# 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.

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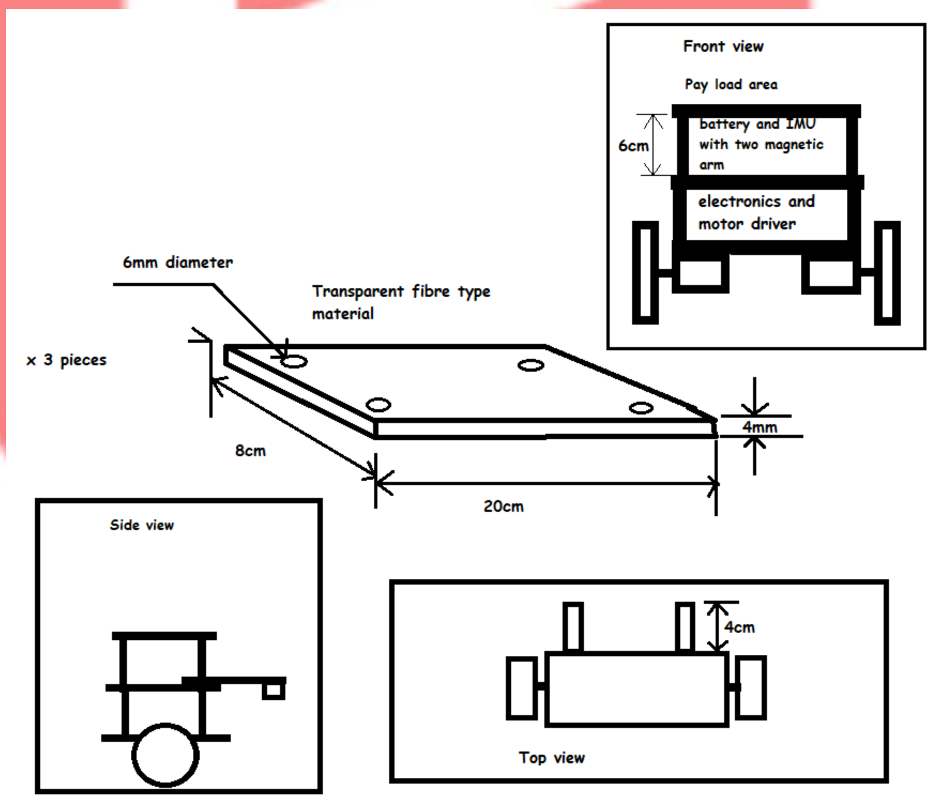
Q 1. Describe hardware design for the Medbot, your team is constructing. Describe various parts with well labeled image. Give reasons for selection of design. [10]

A 1.



The design is chosen for the following reasons:

- IMU (Inertia Measuring Unit i.e unit containing gyroscope) detects deviation quickly if it is placed at upper side.
- Keeping the Battery at upper side keeps Centre of Gravity remains towards upwards which benefits the overall balance of robot during the run.
- Also, a larger torque is generated if heavy elements are kept at upper side ( since, tau= rf sinΘ, f= m.a) and thus wheel have to exert lesser power for movement of bot and power will be saved.
- With two electromagnet attached arms, two boxes (i.e. medical kits, first aid kits or chlorine tablets) can be picked up which increases the efficiency of medbot to complete the task. (the boxes have almost equal weights and the weight is also less. So, it doesn't affect the speed and balance of medbot)

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

$$\bar{} \; X(t) = AX(t) + BU(t) \qquad (1)$$

Where X(t) is a vector of all the state,i.e., $X(t) = [x_1(t); x_2(t); : : : ; x_n(t)]^T$ , and U(t) is the vector of input to the system, i.e. $U(t) = [u_1(t); u_2(t); : : : ; u_m(t)]^T$ . 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]

A2.

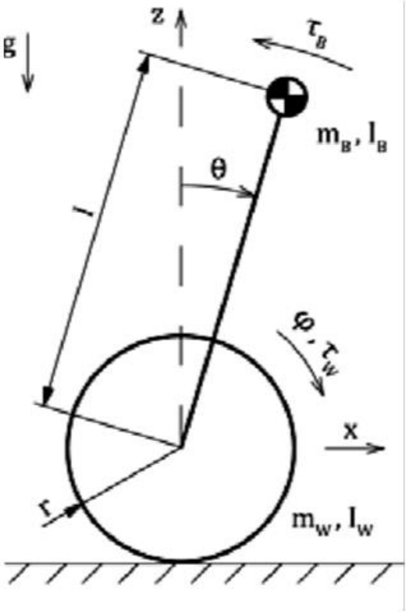



Fig: Free Body Diagram of the Medbot

The no slip condition of movement is given by

$x = r\varphi$ .

The movement of robot's body COG is given by

$x_{COG=}\ x + l \sin\Theta$ ,

$z_{\ COG=}\ l \cos\Theta$ ,

$v_{COG} = \sqrt{(x_{COG}{}^{2} + z_{COG}{}^{2})}$

Kinetic energy of the body is given by

$E_{kB}\ = ½\, m_b\, v_{COG}{}^{2} + ½\, I_{\ b}\ \Theta^{\ 2} + ½\, m_b\ \ x^{2}\ \ 2xl \cos l^{\ 2\ \ 2}\ \ \ \ {}_{2}{}^{1}\, I_b\ {}^{2}$ .

Kinetic energy of the wheel is given by

$E_{kW}\ \ {}_{2}{}^{1}\ m_W\, x^{\ 2}\ \ {}_{2}{}^{1}\ I_{\ w}\ {}^{2}\ \ {}_{2}{}^{1}\ m_W\, x^{\ 2}\ \ {}_{2}{}^{1}\, {}^{I}{}_{r}{}^{w}{}_{2}\, x^{2}$ .

Potential energy of the body is given by

$$E_{pB} = m_b gl \cos\Theta \ .$$ (2.7)

Potential energy of the wheel is given by

$$E_{pW} = 0.$$ (2.8)

We need to consider that there is also some dissipated energy as a consequence of rolling the wheels along the way. For this purpose let us write a Rayleigh dissipation function for both wheels as

$$\underline{1}2 \qquad \underline{b_W} \ 2$$

$$D \ 2 \ 2b_W \qquad {}_r2x \ .$$

The Lagrangian of the system is defined as the difference between the above kinetic and potential energy

$$L \ E_k \ \ E_p \ \ E_{kB} \ \ 2E_{kW} \ \ E_{pB} \ \ 2E_{pW} \ .$$

The Lagrange second order equations with the dissipation function are defined as

$$\frac{d}{dt} \ \frac{L}{qi} \ \ \frac{L}{qi} \ Qi \ \ \frac{D}{qi} \ ,$$

where $q_i$ represents generalized coordinates and $Q_i$ represents generalized forces. Generalized forces are torques from both wheels

$$Q_i \ \ {}_R \ \ {}_L \ .$$

Position $x$ and angular position θ were chosen as system coordinates Substituting system coordinates into generalized coordinates we can rewrite the Lagrange second order equations and get equations of motion. For the $x$ coordinate we obtain

$$m_B \ \ 2m_W \ \ 2 \ \frac{I_W}{r^2} \ x \ 2 \ \frac{b_W}{r^2} \ x m_B \ l \cos m_B l \sin \qquad {}^2 \ \ \frac{{}_{RL}}{r} \ ,$$

and for the θ coordinate the equation is

$$m_B \ l \cos \ x \ \ m_B {}^2 \ l \qquad I_B m_B \ gl \sin_{RL} \ .$$

The derived dynamic equations of motion are nonlinear. Assume that while the robot moves along the $x$ axis only small deviations in the angular position θ are obtained. This means that we can make a linearization around an unstable equilibrium point which makes the model more suitable for controller design. Using this fact the approximations are [10, 11, 3]

$$\cos \quad 1, \quad \sin, \qquad {}^{2} \quad 0,$$

and linearized equations of motion are

$$m_B \quad 2m_W \quad 2\frac{I_W}{r^2} \quad x2 \quad \frac{b_W}{r^2} x \quad m_B l \qquad \frac{RL}{r},$$

$$m_B\, lx \quad m_B\, l^2 \; I_B \qquad m_B\, gl \qquad {}_R \quad {}_L \, .$$

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., $X(k) = [x_1(k); x_2(k); : : : ; x_n(k)]^T$ , and U(k) is the vector of input to the system at $k_{th}$ sampling instant, i.e. $U(k) = [u_1(k); u_2(k); : : : ; u_m(k)]^T$ . $A_d$ 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.

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. No, because 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 can not construct any u(t) input - let alone an optimizing one - to satisfy the main requirement for the existence of a solution; that we can actually reach the final state! Even if we do manage to solve for the LQR, there is no guarantee that the resulting closed-loop system will be stable or well-behaved in any other way; e.g., a state that is "unobservable" from the point of view of the cost functional might well be going unstable and the controller we end up with would not even know it since that particular state had no bearing on its design
- it was "unobservable" Controllability: Consider a

state determined dynamical system with a transition map s(t1, t0, x0, u( )) such that x(t1) = s(t1, t0, x(t0), u( )). This can be continuous time or discrete time. The dynamical system is controllable on [t0, t1] if initial and final states x0, x1, u( ) so that s(t1, t0, x0, u) = x1. It is said to controllable at t0 if x0, x1, t1 t0 and u( ) U so that s(t1, t0, x0, u) = x1

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. Self balancing robot is essentially an inverted pendulum. It can balance better if centre of mass is higher relative to the wheel axels. A higher centre of mass means a higher moment of inertia which means a lower angular acceleration. It act as a robot which can balance by itself.

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. Reasons are: a complementary filter serves this purpose of simplifying the difficulties faced while implementing simple first order high pass and low pass filters. Complementary filters do not act on the signals. They are in fact filters to be associated with noise of the signal present. Thus the task of the filter is to estimate a stable angle from multiple sources containing erro-neous data and which exhibit noise with different frequency content.Complementary filter was also a motivation to develop the self-balancing robot which fuses the data from two sensors such that a better estimation of tilt angle is obtained. Hence, this system would also be designed in such a way that it optimizes the use of energy and satisfies human needs.

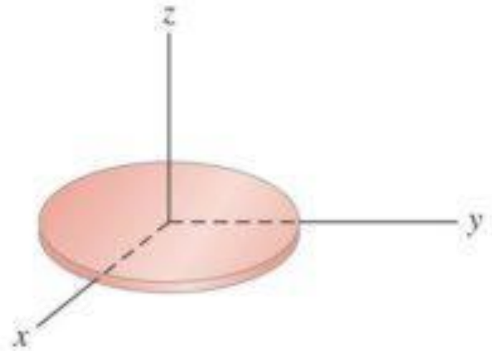
By studying the characteristics of both gyro and accelerometer, we know that they have their own strengths and weakness. The calculated tilt angle from the accelerometer data has slow response time, while the integrated tilt angle from the gyro data is subjected to drift over a period of time. In other words, we can say that the accelerometer data is useful for long term while the gyro data is useful for short term. One of the simplest ways to combine the data from the gyro and the accelerometer is by using the complementary filter. Complementary filter is designed in such a way that the strength of one sensor will be used to overcome the weaknesses of the other sensor which is complementary to each other. In this application, the task of the complementary filter is to make use of the integrated angle from the gyro in short period, and then the low pass filtered data from the accelerometer is used to correct the drift of the angle over long period of time. The offset of the gyro sensor will also be continuously updated and corrected. This will result in a drift free and fast responding estimated 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. 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.

$$I_z = I_x + I_y.$$




In the above figure, we can see the perpendicular body. So Z axis is the axis which is perpendicular to the plane of the body and the other two axes lie in the plane of the body. So this theorem states that IZ = Ix + Iy That means the moment of inertia about an axis which is perpendicular to its plane is equal to the sum of its moments of inertia about two perpendicular axes. 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. $IZ^0$ = Iz +M where, is the distance between two axes. In self balancing we have to determine the center of mass of the bot that's why we required moment of inertia of that bot and that will be determined by these two theorems.

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) Neither penalty will be imposed nor points be awarded(since block is not succesfully picked up and taken out of store). the block will not be re-positioned as re-positioning is only allowed if Medbot falls

(b) Successful Pick up points will be awarded(i.e 20 points),no penalty will be imposed. The block will not be repositioned as the Medbot didn't fall.

(c) No points will be awarded, fall penalty(i.e 50 points)and hit penalty(i.e 50 points) will be imposed. The block will be repositioned to it's initial position and Med bot wil be repositioned to parking area.

(d) Successful Pick up points will be awarded(i.e 20 points) and fall penalty would be imposed(i.e 50 points). both the Medbot and block will be repositioned to parking area and initial position in medical store respectively.

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. Points for Loaded run on Gravel Pathway and Bridge are 50 and 70 respectively and regardless of how many times the Medbot traverses the bridge and Gravel Pathway with one item from Medical Store, points will be awarded once only i.e 70 or 50.

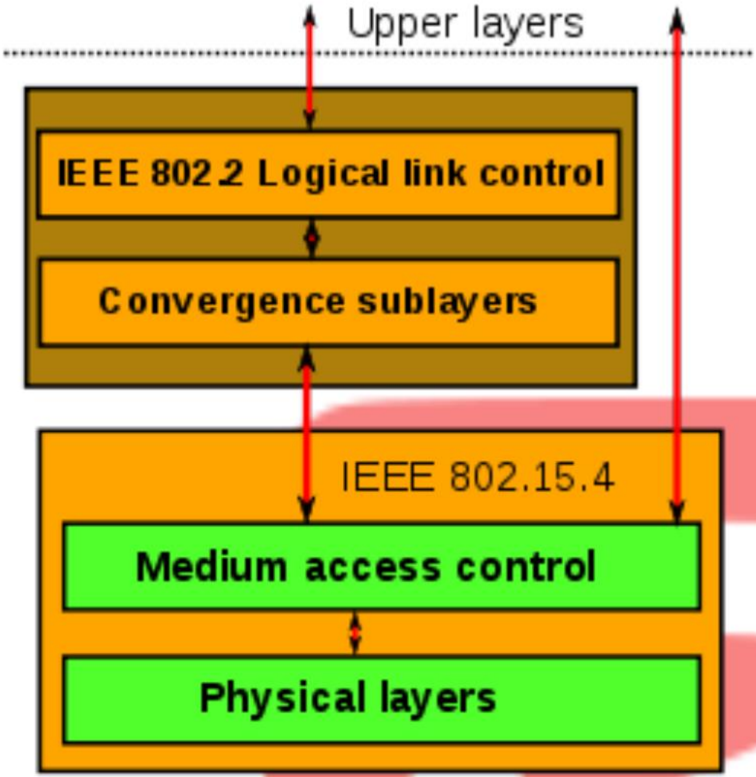
Q 10. What are the different communication protocols you'll be using? Name the hardware interfaced related to each of the communication protocols. Explain how these communication protocols works and what are the differences between them. [8]

A 10. Here we will be using two communication protocols: 1. IEEE 802.15.4 2. UART

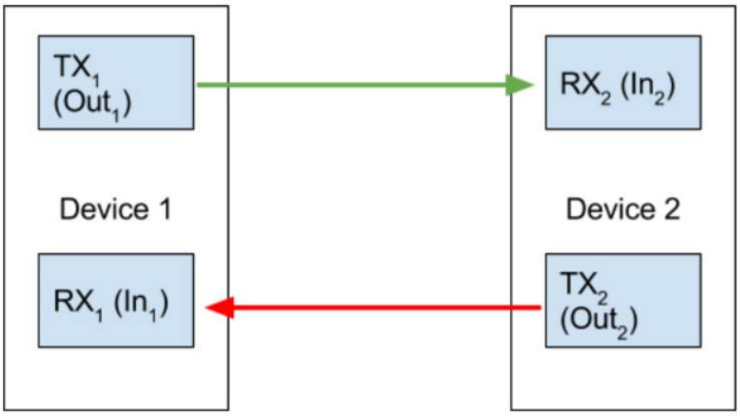
(Universal Asynchronous Receiver/Transmitter) For IEEE 802.15.4 the

two XBee modules are interfaced and for UART, the Arduino Mega 2560 and XBee module is interfaced. IEEE 802.15.4: In this protocol devices are conceived to interact with each

other over a conceptually simple wireless network. The definition of the network layers is based on the OSI model; although only the lower layers are defined in the standard, interaction with upper layers is intended, possibly using an IEEE 802.2 logical link control sub-layer accessing the MAC through a convergence sub-layer. Implementations may rely on external devices or be purely embedded, self-functioning devices.



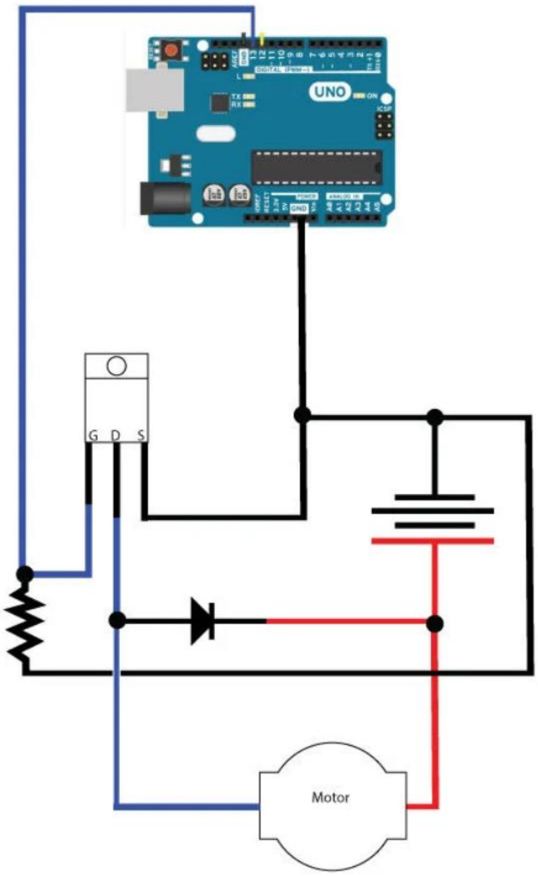

UART: UART is a form of serial communication because data is transmitted as sequential bits. The wiring involved with setting up UART communication is very simple: one line for transmitting data (TX) and one line for receiving data (RX).The TX line is used to for the data to send device, and the RX line is used to receive data. Together the TX and RX lines of a device using serial communication form a serial port through which communication can occur. UART is called asynchronous because the communication does not depend on a synchronized clock signal between the two devices attempting to communicate with each other. Because the communication speed is not defined via this steady signal, the “sender” device cannot be certain that the “receiver” obtains the correct data. Therefore, the devices break data into fixed-size chunks to ensure that the data received is the same as the data that was sent.




The main difference between them is that UART requires a wired interfacing whereas IEEE 802.15.4 requires wireless interfacing. Second, UART has higher data transmission speed than IEEE 802.15.4. because of wired interfacing.

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

A 11. The IRF540N is an N-Channel Mosfet. This mosfet can drive loads upto 23A and can support peak current upto 110A. It also has a threshold voltage of 4V, which means it can easily driven by low voltages like 5V. Hence it is mostly used with Arduino and other microcontrollers for logic switching. The IRF540N is a great MOSFET to start turning bigger loads on and off. With three components you can turn on and off just about any DC load you have. Components needed a IRF540N 1 Diode 1n4004 1 1K ohm Resister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