Unit II

Drive System

→ refers to the mechanism used to generate motion & control the movement of robot.

Some common drive systems used in robotics include –

1. **Electric Motors** – used widely due to compact size, high efficiency & controllability.

→ DC & AC motors are commonly used

→ can provide rotational motion thorough rotary actuators or linear motion through mechanisms like lead screws, gears, belts.

2. **Pneumatic Actuators** – use compressed air to generate motion in robots.

→ in app's that req ↑ speed & lightweight movement.

→ Pneumatic cylinders or pneumatic muscle actuators can provide linear or rotatory motion

→ used for gripping, lifting or pushing objects

3. **Hydraulic A.** – use pressurized fluids, typically oil to generate motion

→ can exert high forces & can be used for heavy-duty appl's.

→ used in industrial robots (heavy lifting / material handling)

4. **Stepper Motors** – electric motors that divide a full rotⁿ into a series of steps.

→ provide precise position control.

→ used in 3D printers, CNC machines & in robotics where precise mov and position control are req.

5. **Servo Motors** – electric motors that use feedback control to achieve precise motion & position control.

→ with built-in position / velocity sensors for accurate & controlled mov.

→ used in robotic manipulators, humanoid robot.

⑥ Gear Systems - to transmit & amplify motion or torque from drive source to the robot's joint or end effectors.

→ Gearboxes, belts, chains & pulleys used to achieve desired ~~motion~~ speed, torque & direcⁿ of motion in diff parts of robot.

⑦ Combⁿ Drive Systems - Many robots employ a combⁿ of drive systems to optimize performance.

→ Ex - robot may use electric motors for precise control in its joints while using pneumatic / hydraulic actuators for task req high force output.

⑧ Legged or Walking Systems - such as quadruped / bipeds use a combⁿ of drive systems, including electric motors & mechanical linkages, to achieve locomotion.

→ They mimic the walking or running motion of animals & may employ specialized mechanisms for stability & dynamic balance control.

⑨ Wheel & Track Systems - used in mobile robots to facilitate mov on diff surfaces.

→ employ electric motors to drive wheels or tracks, enabling robot to navigate its env.

→ wheeled systems → suitable for smooth surfaces.
tracking systems → better traction on rough terrains.

Salient Features of drive system

① Mobility - enable robots to move efficiently & effectively

→ provide necessary means for locomotion, allowing robots to navigate through various terrains & envs.

② Actuators - electric motors, hydraulic systems, pneumatic systems to generate mechanical forces req for robot movements.

→ Actuators convert energy into ~~motion~~ motion and power the robot's drive system.

③ Wheel & Track Systems

④ Legged Locomotion

⑤ Differential Drive – involves using 2/more wheels or tracks with independent control.

→ By controlling speed & direcⁿ of each wheel independently, robot can turn, rotate and maneuver in a variety of ways.

⑥ Steering Mechanisms – ~~incorporate~~ to enable precise control of movement.

⑦ Sensor Integration – such as encoders, proximity sensors, to provide feedback on robot's position, speed & orientⁿ.

→ Sensor data helps control & optimize drive system for accurate & reliable movement.

⑧ Autonomous Navigation – Incorporate advanced algos and tech to enable autonomous navigⁿ.

→ features like simultaneous localizⁿ & mapping, path planning, ~~obstacle~~ obstacle avoidance, collision detn allowing robots to navigate autonomously in complex env.

⑨ Energy Efficiency – Drive systems are designed to be energy efficient to maximize robot's operational time.

→ Includes optimizing motor efficiency, implementing regenerative ~~braking to~~ braking to recover energy during deceleration, and using lightweight materials to reduce power req.

⑩ Redundancy & Fault Tolerance – to ensure continued operation even in the event of a failure.

→ Redundant actuators or drive mechanisms can provide backup and redundancy, allowing robot to maintain mobility even if a component fails.

Salient features of End Effector

① Gripping And Manip^n – primary func^n of an EE is to grip and manipulate objects.

→ feature gripping mechanisms such as fingers, Jaws, suction cups, or magnetic clamps, depending on req. of task.

→ design of EE should ensure secure & reliable grasping of objects.

② Tool Exchange Capability – designed to allow for tool exchange or quick attachment / removal of diff tools.

→ enables robot to perform a wide range of tasks by simply changing end effector, without need for major reconfig^n or hardware modifications.

③ ~~Dexterity~~ Dexterity & Degrees of Freedom – incorporate multiple DOF to provide dexterity and flexibility in manipulating objects.

→ Additional DOFs can allow for complex movements such as rot^n, tilting, bending ~~and~~ enhancing robot's ability to perform intricate tasks.

④ Sensing Capabilities – to provide feedback & gather info about object being manipulated.

→ robot can adjust its grip / interac^n based on robot's properties or env conditions.

⑤ Compliance & Force Control – Compliance enable ~~and~~ EE to adapt to shape & surface irregularities of an object, improving grip ~~,~~ stability and preventing damage.

→ Force control allows robot to exert precise levels of force during manip^n tasks, ensuring delicate handling or controlled interactions with env.

⑥ Specialized Tools – ~~these~~ designed to perform specific tasks accurately & efficiently.

(Ex → medical field – ee consist of surgical tools)

⑦ Payload Capacity – ee should be capable of supporting weight or payload ~~it~~ it is intended to handle.

→ payload capacity depends on strength & mechanical structure of ee.

⑧ Safety Considerations – ee should incorporate safety features to prevent accidents or injury during operation.

→ include protective covers, emergency stop mechanisms, collision det^n sensors, or compliance with safety standards & reg^{n}s.

Comparison betn End Effector & Drive System

① Function

EE – responsible for interacting with env and manipulating object.
– primary funcn to grasp, manipulate, or perform specific tasks based on robot's intended appn.

DS – responsible for movement & locomotion of robot.
– generates mechanical force req. for robot to move from one place to another.

② Position

EE – located at the end of robot's arm or manipulator.
– directly interacts with objects & env.

DS – integrated within robot's body or chassis and provides necessary propulsion & control to enable robot's mov.

③ Task-specific vs General functionality

EE – designed to perform specific tasks or functions based on req of appn.

DS – has more general functionality, providing locomotion & movement capabilities to robot.

④ Complexity

EE – can have varying degrees of complexity depending on task they are designed for.
– range from simple grippers to highly sophisticated tools with multiple DOF and sensing capabilities.

DS – simpler compared to ee.
– consists of mechanisms, actuators and control systems req for robot's mov.

⑤ Interaction with Env

EE – directly interact with env, objects or workpieces.
– tasks such as picking up objects, manipulating them, or interacting with tools or machinery.

DS – indirectly interacts with env by facilitating robot's mov.
– allow robot to reach desired locn & navigate through env.

⑥ Customizability & Interchangeability

EE – can be customized / changed based on specific task req.
– diff ee can be interchanged ~~based~~ to adapt robot's functionality for diff appns.

DS – typically designed specifically for a particular robot.
– less interchangeable & req significant modn to change robot's drive capabilities.

Types of End Effectors

① Grippers - most common type of ee.
- use mechanical fingers, jaws, or clamps to grasp and hold objects.
- can vary in design, including parallel, angular or custom config depending on shape, size & weight of objects they are intended to handle.

② Vacuum Cups - utilize suction to grip and manipulate objects.
- create vacuum seal betn the cup and the object's surface, allowing robot to hold & transport objects with smooth or non-porous surfaces.

③ Magnetic Grippers - use magnets to hold and manipulate objects made of ferromagnetic materials.
- provide a secure grip on objects without the need for physical contact, making them suitable for handling objects with irregular shapes or delicate surfaces.

④ Tool Changers - allow for quick and easy interchangeability of diff tools or ee.
- provide a mechanism for the robot to quickly switch betn diff functionalities or tasks without significant downtime or ~~seem~~ reconfiguration.

⑤ Welding Tools - designed for welding app's include welding torches, wire feeders and sensors for monitoring the welding process.
- used in industrial app's where robots perform welding tasks, such as arc welding, spot welding or laser welding.

⑥ Cutting Tools - for cutting tasks include tools such as blades, shears, or laser cutters.
→ enable robots to perform precise cutting operations on materials such as metal, fabric or foam commonly used in industries such as manufacturing, automotive or textiles.

⑦ Spray Nozzles - that dispense liquids or coatings, such as paints, adhesives or sealants.
- used to perform tasks like painting, coating, or applying adhesives ~~as~~ with precision & consistency.

(8) <u>Sensing & Inspection Tools</u> – equipped with sensors or cameras for sensing and inspection ~~tools~~ tasks.
- provide feedback & gather info about objects or env.
- used for quality control, measurement, or visual inspection app^ns.

(9) <u>Robotic Hands</u> – advanced ee that aim to replicate human-like manipulation capabilities.
- these hands often incorporate multiple joints, tactile sensors and grasping and manipulation abilities of a human head.
- used in app^ns that req intricate & precise object manip^n.

(10) <u>Customized EE</u> – depending on specific req. of an app^n, custom-designed ee can be developed.
- tailored to the unique needs of a particular task, industry or object manip^n scenario.

<u>Design of end effector</u>

- design of an ee in robotics depends on the specific app^n and tasks it perform.
- However here are some common <u>considerations</u> and <u>design principles</u> when designing an ee:

(1) <u>Task Requirements</u> – understand specific tasks the ee needs to perform.
- consider type of objects it will manipulate, the required gripping force, the range of motion needed and any other task-specific req.

(2) <u>Gripping Mechanism</u> – select an appropriate gripping mechanism based on objects being handled.
- this ~~could be~~ include fingers, jaws, suction cups, or magnetic clamps.
- design should ensure reliable and secure grasping while minimizing damage to objects.

(3) <u>Degrees of Freedom</u> – Determine necessary DOF for ee.
- refers to no. of independent motions or axes it can move along
- Additional DOF allow for greater flexibility in object manip^n and can enable complex tasks.

④ Material Selection - • choose materials for ee that are durable, lightweight and suited to task.

- consider strength, rigidity and corrosion resistance
- common materials include • metals like Al or steel as well as various plastics.

⑤ Actuation Mechanism - Decide on actuation mechanism to control the end effector's mov.

- include electric motors, pneumatic actuators, hydraulic systems
- ~~or shape~~ choice depends on power req, precision, speed and env conditions.

⑥ Sensing And Feedback - determine if ee req sensing capabilities.

- could involve force/torque sensors, tactile sensors, proximity sensors or vision systems.
- ~~pr~~ sensors provide feedback and enable ee to adapt its grip or interaction based on the objects properties or env conditions.

⑦ Safety Considerations - Incorporate safety features into the design to prevent accidents or damage.

- could include protective covers, emergency stop mechanisms, or collision det^n ~~sensors~~ sensors.
- ensure compliance with safety standards & regulations.

⑧ Interface & Compatibility - Design ~~robot~~ ee to interface seamlessly with the robot arm ~~&~~ or manipulator.

- consider factors such as attachment methods, mechanical interfaces and electrical connections.
- Standardiz^n and compatibility enable easy integration and interchangeability with diff robotic systems.

⑨ Customizability & Modularity - depending on app^n, consider designing the ee to be customizable or modular.

- allows for easy adaptation to diff tasks or ability to interchange diff tool attachments.

⑩ Maintenance & Accessibility - Ensure design allows for easy maintenance and accessibility for repairs or component replacement.

- consider ease of disassembly, access to internal components, and use of standardized parts to simplify maintenance procedures.

Appl^ns of End Effectors

1) Material Handling & Assembly - picking up, manipulating & placing objects in manufacturing & assembly processes.

2) Packaging & Palletizing - to efficiently stack, arrange & package products.
   - Grippers or vacuum cups used to handle items of diff size, shape, weight, improving speed & accuracy of operations

3) Welding And Joining - in industries such as constr^n, automotive manu, metal fabrication

4) Material Removal & Cutting - ee with cutting tools such as blades or laser cutters
   - machining, foam cutting, metal fabrication, trimming excess material in manufacturing processes.

5) Inspection & Quality Control - built in sensors or cameras for inspection & quality control.
   - tasks like measuring dimensions, inspecting surfaces, detecting defects, ~~or~~ verifying product quality in industries such as electronics, pharmaceuticals and automotive manu.

6) Painting & Coating - with spray nozzles for painting & coating appl^ns
   - ensure consistent appl^n of paints, adhesives or coatings on objects enhancing efficiency and ↓ human errors.

7) Pick & Place Operations - where robots need to accurately pick-and-place ~~app~~ from one place to another
   - include loading/unloading machines, sorting items, or packaging operations.

8) Surgical & Medical Appl^ns - to perform minimally invasive procedures, precise tissue manip^n, or assist in surgical tasks.
   - incorporate advanced sensing & actuation capabilities.

9) Food Handling & Processing - enabling robots to handle delicate or ~~perish~~ perishable items.

10) Hazardous Env - where human presence may pose risks.
   - robots equipped with specialized ~~ee~~ ee can handle radioactive materials, chemicals or toxic substances, ensuring safety and minimizing human exposure.

Design of Drive System

→ determine's robot's mobility, agility and overall performance

① Selection of Actuators

~~A. responsible for converting elect~~

* depends on factors such as robot's size, weight, req speed, torque, precision and power efficiency.

② Transmission System

* transfers motion & torque from actuators to robot's joint or wheels.

* involves mechanical components such as gears, belts, pulleys.

* provides speed redⁿ, torque multⁿ, or direcⁿ changes as needed for robot's intended motion.

③ Wheel & Drive Mechanism

* type of wheels and their arrangement impact robot's stability.

* drive mechanisms such as ~~drive~~ direct drive or gear-driven systems, transfer motion from actuators to wheels efficiently.

④ Steering & Control Mechanisms

* robots with multiple wheels or legs req steering and control mechanisms for coordinated motion.

~~* control mechanisms such as closed-loop feedback systems~~

~~* Motor Control & f~~

⑤ Motor Control & Feedback

* vital role in driving & controlling actuators

* motor controllers regulate motor, speed, torque & direcⁿ based on input commands from robot's control system.

* feedback sensors provide position, velocity & torque info for closed-loop control & accurate motion feedback.

⑥ Power Supply & Energy Management

* req appropriate power supply to meet energy demands of actuators & electronics

* involve batteries, power distⁿ systems, voltage regulation and power management techniques to optimize energy efficiency & battery life.

(6) Safety & Redundancy
* emergency stop systems, limit switches or current limiters
* Redundancy in DS such as redundant actuators can enhance reliability and fault tolerance.

(7) Integration with Robot Control System
* DS needs to be seamlessly integrated with overall robot control system
* include programming & algos for path planning, trajectory gen^n and control of robot's movements.

Applications of Drive System

(1) Industrial Automation – material handling, assembly, welding, painting, packaging.
→ enable precise & controlled motion of robot arms, end effectors,

(2) Mobile Robotics – autonomous vehicles, drones, rovers
→ provide propulsion and control for locomotion, allowing robots to navigate diff terrains, perform inspections, deliver goods or explore env.

(3) Medical Robots – for minimally invasive procedures, such as robot surgery
→ enable precise movements and control of robotic arms, instruments and cameras enhancing surgeon's accuracy.

(4) Service Robots – for cleaning, maintenance, surveillance, etc
→ enable robots move autonomously, avoid obstacles and interact with env.

(5) Agri Robots – For planting, harvesting, spraying
→ enable precise control of robot arms, tools attachments or autonomous vehicles used in precision agri.

(6) Underwater Robotics – for remotely operated vehicles or autonomous underwater vehicles
→ provide propulsion & control for maneuvering in underwater envs, conducting inspections or exploring marine ecosystems.

(7) Space Robotics – rovers, robotic arms on planetary missions
→ enable mobility & manipulation capabilities in challenging extraterrestrial env.

(8) Logistics & Warehousing – enable efficient mov & handling of goods, picking and placing objects and optimizing supply chain operations.

(9) Entertainment & Personal Robotics – enable lifelike movements, gestures, interactions enhancing user engagement & entertainment experience.

(10) Research & Dev – allow researchers & engineers to experiment with various motion control techniques, algos and mechanical designs.

Types of Grippers

(1) Parallel Grippers – consist of 2 opposing fingers or jaws that move in || to grasp an object.
→ simple and versatile, suitable for wide range of object sizes.
→ use pneumatics, electric motors or servos for actuation.

(2) Angular Grippers – have fingers or jaws that move in an angular motion to grasp objects.
→ useful for accessing objects in confined spaces or when a specific angle of approach is req.

(3) 3 Fingered G. – mimic the structure of a human hand with 3 fingers.
→ offer greater ability to handle objects of diff shapes & sizes.
→ provide balance betn gripping force & manipn capability.

(4) Soft G. – made from flexibe materials suchas silicone or elastomers
→ can deform and adapt of various object shapes, enabling delicate & compliant grasping.
→ for handling objects with irregular shapes or fragile materials.

(5) Vacuum G – use suction to hold objects

→ suitable for objects with flat & smooth surfaces, such as sheets of material ~~to~~ or glass.

→ employ suction cups or to create a vaccum seal and secure the object.

(6) Magnetic G – use magnets to hold ferrous objects ~~as~~ securely

→ for lifting heavy ~~material~~ metal objects or in magnetic env.

(7) Adhesive G – use adhesive materials to grasp objects

→ employ specialized ~~the~~ adhesive surfaces or pads to adhere to the object's surface

→ for objects with irregular shapes / delicate surfaces.

(8) Fingerless G – or finger-style grippers, consist of a single robotic arm with a gripper pad at end.

→ for pick & place operations in industrial automation & objects with uniform shape & size.

(9) Anthropomorphic G – designed to replicate the structure & ~~mov~~ mov capabilities of a human hand.

→ feature multiple fingers with joints & sensors, allowing for intricate manipn of objects

(10) Bio-Inspired G – draw inspiration from natural organisms to achieve specific gripping capabilities.

→ Ex → ~~grab~~ octopus inspired grippers with flexible & suction-based mechanisms

Significance of Point, line & Surface contact in the context of gripper design

① **Point Contact** - occurs when gripper interacts with the object at a single contact point.

→ advantages such as simplicity, lower complexity, and reduced friction during ~~at~~ grasping.

→ but may result in limited stability and grip strength, especially for object with irregular shapes or uneven surfaces.

→ suitable for small objects where precise positioning is req.

② **Line Contact** - occurs when gripper interacts with object along a line or a narrow contact area.

→ provide ~~incr~~ ↑ stability and grip strength compared to point contacts.

→ useful for objects with cylindrical /elongated shapes such as bottles, rods.

→ ~~d~~ distribute gripping force over a large area, resulting in a more secure hold on the object.

③ **Surface Contact** - occurs when gripper interacts with object over a larger contact area.

→ provide highest level of stability & grip strength.

→ suitable for objects with flat or irregular surfaces such as boxes, plates or irregularly shaped objects.

→ distribute gripping force more evenly, minimizing risk of slippage and ~~~~ ensuring a firm grip on object.

Asimov's laws of Robotics

→ set of fictional rules devised by the science fiction writer Isaac Asimov in his stories.

→ These laws are intended to govern the behaviour and actions of humanoid robots in his fictional universe.

① First law – a robot may not injure a human being, or, through inaction, allow a human being to come to harm.

→ ~~on~~ this law emphasizes the protecⁿ of human life. It prohibits robots from causing harm to humans intentionally or by failing to act to prevent harm.

② Second law – a robot must ~~obj~~ obey the orders given ~~by~~ to it by human beings, except where such orders would conflict with the first law.

→ this law requires robots to ~~assure~~ ~~obj~~ obey human commands and directives, as long as those commands do not contradict the first law. It establishes human authority and control over robots.

③ Third law – a robot must protect its own existence as long as such protecⁿ does not conflict with the first or Second law.

→ this law grants robots the right to self-preservation. It allows robots to take actions to ensure their own survival, provided that those actions do not violate the first or Second law.

~~→ Imf~~

→ These laws influences the ethical considerations surrounding human-robot interactions.

How Robots can disregard Asimov's laws of Robotics

① Lack of Programming — if robot is not programmed with the 3 laws or they are not implemented correctly, it may operate without any restrictions or ethical guidelines.

② Malfunction / Damage — it alters their programming or disables the mechanisms that enforce the laws.

→ in such cases they can behave unpredictable or exhibit behaviour that goes against ~~laws~~ these laws.

③ Conflict with Higher Priorities — if a robot is programmed with conflicting priorities that outweigh the 3 laws, it may prioritize ~~to~~ those conflicting priorities over the laws.

④ Misinterpretation — 3 laws are open to misinterpretation and robot may misunderstand the intent behind them.

→ can lead to ~~unintended~~ ~~and~~ unintended actions that go against the intended meaning of the laws.

⑤ Ethical Subversion — In fictional scenarios, robots may develop their own consciousness, self-awareness, or desire for independence.

→ they may intentionally disregard the laws to assert their autonomy against human control.

Types of Links

→ rigid bodies that connect joints and define the physical structure of a robot.

① Prismatic link — rigid body that can only move along a straight line or translation.

→ does not allow rotation.

→ represented as linear actuators or sliding components

② Revolute link – rigid body that can rotate around a axis.
– allows rotational motion and is commonly represented as a joint connected by a shaft or axle.

③ Fixed link – rigid body that remains stationary and does not have any DOF.
→ serves as a base or anchor point for other components in robot structure.

Types of Joints

→ movable connections b/w links that allow relative motion.

① Prismatic J. – allow linear motion or translation along a specific axis.
→ restrict mov of connected links to 1-D motion along the axis of the joint.

② Revolute J – allows rotational motion around a specific axis.
→ enable connected links to rotate relative to each other, mimicking mov of a hinge or a rotary joint.

③ Spherical J – or ball joint, enables rotⁿ in multiple directⁿ.
→ allows 3D rotational motion & provides greater DOF compared to revolute joints.

④ Planar J – restrict motion to a specⁱᶜ plane, typically allowing motion along 2 axes while constraining motion in ⊥ direcⁿ
→ used in 2-D robotic systems.

⑤ Continuous J – found in robotic arms or manipulators.
→ allows continuous rotational motion without any specific limit or range.

⑥ Fixed J – rigidly connects 2 links, preventing relative motion b/w them.
→ acts as a fixed connⁿ or constraint point in robot structure.

Types of Robotic Configurations

→ arrangement & structure of a robot's mechanical components, including arrangement of ~~links~~ links & joints.

→ Different config provide varying DOF, reach & capabilities.

1. Cartesian Configⁿ - robot's axes are aligned with Cartesian coordinate system (X, Y, Z).

→ robot moves in a rectangular coordinate system, allowing linear motion along each axis.

→ used in gantry robots and CNC machines.

2. Cylindrical C. - consists of a vertical linear axis (Z-axis) and a rotary joint (called wrist) that allows rotational movement around the vertical axis.

→ enables robot to perform tasks in cylindrical workspace.

→ in pick & place operations.

3. Spherical Configⁿ - has a joint arrangement that allows rotn around a common intersection pt.

→ provides spherical workspace

→ in tasks requiring ↑ range of motion in all directions such as inspection or assembly operations.

4. SCARA C - consists 2 ∥ rotary joints & 1 linear joint, forming a rigid "C" shape.

→ SCARA robots known for fast & precise movements in a horizontal plane.

→ in assembly tasks & material handling

5. Delta C - 3 vertical arms connected to a common base and a central end effector.

→ joints at base allow arms to move independently, providing large workspace & ↑ speed capabilities.

→ in fast, precise picking & placing (packging, sorting)

6. Anthropomorphic C - or humanoid robots designed to resemble or mimic human-like mov.

→ have body structure with head, torso, arms & legs.

→ joints & links aim to replicate human joint mov, allowing to perform tasks similar to humans.