2019

RANK IMPROVEMENT WORKBOOK

Mechanical Engineering

Mechatronics and Robotics

Answer Key of Objective & Conventional Questions

MADE EASY Publications

1 Introduction to Mechatronics

LEVEL 1 Objective Questions

1.	(a)
2.	(b)
3.	(c)
4.	(d)
5.	(c)
6.	(c)
7.	(c)
8.	(b)
9.	(d)
10.	(d)
11.	(d)
12.	(b)
13.	(b)
14.	(d)
15.	(d)
16.	(a)
17.	(c)
18.	(d)

LEVEL 2 Objective Questions

19.	(d)
20.	(c)
21.	(a)
22.	(c)
23.	(b)
24.	(b)
25.	(a)
26.	(c)

■■■■

LEVEL 3 Conventional Questions

Solution : 27

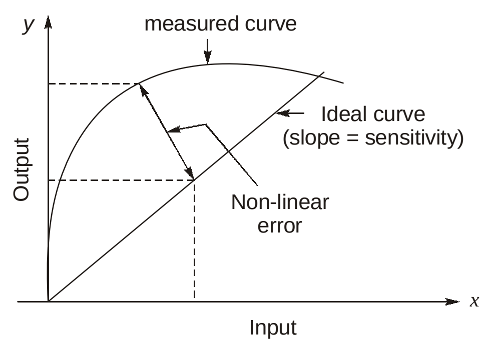
(i) Sensitivity of sensor is defined as the ratio of change in the output value of a sensor to the change in the input that causes the output.

or

Sensitivity is the ratio between output span of a sensor to Input span of a sensor.

For exp: Thermocouple has a sensitivity of 55 μv/°C, this means, thermocouple can generate 55 μv for every 1°C rise in input temperature.

(ii) Linearity: If the data of input and output follows a linear relation ($y = mx$), then we can say the sensor is linear For any sensor consider the following.



Non linear error: The maximum deviation between measured output and actual output at any particular input is called non-linear error.

(iii) Resolution is the Smallest incremental change of input that can be applied to produce the detectable output is called resolution.

Solution : 28

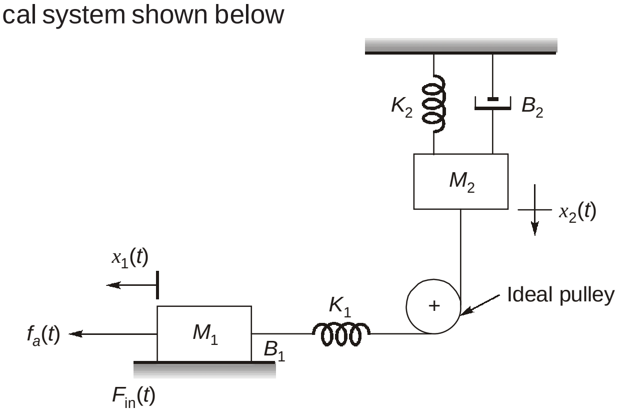
125°C

Solution : 29

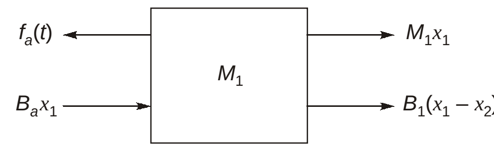
$$A_i = 50.481 \text{ m/sec}^2$$

Solution : 30

Consider the mechanical system shown below



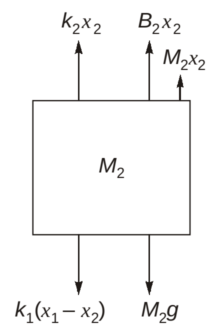
Freebody diagram of Mass 'M',



$$f_a(t) = M_1\ddot{x}_1(t) + B_1\dot{x}_1(t) + k_1(x_1(t) - x_2(t))$$

$$\Rightarrow \quad f_a(t) = M_1\frac{d^2}{dt^2}x_1(t) + B_1\frac{d}{dt}x_1(t) + k_1x_1(t) - k_2x_2(t)$$

Free body diagram of Mass 'M_2'



$$M_2g = M_2\ddot{x}_2 + B_2\dot{x}_2 + (k_1 + k_2) - k_1x_1$$

$$\Rightarrow \quad M_2g = M_2\frac{d^2}{dt^2}x_2(t) + B_2\frac{d}{dt}x_2(t) + (k_1 + k_2)x_2(t) - k_1x_1(t)$$

■■■■

2 Microprocessors and Microcontrollers

LEVEL 1 Objective Questions

1.	(d)
2.	(b)
3.	(d)
4.	(a)
5.	(b)
6.	(c)
7.	(b)
8.	(d)
9.	(a)
10.	(c)
11.	(d)

LEVEL 2 Objective Questions

12.	(d)
13.	(a)
14.	(d)

■■■■

LEVEL 3 Conventional Questions

Solution : 15

ROM: ROM is Read Only Memory. It is used for store elements programs/data. It is not lost when power is removed.

PROM: PROM is Programmable Read Only Memory. It is a type of ROM chip programmed by user for one time only.

EPROM: EPROM is Erasable and Programmable ROM. It is a type of ROM chip programmed by user and contents can be erased for repeated programming.

EEPROM: It is electrically erasable PROM. It is similar to EPROM, but erasing is done electrically by applying high voltage and programmed repeatedly.

RAM: Random Access Memory. It is used to store temporary data/programs during execution. It is lost with power.

■■■■

3 Actuators

LEVEL 1 Objective Questions

1.	(b)
2.	(a)
3.	(b)
4.	(b)
5.	(b)
6.	(b)
7.	(b)
8.	(a)
9.	(c)
10.	(a)
11.	(a)
12.	(d)
13.	(b)
14.	(a)
15.	(b)
16.	(a)
17.	(c)

LEVEL 2 Objective Questions

18.	(c)
19.	(b)
20.	(a)
21.	(c)
22.	(a)
23.	(b)

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4 Sensors and Transducers

LEVEL 1 Objective Questions

1.	(d)
2.	(b)
3.	(c)
4.	(a)
5.	(a)
6.	(c)
7.	(c)
8.	(b)
9.	(b)
10.	(c)
11.	(a)
12.	(a)
13.	(c)
14.	(b)
15.	(b)
16.	(d)

LEVEL 2 Objective Questions

17.	(b)
18.	(b)
19.	(a)
20.	(b)
21.	(a)
22.	(d)
23.	(d)
24.	(a)
25.	(b)
26.	(d)
27.	(a)
28.	(c)
29.	(a)
30.	(c)
31.	(c)
32.	(c)
33.	(d)
34.	(c)
35.	(b)
36.	(c)
37.	(d)
38.	(c)
39.	(d)
40.	(d)

LEVEL 3 Conventional Questions

Solution : 41

Overall sensitivity, K = 0.288 mm/°C
Temperature change = 104.167°C

Solution : 42

(a) Span of potentiometer = 320°
(b) Sensitivity = 0.0375 V/deg
(c) Average resolution = 0.0141 V

Solution : 43

Percentage of error = ± 0.625%
Possible error at 2.5 bar = 5%

Solution : 44

Output voltage, V_0 = 8 V

Solution : 45

$\Delta L = 5.114 \times 10^{-6}$ m
Stress, σ = 6.818 Pa

Solution : 46

Resolution = 0.0125 mm

Solution : 47

(a) Deflection, δ = 0.52 mm
(b) Resolution = 0.04 V
Minimum force = 3.85 N
Maximum force = 1923.08 N

Solution : 48

Displacement sensitivity = – 7383 nF/m

Note: Minus sign indicates that the capacitance will increase for decreasing value of d.

Solution : 49

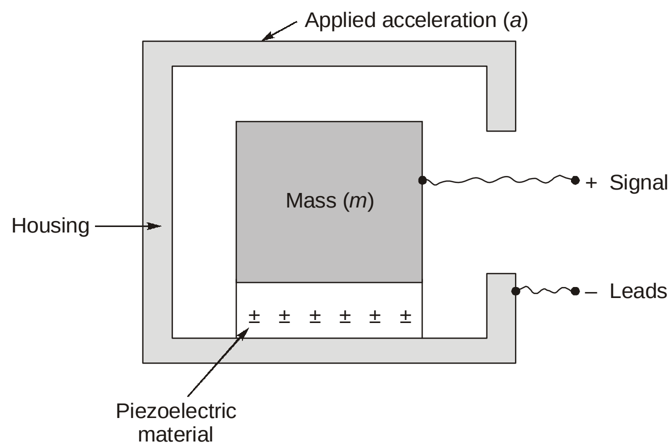
m = 68.81 kg
Deflection, x = 5 coils

Solution : 50

Piezoelectric Accelerometer: A piezoelectric accelerometer that utilizes the piezoelectric effect of certain materials to measure dynamic changes in mechanical variables (e.g. acceleration, vibration and mechanical stock). As with all transducers, piezoelectric accelerometers convert one form of energy into another and provide an electrical signal in response to a quantity property or condition that is being measured. Using the general sensing method upon which all accelerometers are based, acceleration acts upon a seismic mass that is restrained by a spring or suspended on a cantilever beam and converts a physical force into a electrical signal. Before the acceleration can be converted into an electrical quantity it must first be converted into either a force or displacement. This conversion is done via the mass spring system. Piezoelectric accelerometers are widely accepted as the best choice for measuring absolute vibration.

Accelerometer design is based on
1. Shear system
2. Compression system
3. Bending or flexure system

The reason for using different piezoelectric system is their individual suitability for various measurement tasks and their sensitivity to environmental influences. Shear design is applied in the major part of modern accelerometers due to its better performance.



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5 System Response and Process Controllers

LEVEL 1 Objective Questions

1.	(b)
2.	(a)
3.	(b)
4.	(a)
5.	(a)
6.	(d)
7.	(a)
8.	(c)
9.	(b)
10.	(c)
11.	(a)
12.	(c)
13.	(a)
14.	(a)
15.	(b)

LEVEL 2 Objective Questions

16.	(c)
17.	(a)
18.	(a)
19.	(d)
20.	(a)
21.	(b)
22.	(c)
23.	(c)
24.	(a)

■■■■

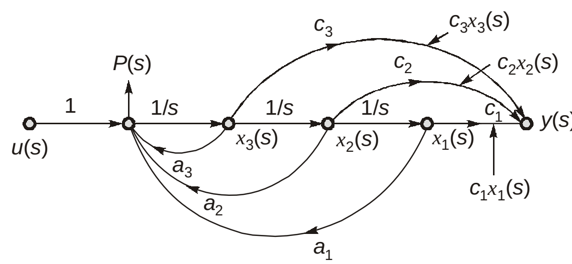
LEVEL 3 Conventional Questions

Solution : 25

$$\frac{F_f(s)}{R(s)} = \frac{G_1(s)G_2(s)}{1+G_1(s)G_2(s)H_1(s)}$$

Solution : 26

Consider the signal flow graph shown



From above

$$Y(s) = C_1x_1(s) + C_2x_2(s) + C_3x_3(s)$$

Apply Inverse Laplace transform on both sides

$$Y(t) = C_1x_1(t) + C_2x_2(t) + C_3x_3(t)$$

The above expression can be written in writer form as

$$Y(t) = \begin{bmatrix} c_1 \, c_2 \, c_3 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{bmatrix} \quad \rightarrow \quad \text{(a)}$$

$$x_1(s) = 1/s\; x_2(s); \quad x_2(s) = s x_1(s)$$

Apply inverse Laplace transform as both sides

$$x_2(t) = x_1(t)$$

$$x_1(t) = 0\, x_1(t) + 1 \cdot x_2(t) + 0 \cdot x_3(t) + 0\, u(t) \quad \text{...(1)}$$

$$\Rightarrow \quad x_2(s) = \frac{1}{s}x_3(s)\,;\; x_3(s) = sx_2(s)$$

Apply inverse Laplace transform on both sides then

$$x_3(t) = x_2(t)$$

$$\Rightarrow \quad x_2(t) = 0x_1(t) + 0x_2(t) + 1x_3(t) + 0.u(t) \quad \text{...(2)}$$

$$\Rightarrow \quad x_3(s) = \frac{1}{s}\left[P(s)\right];\; P(s) = Sx_3(s)$$

$$\Rightarrow \quad P(t) = x_3(t)$$

$$P(s) = a_1x_1(s) + a_2x_2(s) + a_3x_3(s) + 1.\, u(s)$$

Apply Inverse Laplace transform on both sides.

$$P(t) = a_1x_1(t) + a_2x_2(t) + a_3x_3(t) + 1.u(t)$$

$$\Rightarrow \quad x_3(t) = a_1x_1(t) + a_2x_2(t) + a_3x_3(t) + 1.u(t) \quad \text{...(3)}$$

From equation (1), (2), (3), (a) We can develope “state space representation” as shown below:

$$\begin{pmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{pmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ a_1 & a_2 & a_3 \end{bmatrix} \begin{pmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{pmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u(t)$$

$$[y(t)] = \begin{bmatrix} c_1 & c_2 & c_3 \end{bmatrix} \begin{pmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{pmatrix}$$

From the above state space representation

Control system matrix (or)

System matrix $$[A]_{3\times 3} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ c_1 & c_2 & c_3 \end{bmatrix}$$

$\Rightarrow$ Input matrix $$[B]_{3\times 1} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$\Rightarrow$ Output matrix $[C]_{1\times 3} = [c_1, c_2, c_3]$

Solution : 27

A closed loop control system, also known as a feedback control system. It is a control system, which uses the concept of an openloop system as it’s forward path, but has one or more feedback loops.

In closed loop control system, controller can always monitor the output with the help of feedback (sensor).

Exp: Student is allowed to write any example for closed loop control system.

Solution : 28

Controller output(%) = 68.75%

Solution : 29

Controller output(%) = 60%

Solution : 30

Temperature(%) = 33.33%

Solution : 31

(a) Percent per point

SP(%) = 57.9%

(b) Percent measured value

MV(%) = 52.63%

(c) Error Error = 100 rpm

(d) Percent error Error(%) = 52.6%

Solution : 32

$$h = 0.0625i + 0.75$$

$$\text{Differential gap} = 0.25 \text{ m}$$

Solution : 33

$$\text{Total time} = 16.95 \text{ min}$$
$$\text{Total time} = 15.255 \text{ min}$$

Solution : 34

The system is type ‘1’ system.

$$\text{the steady-state errors} = \frac{4}{K_p}$$

■■■■

6 Introduction to Robotics

LEVEL 1 Objective Questions

1.	(b)
2.	(c)
3.	(d)
4.	(a)
5.	(b)
6.	(a)
7.	(c)
8.	(a)
9.	(d)
10.	(d)
11.	(d)
12.	(d)
13.	(a)

LEVEL 2 Objective Questions

14.	(13)
15.	(a)
16.	(d)
17.	(c)
18.	(a)
19.	(c)
20.	(b)
21.	(b)
22.	(a)
23.	(a)
24.	(d)
25.	(b)
26.	(c)
27.	(c)
28.	(a)
29.	(a)
30.	(b)
31.	(c)

■■■■

LEVEL 3 Conventional Questions

Solution : 32

The six characteristics of a hydraulic actuator are —

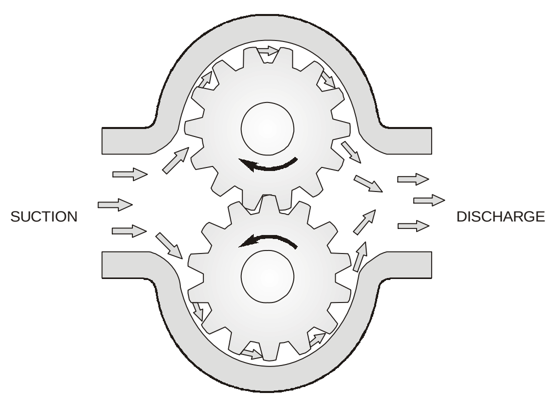
1. It has higher load carring capacity
2. It power to weight ratio is high
3. It can produce large forces to drive loads
4. Its manufacturing cost and maintenance are high
5. It has high accuracy and fast response
6. It poses certain safety concerns as leakage of oils is undesirable and should be avoided.

Solution : 33

Working principle of Gear pump —

A gear pump uses the meshing of gears to pump fluid by displacement. They are one of the most widely used types of pumps for hydraulic fluid power operators. As the gears rotate they separate on the intake side of the pump, creating a void and suction which is filled by fluid. The fluid is carried by the gears to the discharge side of the pump, where the meshing of the gears displaces the fluid. The mechanical clearances are small-in the order of 10 μm. The tight clearances, along with the speed of rotation, effectively prevent the fluid from leaking backwards. The rigid design of the gears and houses allow for very high pressure and the ability to pump highly viscous fluids.

There are two main variations; external gears pump which use two external spur gears and internal gear pump which use an external and an internal spur gears. Gear pumps are positive displacement, meaning they pump a constant amount of fluid for each revolution.



Simple Gear Pump

■■■■

7 Robotics and Transformations

LEVEL 1 Objective Questions

1.	(d)
2.	(b)
3.	(c)
4.	(d)
5.	(a)
6.	(b)
7.	(d)
8.	(a)
9.	(d)
10.	(a)
11.	(b)
12.	(c)
13.	(a)
14.	(d)
15.	(d)
16.	(c)
17.	(b)
18.	(d)
19.	(c)
20.	(a)

LEVEL 2 Objective Questions

22.	(b)
23.	(d)
24.	(c)
25.	(c)
26.	(a)
27.	(d)
28.	(c)

■■■■

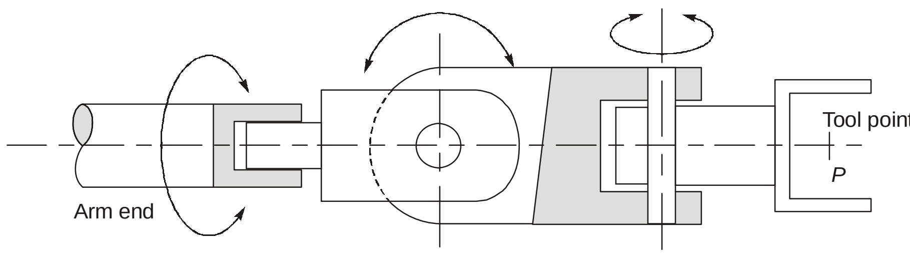
LEVEL 3 Conventional Questions

Solution : 29

$$P' = [-5, -8, 8]^T$$
$$P'' \rightarrow [0, -4, 9]^T$$

Solution : 30

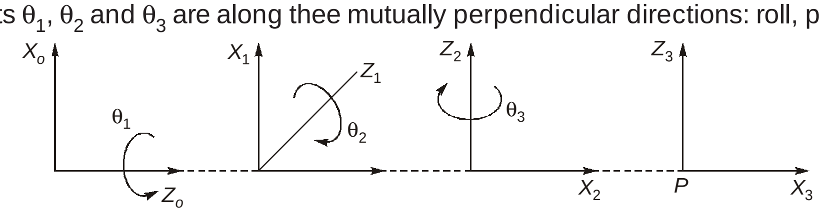
Forward kinematics model for the given three degree of freedom RPY wrist.



A 3-DOF freedom roll, pitch and yaw (RPY) wrist

The 3-DOF RPY wrist has three revolute (RRR) joints which provide any arbitrary orientation to the end effector in 3-D space.

It is assumed that the arm end-point is stationary and can be considered as the stationary base frame [0], for the wrist. The joint are identified and labelled with joint axes as shown in figure. The three joints displacements θ_1, θ_2 and θ_3 are along thee mutually perpendicular directions: roll, pitch and yaw.



Frame assignment for 3 DOF RPY wrist

D-H parameters table

Link	a	α	d	θ
1	0	90°	0	θ_1
2	0	90°	0	$\theta_2 + 90°$
3	0	0	0	θ_3

Individual transformation matrices

$$^0T_1 = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad ^1T_2 = \begin{bmatrix} -s_2 & 0 & c_2 & 0 \\ c_2 & 0 & s_2 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^2T_3 = \begin{bmatrix} c_3 & -s_3 & 0 & 0 \\ s_3 & c_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

And overall transformation matrix for RPY wrist is

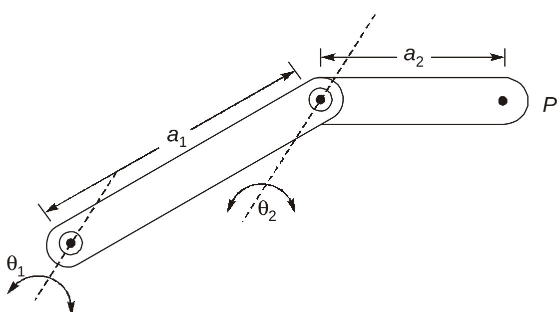
$$^{0}T_3 = {}^{0}T_1 \, {}^{1}T_2 \, {}^{2}T_3$$

$$= \begin{bmatrix} -c_1s_2c_3 + s_1s_3 & c_1s_2s_3 + s_1c_3 & c_1c_2 & 0 \\ -s_1s_2c_3 - c_1s_3 & s_1s_2s_3 - c_1c_3 & s_1c_2 & 0 \\ c_2c_3 & -c_2s_3 & s_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

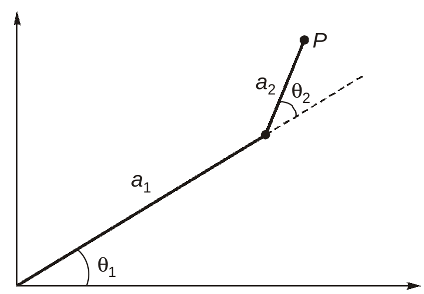
Orientation of the last frame with respect to [0] frame, if $\theta_1 = 0$ and $\theta_2 = \theta_3 = 90°$

$$\Rightarrow \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Solution : 31



2 link 2-DOF planar robot arm



D-H Parameters are —

(1) Link length (a_i)

(2) Joint angle (θ_i)

(3) Link twist (α_i)

(4) Joint depth/offset (d_i)

D-H parameters table for 2 DOF planar robot

	a_i	α_i	d_i	θ_i
link 1	a_1	0	0	θ_1
link 2	a_2	0	0	θ_2

Let composite transformation matrix = ${}_0T^2$

As $\quad {}_0T^2 = {}_0T^1 \times {}_1T^2$

where ${}_0T^1$ and ${}_1T^2$ are individual transformation matrix

$${}_0T^1 = \begin{bmatrix} c_1 & -s_1 & 0 & a_1c_1 \\ s_1 & c_1 & 0 & a_1s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $c \to \cos\theta$ and $s \to \sin\theta$

$$ {}_1T^2 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

And composite transformation matrix will be—

$$ {}_0T^2 = {}_0T^1 \times {}_1T^2 $$

$$ = \begin{bmatrix} c_1 & -s_1 & 0 & a_1c_1 \\ s_1 & c_1 & 0 & a_1s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ = \begin{bmatrix} c_{12} & -s_{12} & 0 & a_1c_1 + a_2c_{12} \\ s_{12} & c_{12} & 0 & a_1s_1 + a_2s_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

∴ Forward kinematic equations are —

$$ P_x = a_1\, c_1 + a_2\, c_{12} $$
$$ P_y = a_1\, s_1 + a_2\, s_{12} $$
$$ P_z = 0 $$

Position of piont, $P = [P_x\ P_y\ P_z]^T$

(b) Given: $a_1 = 15$ units; $a_2 = 10$ units; $\theta_1 = 45°$; $\theta_2 = 45°$ (counter clockwise)

Final position [P] is given as –

$$ P = [P_x\ \ P_y\ P_z]^T $$

where $P_x = a_1 \cos\theta_1 + a_2 \cos(\theta_1 + \theta_2)$

$$ = 15 \cos 45° + 10 \cos (45° + 45°) = \frac{15}{\sqrt{2}} $$

$$ P_y = a_1 \sin\theta_1 + a_2 \sin(\theta_1 + \theta_2) = 15 \sin 45° + 10 \sin (45° + 45°) $$

$$ P_y = \frac{15}{\sqrt{2}} + 10 $$

and $P_z = 0$

∴ Position of tool point, $P = \left[\frac{15}{\sqrt{2}}, \frac{15}{\sqrt{2}} + 10,\ \ 0\right]$

orientation of tool point is given as —

$$ \begin{bmatrix} c_{12} & -s_{12} & 0 \\ s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \cos(45° + 45°) & -\sin(45° + 45°) & 0 \\ \sin(45° + 45°) & \cos(45° + 45°) & 0 \\ 0 & 0 & 1 \end{bmatrix} $$

$$ = \begin{bmatrix} \cos 90° & -\sin 90° & 0 \\ \sin 90° & \cos 90° & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} $$

Solution : 32

The missing element in the frame representation (F) is:

$$\begin{bmatrix} ? & 0 & -1 & 5 \\ ? & 0 & 0 & 3 \\ ? & -1 & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \Rightarrow \begin{bmatrix} 0 & 0 & -1 & 5 \\ -1 & 0 & 0 & 3 \\ 0 & -1 & 0 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Solution : 33

$$Q = [0.707 \quad 3.535 \quad 1.0]^T$$

Solution : 34

$$^1T_2 = \left[\begin{array}{ccc:c} 1 & 0 & 0 & 7.000 \\ 0 & 0.500 & -0.866 & 5.000 \\ 0 & 0.866 & 0.500 & 7.000 \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right]$$

$$^1P = [9.000 \quad 1.804 \quad 13.464]^T$$

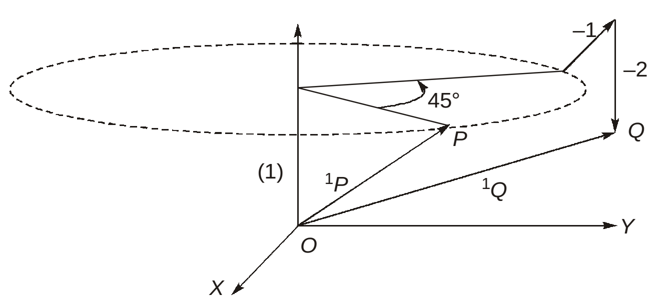
$$^2T_1 = \begin{bmatrix} 1 & 0 & 0 & -7.000 \\ 0 & 0.500 & 0.866 & -8.562 \\ 0 & -0.866 & 0.500 & 0.830 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Solution : 35

Figure shows a point P and a vector from origin as ^1P in frame {1} and its new location after the rotational and transnational transformation as ^1Q. The relation between ^1Q and ^1P is described by equation as

$$^1Q = T\,^1P$$

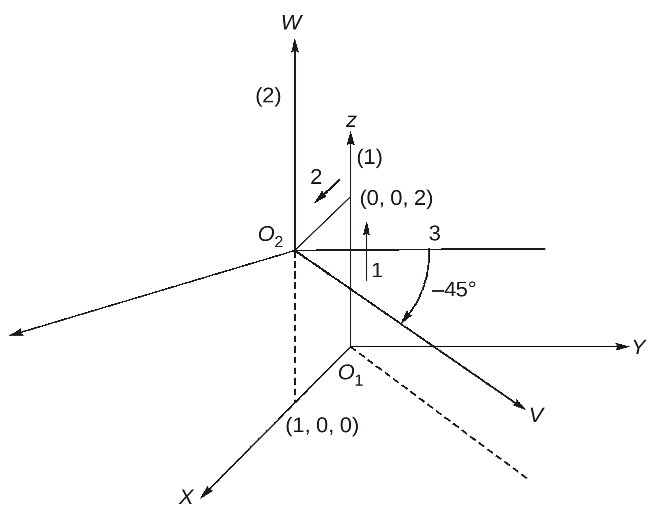
where
$$T = \left[\begin{array}{ccc:c} & R(\theta) & & D \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right]$$



Transformation of point *P* in space

Substituting values gives

$$^1Q = \begin{bmatrix} \cos 45^\circ & -\sin 45^\circ & 0 & -1 \\ \sin 45^\circ & \cos 45^\circ & 0 & 0 \\ 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^1P = \begin{bmatrix} 0.707 & -0.707 & 0 & -1 \\ 0.707 & 0.707 & 0 & 0 \\ 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 1 \end{bmatrix} {}^1P$$



Transformation of frames corresponding to transformation of vectors

Solution : 36

Case I: $\theta_2 \neq 90^\circ$

$$\theta_3 = A\tan 2\left[\frac{r_{21}}{C_{21}}, \frac{r_{11}}{C_2}\right]$$

$$\theta_1 = A\tan 2\left[\frac{r_{32}}{C_2}, \frac{r_{33}}{C_2}\right]$$

Case 2 $\quad \theta_2 = \pm 90^\circ$

If $\theta_2 = +90^\circ$ $\quad \theta_2 = 90^\circ;\ \theta_3 = 0^\circ$ and $\theta_1 = A\tan 2(r_{12}, r_{22})$

With $\theta_2 = -90^\circ$ $\quad \theta_2 = -90^\circ,\ \theta_3 = 0^\circ$ and $\theta_1 = A\tan 2(-r_{12}, r_{22})$

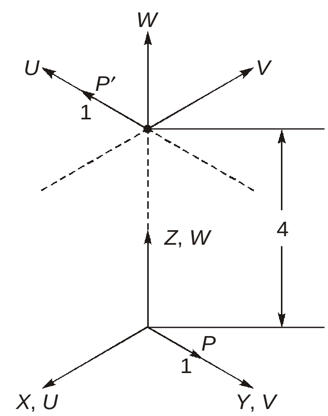
Solution : 37

$$^1R_2 = \begin{bmatrix} 0.866 & 0.354 & 0.354 \\ 0.433 & -0.177 & -0.884 \\ -0.25 & 0.919 & 0.306 \end{bmatrix}$$

Solution : 38

$$P' = TP = \begin{bmatrix} 0 \\ -1 \\ 4 \\ 1 \end{bmatrix} \qquad \text{... (ii)}$$

(b) The initial and final positions of two frames and point P are is shown in figure.



(c) If the order of transformation is reversed, that is, rotation followed by translation, the overall transformation matrix will not change. This can be easily verified by the reader and is the property of screw transformation.

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8 Robot Specifications & SCARA Robot

LEVEL 1 Objective Questions

1.	(a)
2.	(a)
3.	(a)
4.	(b)
5.	(b)
6.	(a)
7.	(a)
8.	(c)
9.	(b)
10.	(a)
11.	(a)
12.	(b)
13.	(a)
14.	(c)
15.	(d)
16.	(d)
17.	(c)

LEVEL 2 Objective Questions

18.	(c)
19.	(c)
20.	(b)
21.	(b)
22.	(b)
23.	(d)
24.	(d)
25.	(a)
26.	(d)
27.	(d)

■■■■

LEVEL 3 Conventional Questions

Solution : 28

Proportional control (P): In the proportional control algorithm, the controller output is proportional to the error signal, which is the difference between the set point and the process variable.

Derivative control (D): In this algorithm, output is directly proportional to the rate of change of error.

Integral control (I): In this control method, the control system acts in a way that the control effort is proportional to the integral of the error.

PID control: In this control method, the controller output is proportional to present error and integral of error and derivative of error.

Solution : 29

$$\tan^{-1}\left(\frac{a_y}{a_x}\right) = \theta_1$$

$$\theta_3 = \tan^{-1}\left[-\frac{o_z}{n_z}\right]$$

$$\theta_2 = \tan^{-1}\left[\frac{a_z}{c_1 a_x + s_1 a_y}\right]$$

■■■■