Day 1: 16 june

- ## What is Joint Actuation in Humanoid Robots?

Actuation means making something move. In humanoid robots, joints (like elbows, knees, or fingers) need to move in a controlled way to imitate human motion.Without actuators, joints are just mechanical parts — they need motors to move.Proper joint movement allows for balance, walking, grabbing, etc.Stability, smoothness, and accuracy are crucial — small errors can cause falls or damage.

- ## Types of Motors Used in Humanoid Joints?

1. **Servo Motors**

   - Integrated motor, gear, sensor, and control board.
   - Common in small-scale humanoids (e.g., robotic hands or fingers).
   - Controlled via PWM signals (typically 1–2 ms pulse width at 50 Hz).

2. **Brushless DC Motors (BLDCs)**

   - Offer higher efficiency, smoother motion, and better power-to-weight ratio.
   - Used in high-performance humanoids (e.g., legs, arms).
   - Require external ESCs (Electronic Speed Controllers) and often FOC (Field-Oriented Control).

3. **Smart Actuators (e.g., Dynamixel, Maxon EC, Harmonic Drives)**

   - Combine motor, reduction gear, encoder, and communication/control interface.
   - Support serial protocols (RS485, TTL) and enable feedback-based motion control.
   - Enable coordinated, precise multi-joint movements in real-time.

- ## Role of PWM (Pulse Width Modulation):

- **Signal Encoding**: PWM encodes joint position, velocity, or torque commands.
- **Speed & Position Control**: Varying pulse width adjusts servo position or motor speed.
- **Torque Control**: For BLDC and smart actuators, PWM is used in modulating current/voltage to control torque output.

- **Voltage, Current & Control Signal Requirements**

Actuator Type	Voltage Range	Current	Control Signal
Servo Motor	4.8–7.4V	0.5–2A	PWM (50Hz)
BLDC (w/ ESC)	12–48V	Up to 20A+	PWM / FOC / CAN
Smart Actuator	12–24V	1–5A	PWM / TTL / RS485 / CAN

- **Voltage** affects speed & power.
- **Current** determines torque capability.
- **Control Signal** type determines how finely the actuator can be commanded.

- Why Accurate PWM Matters

1. **Precision**: Incorrect PWM values lead to joint jitter or overshooting, degrading performance.
2. **Stability**: In dynamic humanoid tasks (e.g., walking, balancing), even slight PWM errors can destabilize the system.
3. **Synchronization**: Coordinated motion requires tightly-timed PWM signals to avoid misalignment between joints.
4. **Feedback Control**: High-precision PWM ensures the control loop (PID, model predictive) functions accurately.

Conclusion

For stable, precise humanoid motion, actuator choice and control method (especially accurate PWM) are **critical**. While servos are sufficient for lightweight limbs, BLDCs and smart actuators with accurate control (via PWM or digital protocols) are essential for realistic, human-like behavior.