Benha University | **Department: Mechanical Eng.**
Benha Faculty of Engineering | **Program: Mechatronics**
Date: 26/05/2018 | **Time: 3 hours.**
Semester: Two | **Subject: Intro. to mechatronics**
Examiner: Dr. Hussein Shehata | **Code: (M1392)**
Total Points: 90 marks | **No. of Pages: 2**

Model Answer

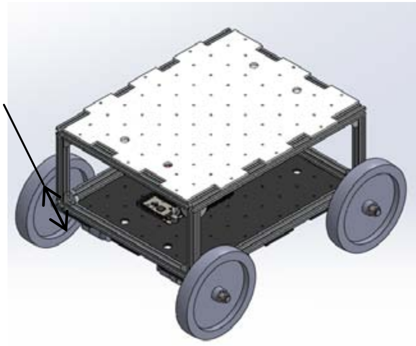
All students are required to solve ***QUESTION 1***

Question ① (30 marks)

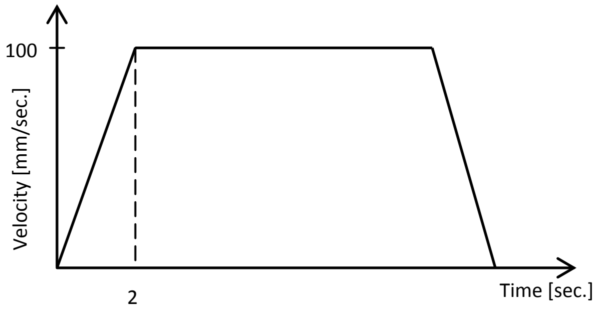
When building a mobile robot, selecting the drive motors is one of the most important decisions you will make. **Assume the 4 Wheeled Drive Mobile Robot (4WD-MR)** as depicted in ***Fig. Q.1,*** with a total mass of **75 kg** is travelling with a **trapezoidal motion profile.** You are required to make a complete motor sizing for this application, considering the **worst case**.

Assume any data that you need.

D 150 mm



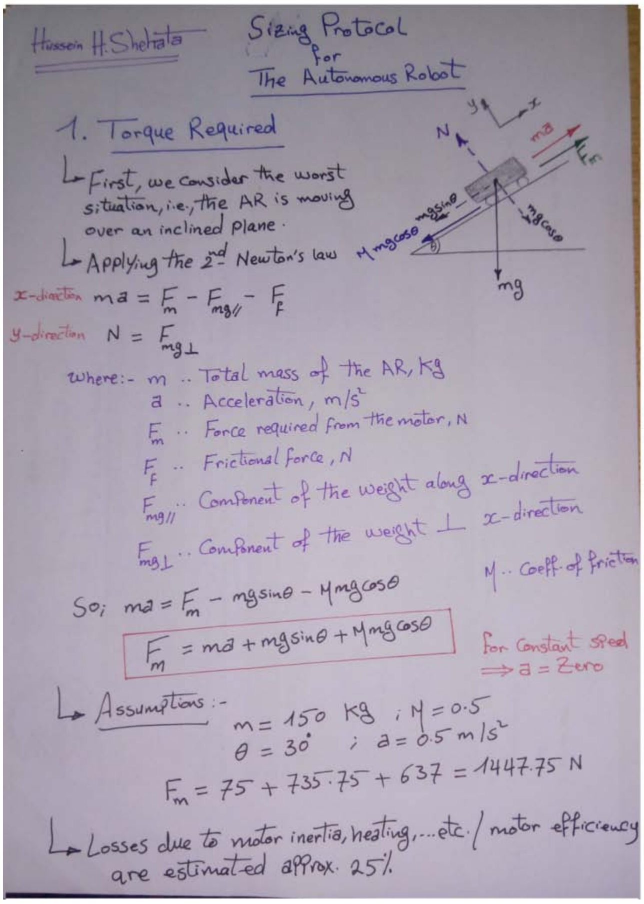
(a) 4WD-MR



(b) Trapezoidal motion profile

Fig. Q.1

Solution ①



Hussein H.Shehata

Sizing Protocol for The Autonomous Robot

1. Torque Required

First, we consider the worst situation, i.e., the AR is moving over an inclined plane.

Applying the 2nd Newton's law

x-direction $ma = F_m - F_{mg//} - F_F$

y-direction $N = F_{mg\perp}$

where:- m .. Total mass of the AR, Kg
a .. Acceleration, m/s^2
F_m .. Force required from the motor, N
F_F .. Frictional force, N
$F_{mg//}$ .. Component of the weight along x-direction
$F_{mg\perp}$ .. Component of the weight ⊥ x-direction
μ .. Coeff. of friction

So; $ma = F_m - mg\sin\theta - \mu mg\cos\theta$

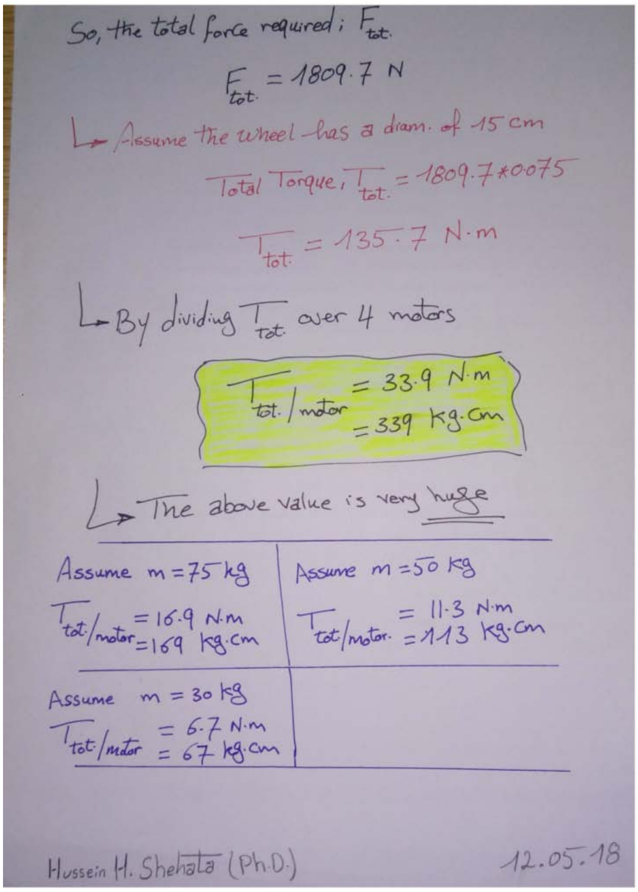
$F_m = ma + mg\sin\theta + \mu mg\cos\theta$

For constant speed ⇒ a = zero

Assumptions:- $m = 150$ kg ; $\mu = 0.5$; $\theta = 30°$; $a = 0.5\ m/s^2$

$F_m = 75 + 735.75 + 637 = 1447.75$ N

Losses due to motor inertia, heating, ...etc. / motor efficiency are estimated approx. 25%.



So, the total force required; $F_{tot.}$

$F_{tot.} = 1809.7$ N

Assume the wheel has a diam. of 15 cm

Total Torque, $T_{tot.} = 1809.7 * 0.075$

$T_{tot.} = 135.7$ N.m

By dividing $T_{tot.}$ over 4 motors

$T_{tot.}/motor = 33.9$ N.m $= 339$ kg.cm

The above value is very huge

Assume m = 75 kg $T_{tot}/motor = 16.9$ N.m $= 169$ kg.cm	Assume m = 50 kg $T_{tot}/motor = 11.3$ N.m $= 113$ kg.cm
Assume m = 30 kg $T_{tot}/motor = 6.7$ N.m $= 67$ kg.cm	

Hussein H. Shehata (Ph.D.) 12.05.18

*For the remaining questions, all students are required to solve **3 QUESTIONS ONLY***

Question ② (20 marks)

a) Explain how the car Anti-lock Braking System (**ABS**) works. State and explain the type of **sensors and actuators** that are used. Enhance your answer with sketch. (05)

b) Explain with sketches how absolute and incremental optical encoders work. (05)

c) Differentiate between sensors and transducer; enhance your answer with examples. (05)

d) Define the following terms: hysteresis, repeatability, dead band, non-linearity. (05)

Solution ②

a) The ABS System

The theory behind anti-lock brakes is simple. A skidding wheel (where the tire contact patch is sliding relative to the road) has less traction than a non-skidding wheel. By keeping the wheels from skidding while you slow down, anti-lock brakes benefit you in two ways: You will stop faster, and you will be able to steer while you stop. There are four main components to an ABS system:

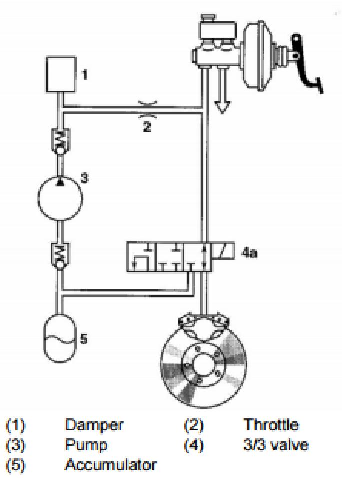
1. Speed sensors: The anti-lock braking system needs some way of knowing when a wheel is about to lock up. The speed sensors, which are located at each wheel, or in some cases in the differential, provide this information.

2. Valves: There is a valve in the brake line of each brake controlled by the ABS. On some systems, the valve has **three** positions: In position one, the valve is open; pressure from the master cylinder is passed right through to the brake. In position two, the valve blocks the line, isolating that brake from the master cylinder. This prevents the pressure from rising further should the driver push the brake pedal harder. In position three, the valve releases some of the pressure from the brake.

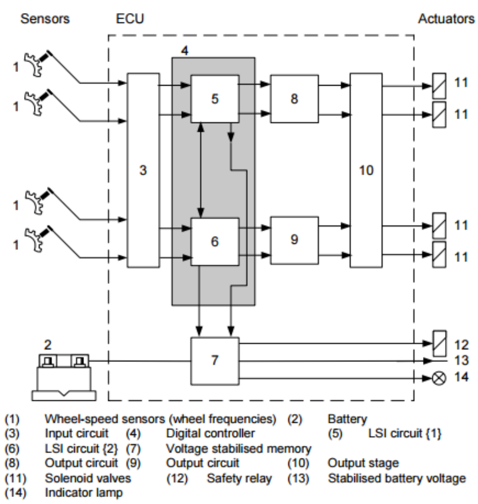
3. Pump: Since the valve is able to release pressure from the brakes, there has to be some way to put that pressure back. That is what the pump does; when a valve reduces the pressure in a line, the pump is there to get the pressure back up.

4. Controller: The controller is a computer in the car. It watches the speed sensors and controls the valves.

ABS at Work: The controller monitors the speed sensors at all times. It is looking for **decelerations** in the wheel that are out of the ordinary. Right before a wheel locks up, it will experience a rapid deceleration. If left unchecked, the wheel would stop much more quickly than any car could. The ABS controller knows that such a rapid deceleration is impossible, so it reduces the **pressure** to that brake until it sees an acceleration, then it increases the pressure until it sees the deceleration again. The result is that the tire slows down at the same rate as the car, with the brakes keeping the tires very near the point at which they will start to lock up. This gives the system maximum braking power.



ABS hydraulic circuit

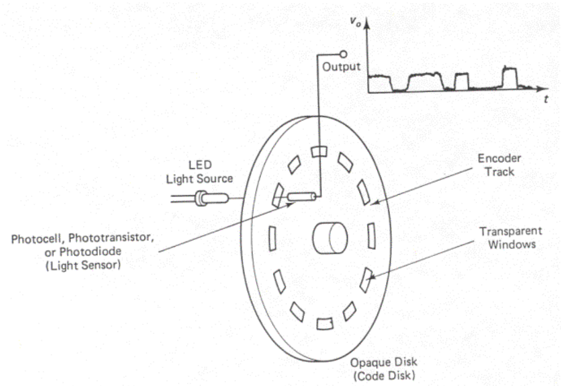


ABS control unit

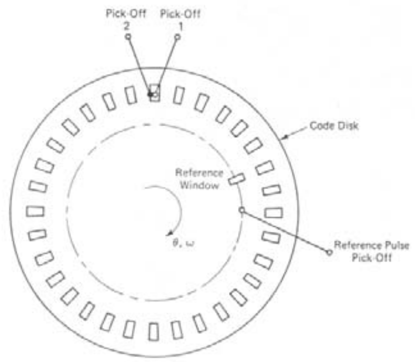
b) Incremental Encoders

Output is a pulse signal that is generated when the transducer disk rotates as a result of the motion that is being measured. By counting pulses or by timing the pulse width using a clock signal, both angular displacement and angular velocity can be determined. Displacement, however, is obtained with respect to some reference point on the disk, as indicated by a reference pulse (index pulse) generated at that location on the disk. The index pulse count determines the number of full revolutions.

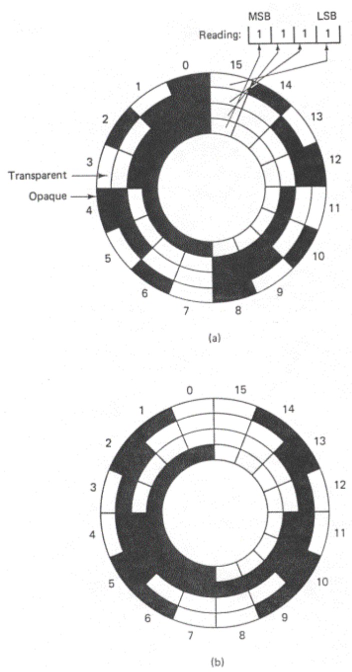
Absolute Encoders: An absolute encoder has many pulse tracks on its transducer disk. When the disk of an absolute encoder rotates, several pulse trains equal in number to the tracks on the disk are generated simultaneously. At a given instant, the magnitude of each pulse signal will have one of two signal levels (i.e., a binary state) as determined by a level detector. This signal level corresponds to a binary digit (0 or 1). Hence, the set of pulse trains gives an encoded binary number at any instant. The pulse windows on the tracks can be organized into some pattern (code) so that each of these binary numbers corresponds to the angular position of the encoder disk at the time when the particular binary number is detected. Pulse voltage can be made compatible with some form of digital logic (e.g., TTL). Direct digital readout of an angular position is possible. Absolute encoders are commonly used to measure fractions of a revolution. However, complete revolutions can be measured using an additional track that generates an index pulse, as in the case of an incremental encoder.



Schematic Representation of an Optical Encoder Configuration

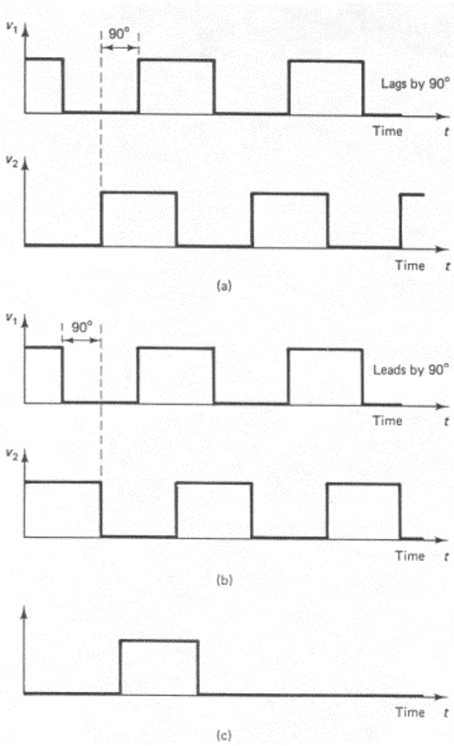


Incremental Optical Encoder Disk Offset-Sensor



Clockwise (CW) rotation: V_1 lags V_2 by a quarter of a cycle (i.e., a phase lag of 90°)

Counterclockwise (CCW) rotation: V_1 leads V_2 by a quarter of a cycle.



Schematic Diagram of an Absolute Encoder Disk Pattern
(a) Binary code (b) Gray code

Incremental Encoder Pulse Signals
(a) CW rotation (b) CCW rotation (c) reference

c) Differentiate between sensors and transducer:

Measurement is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processor(s) for controlling the whole system.

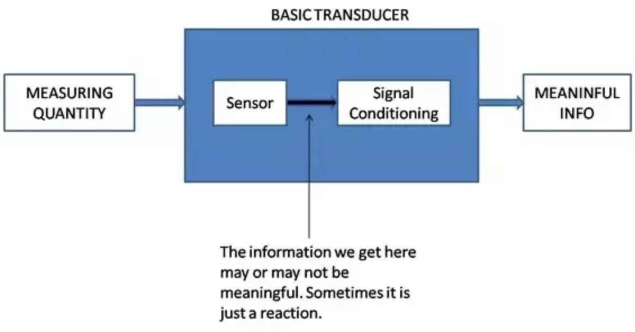
Sensor is defined as an element which produces signal relating to the quantity being measured. According to the Instrument Society of America, sensor can be defined as *"A device which provides a usable output in response to a specified measurand."* Here, the output is usually an 'electrical quantity' and measurand is a 'physical quantity, property or condition which is to be measured'. Thus in the case of, say, a variable inductance displacement element, the quantity being measured is displacement and the sensor transforms an input of displacement into a change in inductance.

Transducers is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measurand into a usable output by using a transduction principle. It can also be defined as a device that converts a signal from one form of energy to another form.

A wire of Constantan alloy (copper-nickel 55-45% alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed as change in electric resistance. This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus we can say that 'sensors are transducers'.

A Transducer is more than a sensor. It consists of a sensor/actuator along with signal conditioning circuits. We can say that every transducer is also(or has) a sensor but every sensor need not be a transducer. Sometimes it is.

A compass is a simple sensor of magnetic north, wherein the **magnetic element** in the compass is the transducer. **A microphone** is a good example for sensors. Sound consists of vibrating molecules. Whenever you speak, you set up vibrations in air molecules. A microphone has a membrane, which also vibrates, as air molecules collide with it. The membrane is connected to an electrical circuit so that oscillations of the membrane cause the electrical current and voltage in the circuit to vary. In this way, the original sound energy is converted into electrical energy. **A loudspeaker** is a transducer. A microphone (input device) is a sensor that converts sound waves into electrical signals for the amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves. **Antennas, stereo speakers and thermostats** are also transducers. **Photocell, infra-red** sensors, and **Barometer** are sensors.



d)

Hysteresis: The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter.

Repeatability: It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

Repeatability = (maximum – minimum values given) X 100 ⁄ full range

Dead band/time: The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

Non-linearity: The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. *Linearity is often specified in terms of percentage of nonlinearity, which is defined as:*

Nonlinearity (%) = Maximum deviation in input / Maximum full scale input

Question ③ (20 marks)

Assume you have two double acting cylinders (1 for clamping & 1 for drilling); the clamping cylinder acts first, followed by the drilling cylinder. **The following data is required:**

Bore size of cylinder (clamping = **80mm**, drilling = **63mm**)
Rod size of cylinder (standard)
Stroke length (clamping= **20mm**, drilling = **120mm**)
Speed of movement (clamping = **1.5 m/min**, drilling = **0.2 m/min**)
Expected load to take (clamping = **600kg**, drilling = **500 kg**). **Calculate:**

a. Calculate pump capacity for hydraulic power unit. (05)
b. Max. working pressure. (05)
c. Horsepower of the electric motor. (05)
d. Reservoir size in liters. (05)

Solution ③

a)

- Capacity (cm3/min) = Area of cylinder (cm2) X Speed of movement (cm/min)

$$Aclamping = \frac{\pi}{4} d_1 (cm^2); d_1 = 8cm$$

$$= 50.24cm^2$$

$$Pump|required = 50.24cm^2 x150cm / \min$$

$$= 7536cm^3 \approx 7.5lit / \min \qquad (1000cc = 1litre)$$

- For drilling, by using similar approach – pump req = 0.623 lit/min; select 7.5 lit/min

b)

$$Clamping\ presure = \frac{clampingforce(kg)}{clampingarea(cm^2)}$$

$$= \frac{600}{50.24} = 11.94kg / cm^2$$

$$Drilling\ presure = \frac{500kg}{31.15} = 16.05kg / cm^2$$

Max. working pressure = 16.05 kg/cm2

c)

$$Power(kW) = \frac{PQ}{600};$$

$$P = working\ pressure(kg / cm^2)$$

$$Q = flowrate(lit / \min)$$

$$Power\ in\ \ kW = \frac{16.05(kg / cm2) \times 7.5(l / \min)}{600} = 0.2kW$$

$$= 0.26hp; \quad \frac{kW}{0.764} = hp$$

- Therefore we can choose the next standard size of electric motor; i.e. 0.5 hp, run at 1440 rpm d)

- Thumb rule: Reservoir should be 4 times of flow rate of the pump
- Here, pump flow rate = 7.5 l/min, therefore, the reservoir should be at least 30 litres
- Manufacturer standard size = 50, 75, 100, 125 litres, etc. So, 50 litres reservoir can be chosen

Question ④ (20 marks)

There is a lightening system, which is controlled by 3 sensors **A, B, and C**. Each sensor has ***high*** or ***low*** value, *i.e.*, ***1*** or ***0***. The output of the lightening system is **ON** in the following conditions:

1. If **A** is high
2. If **B** is high
3. If **A** and **C** are high
4. If **B** and **C** are high

1) Construct the truth table. (04)
2) Extract a formula for the output based on ***SOP*** and ***Minterms***. (04)
3) Draw the original logic circuit. (04)
4) Simplify and re-draw the circuit using ***K-map.*** (04)
5) Extract a formula for the output based on ***POS*** and ***Maxterms***. (04)

Solution ④

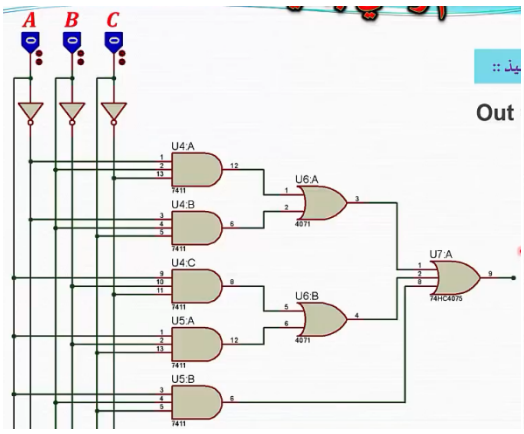
1)

A	B	C	Out
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	1

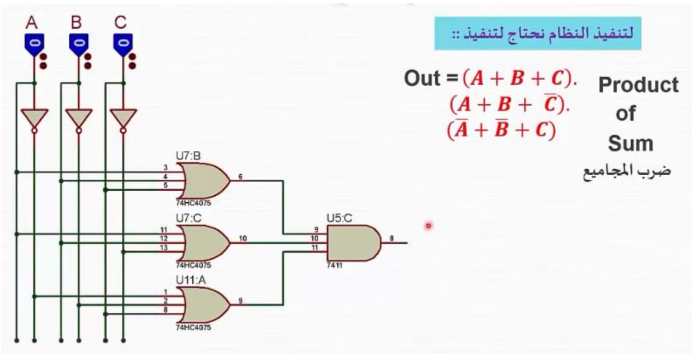
2)

$$\text{Out} = \bar{A}.B.\bar{C} + \bar{A}.B.C + A.\bar{B}.\bar{C} + A.\bar{B}.C + A.B.C$$

3)



5)



Question ⑤ (20 marks)

A **L**aser **M**easurement **S**ystem **(LMS)** is used to acquire information in a **2D** workspace. LMS can measure distances up to **20** meters and its angle of view is $\mathbf{270}^{\circ}$ with angular resolution of $\mathbf{0.5}^{\circ}$. A pattern of measuring data is $(\boldsymbol{r_i}, \boldsymbol{\theta_i})$, where $\boldsymbol{r_i}$ is the radial distance from the LMS to the object, $\boldsymbol{\theta_i}$ is the angular position of the object related to the LMS, and ***i*** is **0, 0.5, 1, …., 270**.

a) How many reading patterns do you obtain in one scan? (05)

b) Propose your idea to identify the robot's position? (10)

c) Suggest a solution/mechanism to use this sensor in a 3D environment. (05)

"Enhance your solution with sketch".

Solution ⑤

a) 541 reading patterns.

b) The robot's position can be identified by using 3 distinct landmarks, which are distributed inside the room at predefined positions. Based on triangulation and trilateration algorithms, the position can be identified easily. We have to notice that the robot must see the three landmarks in order to estimate its position accurately.

c) By simple mechanism that allow the sensor to rotate vertically. One may use a pair of gears to achieve this rotation. Using this mechanism will allow the sensor to measure different planes.

Best Wishes for all,
Dr. Hussein Shehata

Learn from yesterday, live for today, hope for tomorrow. The important thing is not to stop questioning. A. Einstein