)}{RrB_1}$$

$$L_2 = \frac{2k_m (M_b l - rA_1)}{RrB_1}$$

$$A_1 = M_b + 2M_w + \frac{2I_w}{r^2}$$

$$B_1 = A_1 I_b + 2M_b l^2 (M_w + \frac{I_w}{r^2})$$

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \\ \dot{x_4} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & X_1 & X_2 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & X_3 & X_4 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ L_1 \\ 0 \\ L_2 \end{bmatrix} [V_a]$$

In the form

$$\dot{x}(t) = Ax(t) + Bu(t)$$

Q 3. Equation 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. Poles in the laplace transform are represented as

$$(\frac{A_1}{s-p_1}) + (\frac{A_2}{s-p_2}) + (\frac{A_3}{s-p_3}) + ...$$

When continuous time signal is sampled, it becomes discrete and is represented in Z-domain.

$$(\frac{A_1}{1-e^{p_1T_s}Z^{-1}}) + (\frac{A_2}{1-e^{p_2T_s}Z^{-1}}) + (\frac{A_3}{1-e^{p_3T_s}Z^{-1}}) + ...$$

$$where\ T_s\ is\ sampling\ period.$$

$$s = p_r, Poles$$

Hence

$$Z = e^{T_s p_r}$$

Also

$$Z = e^{T_s s}$$

Any point in Z-plane is represented as

$$Z = re^{j\omega} \Rightarrow (1)$$

Any point in s-plane is represented as

$$s = \sigma + j\Omega \Rightarrow (2)$$

$$\sigma \Rightarrow real\ \ part$$

$$\Omega \Rightarrow imaginary\ \ part$$

We know that

$$Z = e^{T_s s}$$

$$re^{j\omega} = e^{\sigma + j\Omega T}$$

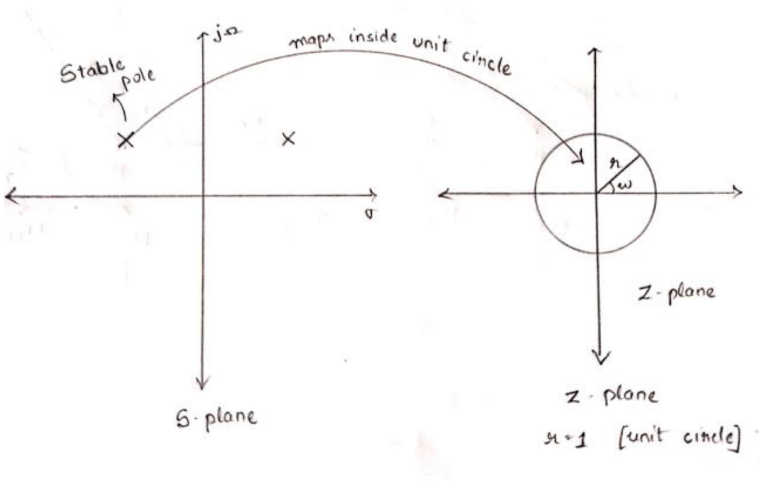

Figure 6: Mapping

$$re^{j\omega} = e^{\sigma T} e^{j\Omega T}$$

Comparing real and imaginary parts

$$r = e^{\sigma T}$$

$$where \ \ r \rightarrow radius \ \ of \ \ circle \ \ in \ \ Z-plane$$

$$\omega = \Omega T$$

$$Consider \ \ r = e^{\sigma T}$$

$$when \ \ \sigma < 0 \Rightarrow r < 1$$

$$\sigma > 0 \Rightarrow r > 1$$

For system to be stable, pole must be at the left side of the s-plane. That means real part must be less than 0, i.e. σ<0. Hence r<1.

Hence,the position of eigen value of A_d for a stable system must lie inside a unit circle in Z-plane.

For marginally stable systems, the position of eigen values maps on the unit circle in Z-plane.

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 is an optimal/ state feedback controller. The control gain **K** can be obtained based on minimising the performance of cost function. Q and R determine the relative importance of the error and energy cost.
The LQR control will **not** always work.
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 we cannot construct any u(t) input.Even if LQR is solved, there is no guarantee that the resulting closed loop system will be stable or well-behaved. The **disadvantage** of LQR control is that it is calculated based on a linear model of the plant under control. If the linear model represents plant exactly, then the controller is optimal. However, If there is a mismatch due to model inaccuracy,plant changes, power level or non-linearities, then the resulting controller will degrade and the system may even become unstable.

- LQR controller will always return stabilised feedback gain only if the system is controllable.
- LQR generates a static gain matrix K, which is not a dynamical system.

Controllability: A control system is said to be **controllable** if the initial states of the system are changed to some other desired states by a controlled input in finite duration of time, if only if rank(**C**) is equal to number of state variables.

$$\mathbf{C} = [A \quad AB \quad A^2B \; .....A^{(\mathbf{n-1})}B] \qquad rank(\mathbf{C}) = \mathbf{n}$$

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 Moment of Inertia of the MedBot will depend upon its height and center of mass (mass distribution). Since the angular acceleration is inversely proportional to the moment of inertia of a body.

$$\tau = I * \alpha \quad \Rightarrow \quad \alpha = \frac{\tau}{I}$$

Here, τ is the torque, I is the moment of Inertia and α is the angular acceleration. Therefore, if the MedBot has lower moment of inertia it will accelerate faster and hence, fall faster.
In contrast, a MedBot with a higher value of moment of inertia, the angular acceleration in this case, is lower, hence slower fall. The controller can have enough time to correct the MedBot. Therefore, if the center of mass is **high** it provides better control **stability** and slower response to offsets, that gives the motors more time to balance it back.

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. An **accelerometer** measures all forces/accelerations on the object including the forces that drive the system. So in Dynamic Conditions, It is affected by acute noise i.e. vibrations which may give us false angle computations even when there is no rotation. This gives us *High frequency noise* i.e. useful for long term.
A **gyroscope** has the tendency to drift, not returning to zero when the system comes back to original position, which has a cumulative effect and Hence it is accurate for short term i.e. *Low frequency noise.*
Therefore, a **Filter**(complimentary filter) is required to remove both of these noises. This filter is a combination of Low pass filter and High pass filter to fuse the angles calculated by the accelerometer and gyroscope reading respectively.

*angle = (1- alpha)(angle + gyro * dt) + (alpha)(acc)*

Accelerometer	Gyroscope
Accelerometer measures the acceleration due to gravity when static. So, we can compute the orientation angle.	**Gyroscope** measures angular velocity around a particular axis which needs to be integrated over discrete time to find the angle.
it also measures the vibrations, which may give us false readings for the angle.	Since it measures angular velocity alone, it is unsusceptible to vibrations caused.
It has precise calculation of average angle over a period of time.Hence, suitable for static angle calculation	Increases in calculation error over longer periods i.e. drift. Hence suitable for instantaneous in-motion angle calculations.
Slow response time	faster response time

Because of the above reasons we need both **accelerometer** and **gyroscope** for measuring tilt angle.

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. Parallel axis theorem:
Suppose we have to obtain the moment of inertia of a body about a given line AB.

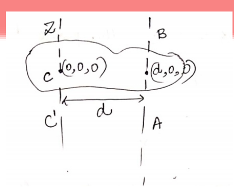

Figure 7: Parallel axis theorem

Let M –> Mass of the body and C –> centre of mass of the body C'Z be to axis through C parallel to AB.

then, $I_{AB} = I_o + Md^2$
Hence using parallel axis theorem, Inertia about AB is calculated.
Perpendicular axis theorem: This theorem is applicable only to the plane bodies.Let, X

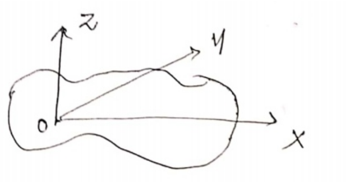

Figure 8: Perpendicular axis theorem

and Y axis be chosen in the plane of the body. Z axis is perpendicular to the plane. All the three axis X, Y, Z and all axis being mutually perpendicular.
then, $I_Z = I_X + I_Y$
Hence Moment of Inertia about Z axis is calculated.
–> Using **Parallel axis theorem** we model our MedBot.
–> We do not use perpendicular axis theorem to model MedBot because it is only used for planar bodies.

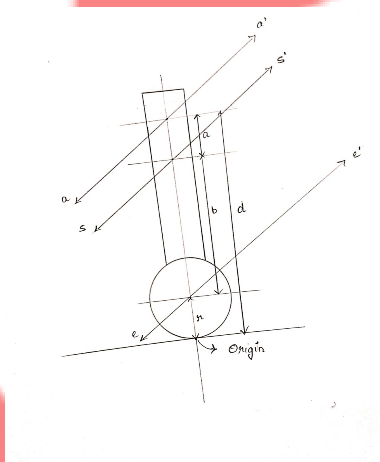

Figure 9: MedBot design

Let M_w –> mass of wheel
r –> radius of the wheel
M_b –> mass of the body.
'd' be the distance of centre of mass of the body from the origin.
Let I_w –> moment of inertia of the wheel I_b –>Moment of Inertia of the body. a –> distance from centre of mass of the system.
First we need to calculate centre of mass of the system.

$$Centre\ of\ mass\ of\ system = \frac{M_b d + M_w r}{M_b + M_w}$$

Hence (b+r) is the distance of centre of mass of the system from origin.
The system(MedBot) totally has two parts:

- body
- wheel

Inertia contributed by wheel:
The moment of Inertia must be calculated about the centre of mass of system. Hence by parallel axis theorem. $I_{ee'} = I_w + M_w b^2$
Inertia contributed by body:
$I_{aa'} = I_b + M_b a^2$
Hence Total Inertia:
$I_{ss'} = I_{ee'} + I_{aa'}$
$I_{ss'} = I_w + M_w b^2 + I_b + M_b a^2$

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) No penalty will be imposed and No points will be awarded. No, The First Aid Kit will not be repositioned.

(b) No, Penalty will not be imposed. One Pickup Point will be awarded M_{PU} = 20***PUC** $M_{PU} = 20$. No, The First Aid kit will not be repositioned

(c) No points will be awarded. Fall penalty marks will be awarded as per the count of the fall of the MedBot. $M_{FP} = 50$ x **FC** $= 50$ x $1 = 50$. Only the MedBot will be repositioned Not the First Aid kit.

(d) One Pick Up Point will be awarded, $M_{PU} = 20$. Fall Penalty marks will be awarded as per the count of fall of Medbot $M_{FP} = 50$ Only Medbot will Be repositioned ,The First Aid Kit will not 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. One Pickup Point will be awarded $M_{PU} = 20$.

LRG/LRB is Loaded run on gravel pathway or Loaded run on Bridge which will increment one on each successful crossing of grave pathway or bridge with any of the item from Medical store. For One item **LRG/LRB** = 1.

M_G = 50 x (0.5x1) = 50 x 0.5 = 25

M_B = 70 x (0.5x1) = 35

Total points = 20 + 25 or 20 + 35 = **45** or **55**

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. Here, We use **Zigbee** and **I2C** communication protocols.
Hardware Interface:

- **Zigbee** protocol involves Xbee S2C module, joystick module, toggle swith and Arduino Mega.
- **I2C** protocol involves IMU MPU6050 sensor and Arduino Mega.

Zigbee network consists of 3 devices i.e. coordinator, router and an end device. An end device can be a smart thermostat, door, CCTV, cameras etc. coordinator acts as a bridge and root for the entire network. It stores and handles information along with various data transfer operation. Routers act as intermediate devices allowing the data to pass to and fro via them to other devices.
Out of 4 layers in a **Zigbee** device, Physical layer performs various modulation and demodulation tasks for signals being sent and received continuously. Media Access control(MAC) is responsible for the successful transfer of data by using Carrier Sense Multiple Access. Collision Avoidance (CSMA/CA) Network layer looks after network operations such as setting up a network, connecting to a device, routing the incoming data, device configurations. Application layer allows a device and an application to interface with network layer.
In **I2C protocol**, the data signal is transferred in sequences of 8 bits. So, after a special start condition occurs then comes the first 8 bit sequence which indicates the address of the slave to which the data is being sent.
After each 8 bit sequence follows a bit called acknowledge. After first acknowledge bit comes another addressing sequence but this time for the internal registers of the slave device. After the addressing sequences follows the data sequences until data is completely sent and it ends

with special stop condition.
Differences:

Zigbee	I2C
Simple and easy to implement.	Compared to Zigbee It is a bit complex.
It involves wireless communication.	Uses 2 wires for communication.
Consumes less power	Consumes more power.

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

A 11.
- IRF540N is a logic level N-Channel MOSFET and can drive loads up to 23A and is driven by 5V.
- It has good switching characteristics and low threshold current, it is used with Arduino for logic switching.
- Since an Electromagnet(12V DC) is an inductive load, so when transistor is turned off the magnetic field will collapse. This results in very high voltage at transistor collector/drain. Hence a diode is placed backwards across to prevent inductive spikes damaging the MOSFET at moment of switch-off.
- It has a maximum drain-source voltage of 100V.

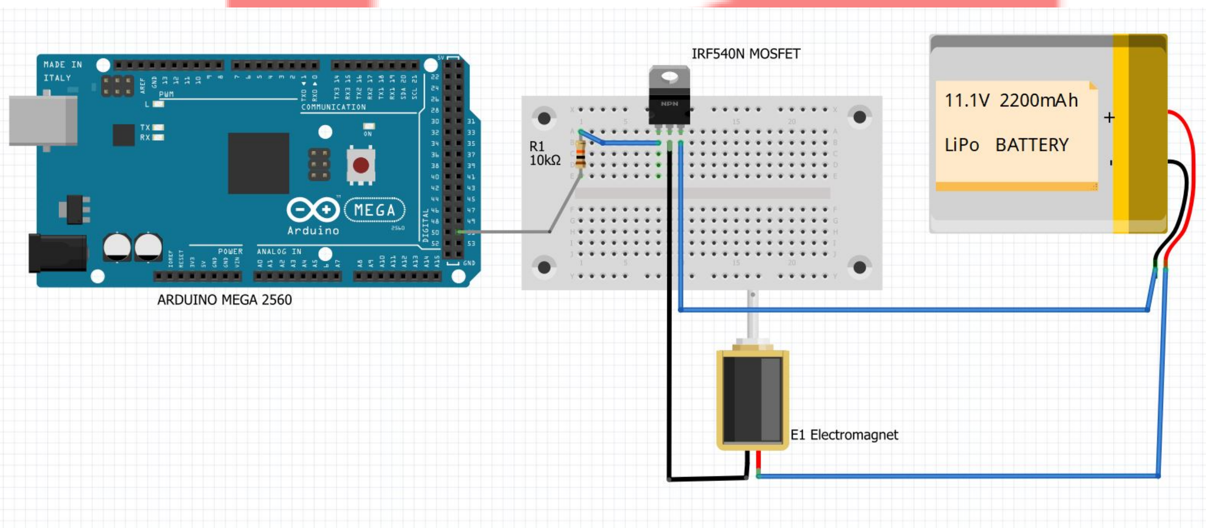

Figure 10: circuit diagram

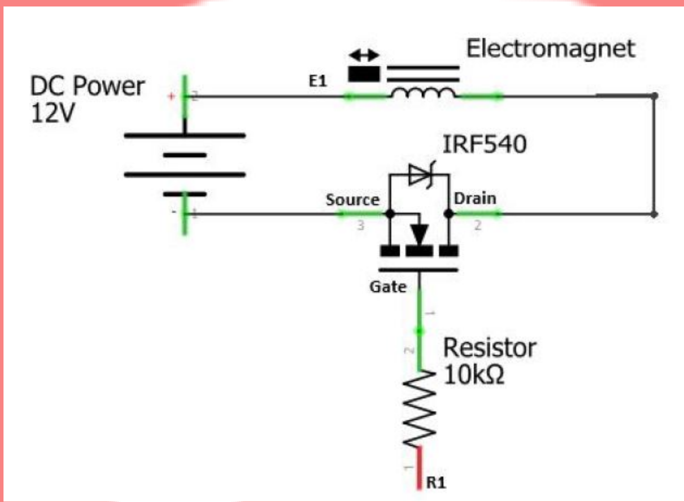

Figure 11: circuit diagram with symbols