ME 639

INTRODUCTION TO ROBOTICS

Assignment 1

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TASK 2

1. Manipulator Robots

i. **SCARA robot:** [YouTube link]
SCARA stands for Selective Compliance Articulated Robot Arm. It is compliant in the x- and y-axes and rigid in the z-axis. It is suitable for use in material handling applications. Its structure is such that the two arms are joined at the base and there is an intersection between the two.

ii. **Canadarm:** [YouTube link]
Officially called the Shuttle Remote Manipulation System, it was designed to handle large payloads on the NASA Space Shuttle program. The end effector used by the robot is a three-wire design that is inspired by elastic bands around fingers, rather than a claw-like structure.

2. Mobile Robots

i. **Teledyne FLIR PackBot 510:** [YouTube link]
PackBot 510 is a man-transportable robot that performs bomb disposal, surveillance and reconnaissance, CBRN detection and HazMat handling operations. It can climb stairs and navigate narrow passages, while relaying real-time video, audio and sensor data to the operator staying at a safe distance.

ii. **RoboticsDesign ANATROLLER ARI-50:** [YouTube link]
It is robot that specializes in air duct cleaning and inspection. It is small in size and can clean ducts 6” x 6” in size. It can carry four times its weight and can tow nine times its weight.

3. Aerial Robots

i. **Elbit Systems Skylark 3:** [YouTube link]
Skylark 3 is a tactical mini UAV system (UAS) optimized for either dismounted or vehicle-based operation. The platform is fully autonomous from take-off to landing and is designed for mission oriented operation that doesn’t require any piloting skills.

ii. **Foxtech Kraken 130 V3:** [YouTube link]
It is equipped with powerful motors and high efficiency 18inch CF propeller. It has installed with unique Easy-folding system and automatic folding landing gear allow for a quick set up and immediate launching at job site.

4. Legged Robots

i. **Boston Dynamics Atlas:** [YouTube link]
It is a bipedal humanoid robot. It is designed for search and rescue operations, performing asks such as shutting off valves, opening doors and operating powered equipment in environments where humans could not survive.

ii. **Boston Dynamics Spot:** [YouTube link]
The Spot is a four-legged canine-inspired robot. It is used to monitor and operate sites by organisations. It can provide data about the site to the operators in various spaces such as construction sites, research labs, etc.

5. Soft Robots

i. **MIT SoFi:** [YouTube link]
It is a soft robotic fish that can independently swim alongside real fish in the ocean. SoFi can swim in a straight line, turn, or dive up or down. It has a single camera, a motor, and the same lithium polymer battery that's found in consumer smartphones.

ii. **Harvard Soft Gripper:** [YouTube link]
It is a soft, robotic gripper that uses a collection of thin tentacles to entangle and ensnare objects. The gripper relies on simple inflation to wrap around objects and doesn't require sensing, planning, or feedback control.

6. Nanobots

Xenobots: [YouTube link]
Recent research has helped to establish xenobots, nanorobots that are less than 1 mm in length and constructed of 500-1000 living cells. They have been created in a variety of basic shapes, including some with legs. Studies have shown they can effectively move linearly or circularly, join with other xenobots to act collectively, move tiny objects, and live for around 10 days.

7. AUV

i. **Hydroid Inc. REMUS 600:** [YouTube link]
The REMUS 600 AUV was designed through funding from the Office of Naval Research to support the Navy's growing need for operations requiring extended endurance, increased payload capacity, and greater operating depth.

ii. **General Dynamics Mission Systems Bluefin-9:** [YouTube link]
It features a carbon fibre body and can handle payloads such as HD Machine Vision Camera, Side Scan Sonar, Turbidity, Fluorometry, etc.

TASK 3

1. **Brushed DC motor:** It uses brushes to supply current to the motor windings. It typically consists of a pair of permanent magnets named as the stator and a motor coil named as the rotor connected to a commutator. It is cheap and doesn't need a controller for fixed speed and the controller is simple for variable speed. However it is less efficient and creates a lot of electrical noise.

2. **Brushless DC motor:** They are also called electronically commutated motors (ECM). In this motor, the permanent magnets attach to the rotor. The current-carrying conductors or armature windings are located on the stator. The main design difference between a brushed and brushless motors is the replacement of mechanical commutator with an electric switch circuit. They require less maintenance and have lower noise, but they are costly and require complex drive circuitry.

3. **AC Induction motor:** These motors convert AC power to mechanical power by use of electromagnetic induction. The armature winding serves as both the armature winding and field winding. When the stator windings connect to an AC supply, a flux is produced in the air gap. The flux rotates at a fixed speed called synchronous speed. This rotating flux induces voltages in the stator and rotor winding.

4. **AC Synchronous motor:** These motors convert AC power to mechanical power and operate only at the synchronous speed. In this motor, stator has axial slots which consist stator winding wound for a specific number of poles. Rotor winding is fed with a DC supply with the help of slip rings. It is not self-starting, so it has to be brought up to synchronous speed before it can be synchronized to AC supply.

5. **Stepper motor:** A stepper motor is a DC motor that converts electrical pulses into step-wise mechanical motion of the shaft. Unlike other DC motors, this motor has a permanent magnet rotor that operates when the stator is energized. The construction of the stator is similar to a normal DC motor, with the difference being the stator having mechanical teeth. The sequence of the pulse generated by the microcontroller allows the shaft of the motor to rotate in discrete steps.

6. **Servo motor:** They can be based on either DC or AC motors. The thing that differentiates them from regular DC and AC motors is the incorporation of a feedback element. An encoder or a potentiometer can be used as a feedback device. The feedback element is connected to the motor shaft and by measuring the value of the output, the position of the motor shaft can be known. A comparator may also be added that can help in knowing whether the shaft has reached the desired position or not.

Task 6:

Consider a rotation matrix R describing a rotation of angle θ about the x-axis.

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$$

$$\text{So, } R^T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix}$$

$$\text{Now, } R \cdot R^T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos^2\theta + \sin^2\theta & \cos\theta\sin\theta - \cos\theta\sin\theta \\ 0 & \sin\theta\cos\theta - \sin\theta\cos\theta & \sin^2\theta + \cos^2\theta \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} = I$$

$$\Rightarrow R \cdot R^T = I$$

$\therefore$ R is orthogonal

Now, let e_1, e_2, e_3 be the column matrices of R, where,

$$e_1 = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}, \quad e_2 = \begin{bmatrix} 0 \\ \cos\theta \\ \sin\theta \end{bmatrix}, \quad e_3 = \begin{bmatrix} 0 \\ -\sin\theta \\ \cos\theta \end{bmatrix}$$

$$e_1 \cdot e_2 = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ \cos\theta \\ \sin\theta \end{bmatrix} = 0$$

$\therefore$ e_1 & e_2 are orthogonal

$$e_2 \cdot e_3 = \begin{bmatrix} 0 \\ \cos\theta \\ \sin\theta \end{bmatrix} \cdot \begin{bmatrix} 0 \\ -\sin\theta \\ \cos\theta \end{bmatrix} = 0 - \cos\theta \sin\theta + \sin\theta \cos\theta = 0$$

$\therefore$ e_2 & e_3 are orthogonal

$$e_3 \cdot e_1 = \begin{bmatrix} 0 \\ -\sin\theta \\ \cos\theta \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} = 0$$

$\therefore$ e_3 & e_1 are orthogonal

$\therefore$ The column matrices of rotation matrix R are orthogonal //

Task 7:

Consider a rotation matrix R_x describing a rotation of angle θ around the x-axis.

$$R_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$$

$$\det(R_x) = 1(\cos^2\theta + \sin^2\theta) - 0 + 0 = 1$$

Now, R_y is a rotation matrix of rotation of angle θ about y-axis

$$R_y = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$$

$$\det(R_y) = \cos\theta \cdot \cos\theta - 0 + \sin\theta \cdot \sin\theta = 1$$

Finally R_z is a rotation matrix describing a rotation of angle θ about z-axis

$$R_z = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\det(R_z) = \cos\theta \cdot \cos\theta + \sin\theta \cdot \sin\theta + 0 = 1$$

$$\therefore \det(R) = 1$$

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