

# **MCT333/ MCT344: Mechatronic Systems Design**

## **Course Project**

## **Modular Omni-Wheel Mobile Manipulator**

*Project Description, Rules, Design Plan, and Assessment Criteria*

*Mechatronics and Robotics Engineering Program*

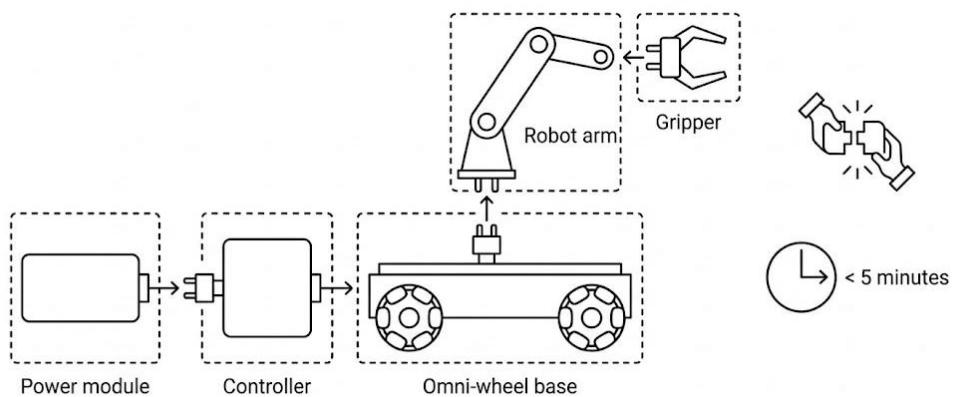
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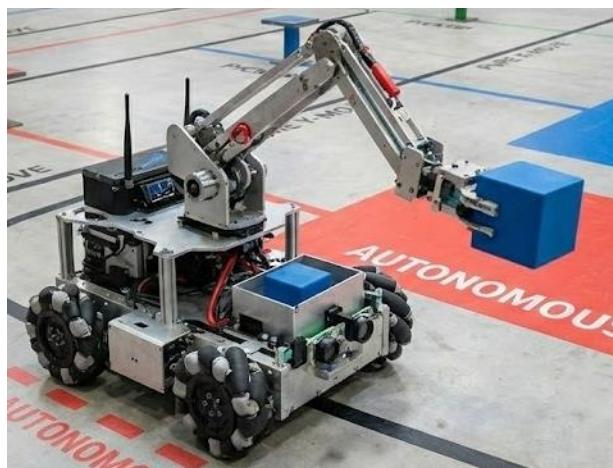
## 1- Project Description

Please fill the following form for team selection <https://docs.google.com/forms/d/1gvctZR-4t-Cygb0ilw22WUxBrskxR7Wvzrluy53rO1w/edit>

In this team project, students will design and realize a complete mechatronic system: a mobile manipulator robot composed of an omni-wheel mobile base and a robotic arm with a gripper. The system will be developed as a modular platform where each module is engineered as a standalone, professionally packaged subsystem that can operate independently or integrate through plug-and-play interfaces within a few minutes. The goal of the project is to develop a **fully integrated mechatronic system** in which mechanical, electrical, control, and software subsystems are seamlessly combined to operate as one cohesive and synchronized unit.



*Figure 1 Main actuation components*



*Figure 2 Robot example*

The project is executed as a structured competition (the **Spring 2026 Mechatronics Omni-Challenge**). The **robot is manually operated** along the track until it reaches a **predefined landmark**. At this point, the **robot** switches to **autonomous mode** to pick up a **cube**. Each **cube** is covered with a **QR code** that encodes the target **box color**, which determines the **correct landmark** where the cube must be placed.

The competition includes both manual teleoperation and fully autonomous segments. During teleportation, teams can combine wheel encoder odometry, IMU-based heading stabilization, and additional sensors/AI tools as needed. During the design process, teams must apply functional analysis

(functional decomposition and functional diagrams) and TRIZ to generate innovative concepts and resolve design contradictions.

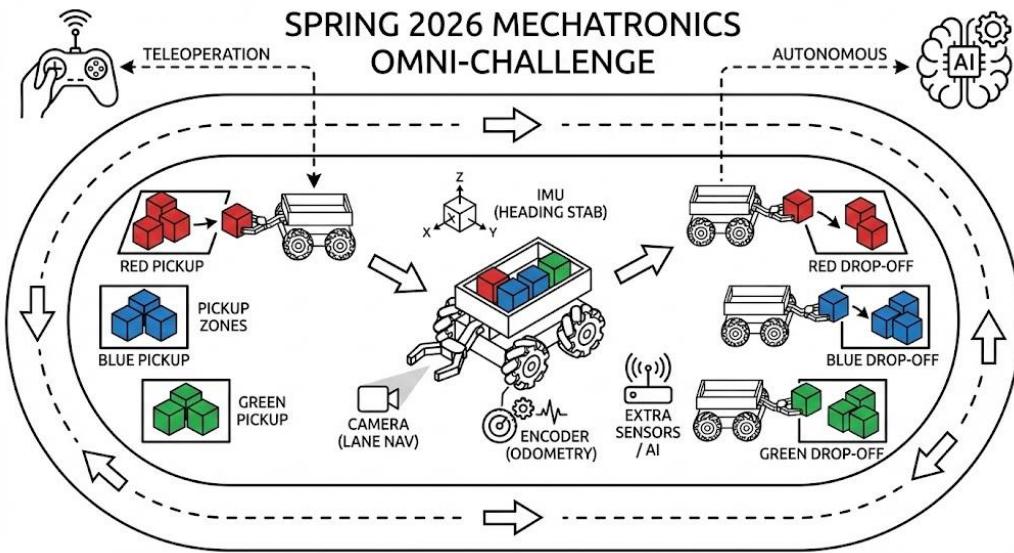


Figure 3 Competition illustration

## 2- Project Requirements and Constraints

### A. Functional Requirements

- Mobile base with holonomic motion using omni wheels (translation in X/Y and rotation about its center).
- Robotic arm + gripper capable of grasping the predefined competition objects and placing them into on-board storage bins.
- Two operating modes: (1) manual wireless teleoperation for track movement, (2) autonomous pick and place.
- Color-based sorting into dedicated on-board bins (Red, Blue, Green) and delivery to the correct ground drop-off zones.
- Obstacle detection and repeatable task execution.

### B. Modularity Requirements

Note: For modularity, online sources are allowed (e.g., 3D models, open-source libraries, reference designs). However, each team is fully responsible for verifying, validating, and understanding any adopted component from an engineering perspective before integration.

- Two main modules: Mobile Base Module and Manipulator Module. Each module must have its own controller and power distribution (as applicable).
- Standardized mechanical interface (mounting pattern + alignment features) for fast attachment/detachment.
- Standardized electrical interface (power connector + communication connector) to enable plug-and-play integration.
- Defined communication protocol between modules (e.g., CAN/UART/Ethernet/RS-485) including heartbeat and safety states.

- If any online component or library is used (e.g., a 3D CAD model, robotic arm design, QR-code detection library), it must be checked from an engineering POV (checking the mechanical design for the part, understanding the used functions and their params).

#### C. Constraints (must not exceed)

Parameter	Limit / Requirement	Notes
Total weight	Less than 10kg	Including motors, mechanics, electronics, and battery. Lighter is better.
Max dimensions (arm folded)	50 cm (W) x 50 cm (L) x 70cm (H)	Robot must start arm folded in this configuration.
Boxes sizes	5cm x 5cm x 5cm	Each box will have a QR code for the color
Materials	3D printing and/or laser cutting, or any other relevant materials.	Other methods require instructor approval.
Power source	Battery operated	Include fuse, main switch, and safe charging approach.
Safety	Mandatory safety inspection	Must pass Phase 1 to enter competition.

#### D. Phase 1: Safety Check (Mandatory Gate)

1. No hanging or exposed wires (use proper harnessing, strain relief, and cable management).
2. No sharp edges or unsafe protrusions (de-burr and cover).
3. Robot weight within the specified limit.
4. Robot dimensions within the specified limit when the arm is closed/folded.
5. Main fuse installed and correctly rated; include emergency stop or clearly accessible main power cutoff.
6. Electronics are mounted professionally (PCB fixed inside an enclosure, no loose boards, insulated terminals).

## 3- Team Numbers, Instructions, and Task Allocation

Teams will consist of 7-8 students. Each student must own a well-defined set of tasks and deliverables and integrate them with the rest of the team through scheduled interface checkpoints.

Recommended Team Roles (example distribution):

- Project Manager & Systems Engineer (requirements, schedules, integration readiness reviews).
- Mechanical Lead (base/arm CAD, manufacturing drawings, assembly).
- Actuation & Power Lead (motor sizing, transmission selection, battery sizing, fusing, power board).
- Electronics Lead (schematics, PCB, wiring, connectors, protection).
- Embedded/Real-Time Lead (MCU firmware, motor control loops, safety state machine).
- Software/Perception Lead (camera pipeline, line detection, object detection, color sorting).
- Controls & Estimation Lead (kinematics, odometry fusion, trajectory tracking, autonomous behaviors).
- Documentation & QA Lead (VDI 2206 deliverables, test plans, datasheet, revision control).

### Responsibility Sheet (Mandatory):

Each team **must** maintain a responsibility sheet (table) from Week 1 and keep it updated weekly. It will be assessed by the TAs and course instructors and will be used in individual contribution grading.

Student Name / ID	Role	Owned Tasks	Interfaces / Dependencies	Evidence (links, files, commits)	Hours / Week (est.)	TA / Lead Sign-off

### Important rules for teamwork:

- Use a shared repository (Git) for software and a shared folder structure for CAD/electronics/documents.
- Define interface documents early: mechanical mounting, electrical pinout, and communication protocol.
- Hold weekly integration checkpoints and keep a decision log (trade-offs, risks, changes).
- All team members **must** understand the full system at a high level; specialists must deeply know their owned subsystem.

## 4- Competition Description, Instructions, and Track Layout

This section outlines the rules, requirements, and procedures for the Spring 2026 Mechatronics Omni-Challenge.

### Competition Overview: The Omni-Sort Protocol

**Mission Statement:** Teams must design and build a modular mobile manipulator robot equipped with an omni-directional drive (e.g., Mecanum or Kiwi). The robot must manually navigate a marked lane, autonomously retrieve QR code encoded colored cubes from constrained pickup stations using its arm, store them on-board, and deliver them to matching colored drop-off zones.

**Core Challenge:** The run is split into two phases: (1) a Manual Teleoperation Phase for initial maneuvering, and (2) a fully Autonomous Phase where the robot must rely solely on onboard sensors and computation to pick up/place the box and detect its color.

### 1. Arena and Track Specifications

The arena is a concrete floor marked with vinyl tape and printed/painted lane boundaries (Figure 4).

- Total track length (defined path): approximately 10m.
- Manual Control Zone (Start): 10m x 5 m.
- Track Lane: two parallel black boundary lines. Lane width is 0.8 m.
- Obstacles may be placed near the lane.

## Interactive Zones

Pickup Stations: elevated pedestals (approx. 40 cm height) holding cubes with QR code encoding their color. Access is constrained to test omni-capabilities:

- Station A - RED (Pure Y Move): approach straight-on and move purely forward/backward during final alignment and place the cube.
- Station B - BLUE (Pure X Move): face parallel to the station and strafe sideways (pure lateral movement) to place the cube.
- Station C - GREEN (Rotation Station): align and rotate in place to access and place the cube.

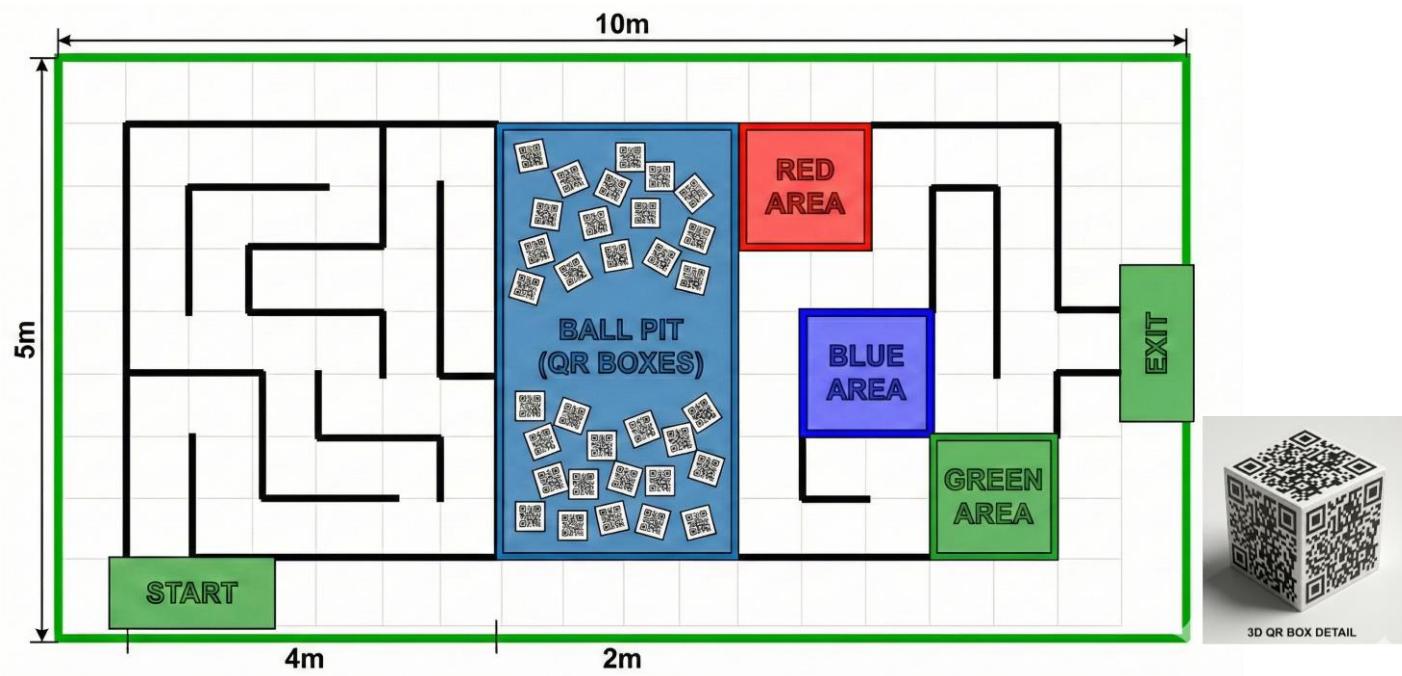


Figure 4 Track layout

## 2. Robot Design and Sensor Requirements

The robot must be a self-contained mobile unit with an onboard power source and safe power distribution.

Mechanical requirements:

- Drivechain: holonomic/omni-directional (instantaneous motion in any direction + rotation).
- Manipulator: arm or gripper capable of lifting cubes from a ~40 cm pedestal height and placing them into storage.
- Storage: on-board bin/rack to securely hold at least 3 cubes simultaneously during transit.
- Modularity: base module and manipulator module must be independently testable and integrate via plug-and-play interfaces.

Required/expected sensors and control subsystems:

- Vision system (camera): QR code read to define box color.
- Wheel motor encoders (odometry): distance/speed measurement and precise holonomic motion control for Pure X and Pure Y maneuvers.

- IMU: heading stabilization to prevent unintended rotation and improve accuracy in strafing and rotation-zone maneuvers.
- Optional sensors: proximity/ToF, depth camera, bump sensors, etc.

### 3. Competition Procedure and Instructions

Each team receives a 5-minute time slot for an official run (unless instructors announce otherwise).

Pre-Competition Gate - Safety Check (Pass/Fail): the robot is inspected for wiring, sharp edges, mass, dimensions, fuse/protection, and PCB/electronics integrity. Failing teams must fix issues before competing.

#### Phase 1 - Manual Teleoperation (Setup):

- Start with the robot fully inside the Manual Control Zone and within folded-dimension limits.
- Using a wireless controller, the operator drives the robot through the start area and positions it just the ball pit area (pick and place area).
- Handover: the operator places the controller down. The robot is switched to autonomous mode to pick and identify the box color which should be printed on laptop screen.

#### Phase 2 – Handling Operation:

- After picking the box, no human intervention is allowed for handling/dropping the box.
- Constrained place: manually reach stations red, blue and green depend on box color and execute the required maneuver (Pure Y, Pure X, or rotate-in-place), encoders + IMU readings should be printed on laptop screen.
- Completion: the run ends when time expires or the team completes its deliveries and reaches the exit.

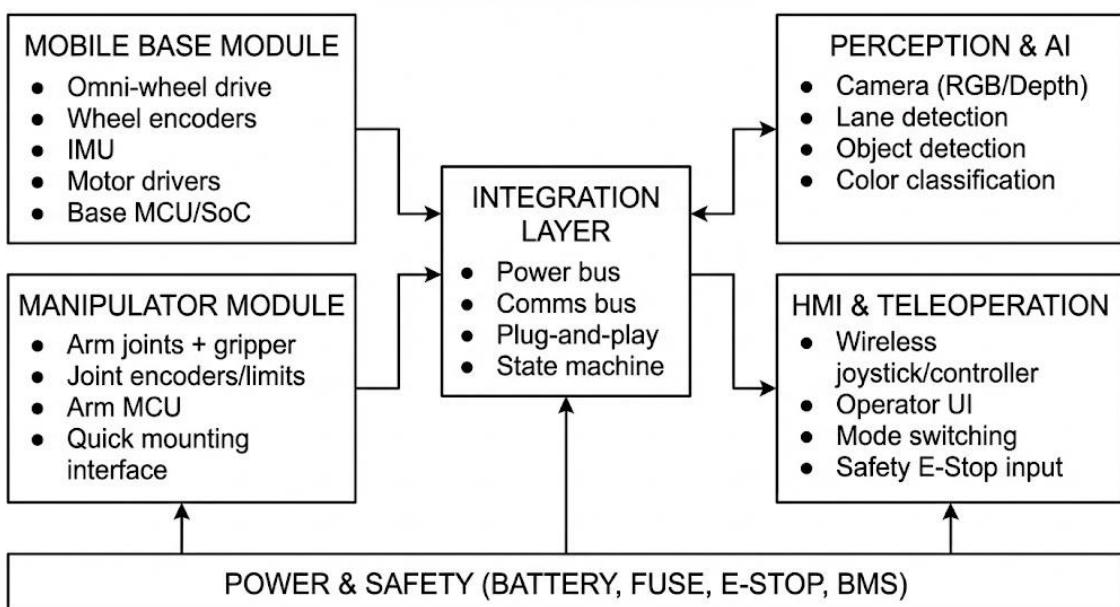


Figure 5 Reference modular architecture for plug-and-play integration (example)

## 5- Project Design Plan and Design Phases (VDI 2206)

Teams must follow the VDI 2206 mechatronic design methodology (V-model). Deliverables and reviews will be aligned to its phases.

**Innovation Requirement (Functional Analysis + TRIZ):** In addition to VDI 2206, each team must perform a functional analysis (functional decomposition, function structure, and functional block diagrams) and apply TRIZ to generate innovative concepts and resolve key design contradictions (e.g., speed vs. accuracy, stiffness vs. weight, payload vs. battery life). Evidence of this process must be included in the technical report and design reviews.

- Functional decomposition and function structure diagram (functions, flows of energy/material/signal).
- Functional block diagram for the whole system and for each module (base, manipulator, perception, HMI).
- TRIZ worksheet: contradiction statement(s), selected inventive principles, and resulting concept alternatives.
- Concept selection rationale (trade-off table/morphological chart) linked back to requirements.

### Phase 0 - Problem Definition and Requirements

- Translate competition rules into measurable system requirements (speed, payload, accuracy, autonomy level, safety).
- Define interfaces (mechanical, electrical, communication) and success metrics.
- Perform risk assessment (FMEA-style) and define mitigation actions.

### Phase 1 - System-Level Design (Concept & Architecture)

- Select base configuration (3-omni vs 4-omni) and arm DOF/gripper concept.
- Define system architecture, module boundaries, and power + communication buses.
- Preliminary BOM and budget planning.

### Phase 2 - Domain-Specific Design

- Mechanical: CAD, material selection, manufacturing drawings, stress/deflection checks where needed.
- Actuation sizing: compute required wheel torque and arm joint torques; select motors, gearboxes, drivers.
- Electronics: schematics, PCB, connectors, protection (fuse, TVS, reverse polarity), and enclosure.
- Control: kinematic modeling, controllers for base/arm, state machine, safety interlocks.
- Software: perception pipeline, autonomy behaviors, calibration procedures, logging and testing tools.

### Phase 3 - Modeling and Simulation

- Model base holonomic kinematics and validate inverse/forward kinematics.
- Simulate actuator sizing (torque/speed profiles) and verify margins.
- Simulate control performance (tracking, stability, disturbance rejection).
- Validate perception approach on recorded data or synthetic images.

### Phase 4 - Implementation and Subsystem Verification

- Fabricate and assemble modules (base and arm).

- Verify each module independently: motor control loops, sensor calibration, communication, safety response.
- Document test results and iterate the design.

#### Phase 5 - System Integration, Validation, and Competition Readiness

- Integrate modules using defined interfaces; conduct integration tests with checklists.
- Run repeatability tests (perform the task for X times without errors).
- Finalize documentation, datasheet, and demonstration videos.

## 6- Assessment Criteria in the Competition

### A. Competition Scoring (suggested - instructors may finalize):

Event	Score / Rule
Safety inspection passed	Mandatory gate (no points).
Manual phase: reach and stop at transition line	10 points.
Autonomous pick the box	5 points per box
Correct on-board color sorting	+2 bonus per box (only if correct bin).
Correct maneuvering to the drop-off zone	10 points per box
Correct delivery to matching drop-off zone	10 points per box (box must end fully inside the target square).
Penalties / invalidation / tie-breaker	Lane boundary crossing: -3 each; collision: -5; manual intervention after transition: -10 (repeat may invalidate run). Tie-breaker: highest score, then fastest valid time, then lightest robot.

The scoring table above summarizes the point system for manual setup, autonomous navigation, constrained pickup, sorting, and delivery, including penalties.

### B. Valid Run Conditions

- Robot starts inside the start box within the Manual Control Zone with the arm folded within the maximum dimensions.
- Robot must follow allowed control mode per segment: manual control is allowed only in the Manual Control Zone and before the Transition Line; in ball pit area robot should pick the boxes autonomously.
- Unsafe behavior (uncontrolled motion, exposed wiring, battery issues) results in immediate stop and run invalidation.
- If a reset is requested by the team, the run time continues (unless instructors state otherwise).

## 7- Submission Deadlines and Requirements

Deadlines are organized by project weeks (relative schedule). Instructors may publish exact calendar dates.

Week	Expected Submission / Demo
Week 1	Team formation, role assignment, responsibility sheet started.
Week 2-3	Requirements document + competition interpretation + initial risk assessment + functional decomposition/functional block diagrams + TRIZ ideation worksheet (concept alternatives).
Week 5	System concept review: architecture, base/arm concept, interface definitions, preliminary BOM.
Week 7	Modeling & simulation demo: kinematics, actuator sizing, initial control simulation.
Week 9	Subsystem prototype check: base driving + arm/gripper basic motion; initial wiring + safety items.
Week 11	Autonomy demo: pick/place the box + odometry/IMU fusion; prototype for QR code reading.
Week 13	Full integration dry-run: end-to-end task rehearsal + repeatability test report.
Week 14-15	Final competition + final submissions.

Required submissions throughout the semester:

- Short progress presentations (5-7 minutes) at the assigned reviews.
- Updated responsibility sheet (weekly).
- Engineering notebook / decision log (weekly updates).
- Subsystem test evidence (videos and logs).

Final submission package (after the competition):

- Final technical report (PDF) with full VDI 2206 documentation (requirements, design, modeling, implementation, tests).
- System datasheet and specifications sheet (1-2 pages).
- CAD package (assembly + drawings) and manufacturing files (STL/DXF as applicable).
- Electrical schematics + PCB files + wiring diagram and harness plan.
- Source code repository with README, build instructions, and license declarations.
- Short videos: (1) system walkthrough, (2) autonomy demo, (3) competition run highlight.
- Test report including repeatability results and failure analysis.

## 8- Overall Assessment Criteria (Team + Individual)

The project grade is based on both team outcomes (technical quality and competition results) and individual contribution. Total = 100%, split as 50% team overall assessment + 50% individual student contribution assessment.

### A. Team Overall Assessment (50% of total assessment marks)

#	Evaluation Criteria	Weight
1	Professional system documentation + system datasheet and specifications	15%
2	Professional system design (mechanical, actuation sizing & selection, sensors, electrical/electronics, control, software, etc.) and correct application of VDI 2206	20%
3	Modeling and simulation activities for project elements and their integration (including actuator sizing) and correct application of VDI 2206	15%
4	Professional design of control panel, wiring, HMI, etc.	10%
5	Professional implementation of hardware components and system integration (mechanical, electrical, electronics, control panel, etc.) and correct application of VDI 2206	20%
6	Professional system integration in a functional way	10%
7	System overall performance, accuracy, and repeatability (perform the task for X times without errors) - including competition performance	10%

### B. Individual Student Contribution Assessment (50% of total assessment marks)

#	Evaluation Criteria	Weight
1	Knowledge about all project activities and tasks	15%
2	Real contribution in the project (tasks done by the student) and their role in the project	15%
3	Detailed and deep knowledge about all aspects associated with the student's own tasks	25%
4	Professional implementation quality of the student's own tasks	20%
6	Team members' evaluation of the student's work, contribution, and supportiveness	15%
7	Presentation skills in presenting the student's own work	10%

How individual grades are determined (process):

- Responsibility sheet review: ownership evidence, weekly updates, and sign-offs.
- Individual technical discussion/interview: student explains design choices, calculations, implementation details, and testing results.
- Peer evaluation: confidential form where each member rates collaboration and contribution.
- Artifact review: commit history (software), CAD revisions, schematics/PCB work, test logs, and documentation authored by the student.

## 9- Lab Activity plan

Week	Topic	Notes	Activities	Milestone/Deliverables
1	Project description sharing & Team formation	--	Kickoff: project rules, workflow, team roles, repo/folder setup	Team formed + roles assigned + responsibility sheet started
2	Project Description, brainstorming and 1st time inquiry	--	Requirements interpretation + functional decomposition + TRIZ ideation + initial risks	Requirements draft + competition interpretation + initial risk assessment + functional blocks + TRIZ worksheet
3	CAD export & actuator sizing in matlab	--	Detailed design sprint: CAD maturation + actuator & power sizing Modeling & simulation demo + actuator sizing + initial control simulation	Actuator sizing draft + updated CAD + power calculations
4	Omni wheel introduction + mobile robot dynamics + Tips for robot arm design	--	Omni/holonomic drive concept, system designs and calculations + control architecture	
5	Individual/team Presnetations/Progress Report System concept review report/presentation: system architecture, design and initail implementation <b>Marks Evaluation</b>	--	Detailed design sprint: CAD maturation + electrical and electronics and embedded components+ actuator & power sizing + electronics/wiring plan + teleop plan + Simulation + Inital Implementation	
6	ESP and wireless communication	--	ESP programming, sensor integration, data transfer, and logging	
7	<b>OFF</b>	عيد الفطر		
8	<b>Midterm</b>	<b>Mid-terms</b>		
9	Introduction to machine vision			
10	PID control + discretization + encoders/IMU integration + logging			
11	Individual/team technical discussions and evalutions without marks			
12	Individual/team Presnetations/Progress Report progress presentation + complete integration+ initial testings and trials <b>Marks Evaluation</b>			
13	Individual/team technical discussions and evalutions			

	including testings without marks			
14	Individual/team technical discussions and evaluations including testings without marks			
15	Project Submission			