RoboCup Robot Arm Challenge

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I. INTRODUCTION

Autonomous robotic manipulation has growing importance in industrial and research settings because it requires perception, planning, and physical interaction to operate as one system. Within this context, the RoboCup ARM Challenge Project explored how a simulated UR5e robot in Gazebo could detect, localise, grasp, and sort objects through an end-to-end MATLAB–ROS connection. The project focused on combining perception, localisation, motion planning, and grasp execution in a structured simulation environment.

My own contribution was mainly within the motion and planning part of the project. I initially explored a waypoint-based method for robot motion, but this approach required too many inverse kinematics solves and became less practical for reliable global transfer motions. As the system developed, I instead contributed to the joint-space point-to-point planner used to move the robot efficiently between key poses, such as pre-grasp and bin locations. I also carried out some early integration work between the motion-planning stage and the YOLO-based perception output, and supported parts of the team organisation through meeting coordination and task tracking.

This report reflects on the project not simply as a technical task, but as a broader engineering case study. Although the work remained simulation-based, it still raises wider questions about reliability, integration, engineering trade-offs, and the role of robotics within larger technical and societal systems. The report argues that successful robotics development depends not only on technically advanced methods, but on realistic planning, reliable integration, and responsible engineering decisions made within practical constraints. The following sections therefore examine the project through project management and stakeholder dialogue, sustainability and ethics in a wider systems context, simplified life cycle assessment, and failure modes and effects analysis.

II. PROJECT CONTEXT AND MY ROLE

The RoboCup ARM Challenge Project is a simulation-based group project carried out by a team of seven students. Its aim was to develop an integrated UR5e pick-and-place system in Gazebo using MATLAB and ROS, capable of locating objects, planning robot motion, grasping them, and sorting them into the correct bins. Although the project remained entirely in simulation, the final version achieved a mostly working system, which is able to grasp and sort most of the target objects successfully.

My own role was mainly within the motion-planning side of the project. I initially explored a waypoint planning approach, but as the project developed I contributed instead to the joint-space point-to-point planner used for global transfer motions, such as moving the robot to pre-grasp and bin locations. This was the part of the system I can most confidently claim as my technical contribution, although it was developed collaboratively with one teammate rather than fully solo. I also completed some early integration work between the motion-planning stage and the perception output. Beyond the technical work, I also supported some aspects of team coordination and communication. This combination of technical work and partial integration gave me a useful perspective on how the overall system depended not only on individual algorithms, but on reliable coordination between each technical section and between people.

III. PROJECT MANAGEMENT, VALUES THINKING, AND STAKEHOLDER DIALOGUE

A. *Project Management*

One of the main project-management challenges in the RoboCup ARM Challenge Project was the gap between early technical ambition and what could realistically be implemented as a stable system. In my own area, the initial motion-planning direction was more waypoint directed and parabolic in style, but this became difficult to maintain within the wider pipeline because it required too many inverse kinematics solves. The later move towards joint-space point-to-point transfer was therefore not only a technical improvement, but also a project-management decision in favour of a method that was more practical to integrate and complete within the available time.

A second challenge was that the project was not strongly organised from the beginning and only became more focused later in the project. This reduced the time available for refinement and made some decisions more reactive than planned. The proposal had already included planning tools such as Gantt-based scheduling, Trello tracking, weekly milestones, and a shared risk register [5], but the practical lesson was that these tools only added value when they were used consistently and on daily basis [9]. Meetings with the professor were usually the most useful because they gave direction for the project, whereas internally organised meetings became less effective over time as attendance varied and people focused more on their own technical tasks.

B. *Values Thinking*

The clearest value conflict in the project was between technical ambition and reliable integration. Robotics projects naturally encourage ambitious ideas, especially when different team members are exploring perception, inverse kinematics, and motion-planning methods in parallel. However, an approach that looks technically interesting and complex in isolation is not always the best option when the actual objective is to produce a reliable working system. In our case, reliability gradually became the more important value. The system needed to run, connect properly, and complete the sorting task with acceptable consistency, rather than depend on a more complex planning strategy that was harder to maintain. This was also visible in the broader workflow, where perception, grasp estimation, IK, global transfer, and fine approach all had to function together as one chain rather than as separate sections. Values thinking is useful here because it shows that the decision was not simply about choosing the "most advanced" method, but about deciding what mattered most under the real constraints of time and experience.

C. *Stakeholder Dialogue*

The stakeholder dialogue in this project can be understood most clearly through the relationship between the student team and the academic stakeholders, including lecturers, supervisors, and assessors. The practical priority for the student team was to achieve a working demo and make the whole system function together. Academic stakeholders, by contrast, also cared about process, justification, reflection, and good engineering reasoning in particular values thinking, and constructive stakeholder dialogue.

Within the team itself, there were also periods where working relationships became strained, which made collaboration harder than expected. The most useful strategy in that situation was not to force complete agreement, but to move people away from personal frustration and back towards direct communication and shared importance of the project. That approach did not remove every difficulty, but it helped make later collaboration more workable. In reflective terms, this was an important lesson from the project: constructive dialogue in engineering is often less about solving every interpersonal disagreement and more about restoring enough trust and communication for shared technical goals to remain possible [10].

IV. SUSTAINABILITY, ETHICS, AND SYSTEMS CONTEXT

A. *Systems Context*

The wider significance of the RoboCup ARM Challenge Project is best understood by viewing it as more than a simulation exercise. It was an educational robotics project that developed practical skills in perception, manipulation, motion planning, and system integration. This is important because educational robotics has been shown to support STEM learning and student development through hands-on technical problem-solving and integration work [11].

At the same time, the project also reflected a simulation-first model of industrial robotics development. The overall workflow combined object detection, grasp estimation, motion planning, and sorting logic in a way that resembles real automated handling and recycling-style sorting systems. Therefore, the project was not only educational but also a simplified model of how intelligent robotic sorting systems may be designed and tested before physical deployment.

From a systems perspective, this means the project should not be judged only by whether the robot could complete a pick-and-place task in Gazebo. It also connects to wider questions about how robotics supports technical education, how automation may improve industrial productivity and sorting performance, and how this may also create environmental and social trade-offs. The UN's Sustainable Development Goal framework is built around exactly this kind of perspective rather than isolated single-goal thinking [1]. Fig. 1 summarises this systems view by illustrating how technical complexity, integration difficulty, testing coverage, and team coordination influenced reliability through both reinforcing and balancing feedback loops.

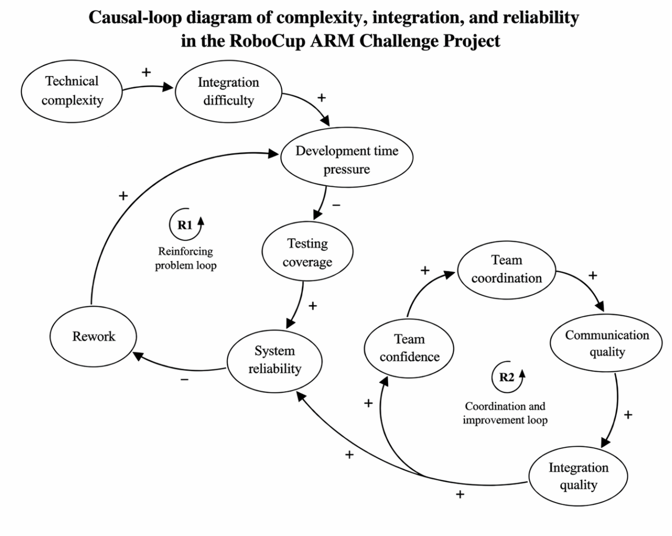

Fig. 1. Simplified causal-loop diagram showing feedback dynamics in the project.

B. *SDG Links and Sustainability Trade-Offs*

A useful way to analyse the sustainability dimension of the project is through the SDG interconnection approach from Lecture 3, which encourages consideration of synergy, trade-off, help, and obstruction relationships rather than a single positive claim. For this project, the strongest positive SDGs are SDG 4 (Quality Education) and SDG 9 (Industry, Innovation and Infrastructure). SDG 4 is relevant because the project functioned primarily as a university robotics platform through which students developed practical skills in sensing, control, planning, and integration, while SDG 9 is supported because robotics and automation directly relate to innovation and future industrial capability [13], [14]. Even though this project remained in simulation, it still represented a small-scale model of how future industrial robotic systems can be developed and tested.

The strongest mixed SDG in this case is SDG 12 (Responsible Consumption and Production). On the positive side, robotics can improve sorting consistency, reduce waste, and support material recovery in applications such as recycling. However, robotics can also generate environmental difficulties through hardware manufacture, electronics, energy use, and eventual e-waste. More broadly, recent research argues that robotics can act as both an enabler and an inhibitor of SDG progress: Haidegger reports enabling effects across many targets, but also slowing effects through inequality and tensions between goals [12].

Using the lecture's interconnection language, SDG 4 helps SDG 9, because better robotics education develops the technical skills needed for future innovation and industrial capability. By contrast, SDG 12 creates a trade-off with SDG 9, because expanding automation capability without lifecycle thinking can increase material and energy burdens. The project therefore has positive direct educational value and indirect innovation value, but it also highlights why sustainability is essential and must be considered early rather than added after technical development is already complete.

C. *Ethical Dilemmas*

The first ethical dilemma relevant to this project is automation efficiency versus labour displacement. Robotic sorting systems can improve consistency and reduce repetitive manual tasks, but automation can also shift or reduce certain forms of labour and may worsen inequality if the benefits are distributed unevenly. Recent work on robotics and the SDGs identifies inequality as one of the main parts where robotics can slow this progress, which makes this concern reasonable even for a small educational project [12].

The second dilemma is innovation and performance versus accuracy, rigour, and responsible validation. Because the project was simulation, it allowed rapid iteration without the cost, risk, and hardware wear associated with constant physical testing. That is a genuine engineering advantage. However, a simulation result should not be overstated as proof of real-world readiness. This creates an ethical tension between presenting a successful technical system and being rigorous about what has and has not actually been validated. The Engineering Council's ethical guidance is directly relevant here because it stresses responsibility to society, accuracy and rigour, and ethical management of technology across its lifecycle [15]. A responsible approach, therefore, is not to reject simulation-first development, but to describe it properly: it is valuable for learning, iteration, and early systems integration, yet still requires further testing before stronger real-world claims can be made.

D. *What an Engineering Company Should Learn*

The broader lesson from this lecture and project is that sustainability should be considered early rather than treated as a late paperwork exercise. For an engineering-intensive company, tools such as SDG mapping, trade-off analysis, and ethical reflection are most useful when they give you the concept development from the start, not after the design is already fixed.

V. SIMPLIFIED LIFE CYCLE ASSESSMENT

This section presents a simplified prospective Life Cycle Assessment (LCA) of a comparable physical pick-and-place system derived from the RoboCup ARM Challenge Project. Because the actual project remained a simulation, this is not intended as a full standards-compliant product LCA, but as a reduced analysis designed to identify likely environmental spots, compare design and development alternatives, and reflect on whether LCA is a suitable method in this case. The approach follows the general lifecycle thinking framework of ISO 14040 and ISO 14044 [2], [3], while remaining appropriately simplified for this work.

The functional unit used here is one hour of operation. This was chosen because it provides a simple and comparable basis for assessing the environmental implications of a robotic sorting system during active use. The system boundary includes the robot arm, controller, end effector, vision sensor, the local workstation running MATLAB together with the VM (ubuntu) simulation environment, and electricity during operation. Transport and further infrastructure were excluded because such data was not available and these elements were outside the scope of a simplified coursework analysis. End-of-life was considered only qualitatively. The inventory was therefore based on a mixture of project evidence, typical UR5e-class component assumptions, and clearly labelled engineering estimates. Table I summarises the simplified inventory.

TABLE I
SIMPLIFIED INVENTORY SUMMARY.

Component	Proxy Type	Est. Mass / Power	Main Relevance
Robot arm	Al/steel electro-mechanical	∼21 kg	Embodied impact
Controller	Steel/electronics enclosure	∼12 kg	Embodied + use
Gripper	Light vs robust scenario	0.5–1.8 kg	Design comparison
Vision sensor	RGB-D camera	∼0.15 kg	Small embodied / e-waste
Workstation	MATLAB + VM load	∼180 W	Use-phase electricity

The most important hotspots are the embodied impact of the robot arm and controller, together with the electricity used by the workstation and robotic system during operation. The workstation was treated as the main computing contributor because it hosted both MATLAB and the VM-based Gazebo/ROS simulation environment, estimated at around

180 W under mixed load, while the gripper and vision sensor contributed much smaller direct operational loads. The main comparison in this simplified LCA was between initial simulation development and more hardware-heavy testing or prototyping. For a fixed hour of steady operation, the environmental burden may be similar regardless of development path, since the same physical robotic system would still consume similar electrical power. However, over the wider project phase, simulation-first development is going to reduce material waste, hardware wear, failed prototype iterations, and the need for replacement parts.

A secondary comparison was made between a lightweight gripper and a heavier, more robust gripper. The lighter option appears preferable in terms of lower embodied material burden, while the heavier option may provide better repeatability and reduce the likelihood of redesign or replacement. This means the result is not one-sided: lower mass alone is not always the main criterion, because reliability, service life, and replacement frequency also matter. Table II summarises both comparisons.

TABLE II
COMPARISON OF SIMPLIFIED LCA ALTERNATIVES.

Comparison	**Lower-Impact Tendency**	**Main Trade-Off**
Simulation-first vs hardware-heavy testing	Reduces prototype waste, spare parts, and hardware wear	May still require substantial workstation energy
Lightweight vs robust gripper	Reduces embodied material burden	Heavier gripper may improve durability and reduce replacement

Overall, this simplified LCA suggests that simulation development can reduce avoidable prototyping burden, lighter and more modular end-effector design may reduce lifecycle impact, and computing and control energy should not be ignored. At the same time, the analysis remains useful but limited because it relies on guessed masses, estimated power values, and simplified boundaries rather than supplier-specific manufacturing data or measured product lifecycles. The results should therefore be interpreted as a comparative and exploratory sustainability analysis rather than a precise carbon footprint.

VI. FAILURE MODES AND EFFECTS ANALYSIS

A Failure Modes and Effects Analysis (FMEA) was applied to identify credible failure mechanisms affecting simulation and demonstration reliability for the robot arm built with MATLAB, ROS, and Gazebo. The focus is on task failure, rework, timing risk, and integration behaviour rather than industrial safety or injury scenarios. Scoring uses severity (S, 1–5), occurrence (O, 1–5), and detection (D, 1–6), with RPN = S × O × D as introduced in the module lecture [4].

A. Selection of Failure Modes

Three key details were selected to reflect different aspects of the project. The first is the **choice of motion-planning approach for global transfers**, treated as a design-stage risk that informed the later move toward joint-space point-to-point transfers. This was chosen because global moves constrain cycle time, solver load, and integration complexity, and an early IK-heavy strategy posed a real risk of rework and impractical integrated motion. The second is **depth/PCA-based grasp pose estimation**, selected because grasp pose quality the main drive to success, repeated attempts, and sorting performance when objects are noisy, symmetric, or awkwardly oriented. The third is **perception-to-motion handoff**, selected because full reliability often fails where modules are individually plausible but frames, interfaces, or validation are inconsistent across the ROS/MATLAB split pipeline. Table III summarises the results.

B. Discussion

The highest RPN belongs to the depth/PCA grasp pose estimation item (RPN = 48), because both occurrence and detection scores are relatively high: grasp errors occur repeatedly on difficult objects and orientations, and they are often only detected at the point of a failed grasp rather than through a dedicated pre-check. The main causes include noisy or incomplete depth data, PCA axis mistakes on symmetric or slender objects, and several calibration errors. The recommended mitigations include pre-grasp validation, improved depth filtering and outlier rejection, and sanity checks on the principal axes before committing to a grasp pose.

The motion-planning method item (RPN = 24) has a lower RPN primarily because its detection score is low: integration profiling and early testing tend to surface impractical IK solve budgets before the final demo. This item is treated as a design risk rather than a logged operational failure, and it documents the recognised risk that informed the shift from the initial waypoint method to the new joint-space point-to-point. The recommended response is to prefer scalable joint-space transfers for global moves and to validate motion early in the project.

The perception-to-motion handoff item (RPN$\cong\tilde{2}$7) sits between the other two. The main causes include mismatches between MATLAB and ROS coordinate frames, missing checks for invalid or out-of-range values, and the time differences between components. Recommended improvements include clearly defining frames, units, and timestamps, checking that target poses are inside the valid workspace before execution, and adding a full integration tests so the full perception-to-motion pipeline can be verified without manual correction.

C. Design Implications

The FMEA supports three main design lessons. Motion-planning strategies should be validated for feasibility and integration cost early, grasp pose estimation requires explicit validation and filtering steps, and interface contracts and integration tests are as important as subsystem performance.

TABLE III
SIMPLIFIED FMEA SUMMARY FOR THE ROBOCUP ROBOT ARM CHALLENGE.

Item	**Failure Mode**	**Main Effect**	**RPN**	**Recommended Action**
Motion-planning method (global transfer)	Retaining an IK-heavy or impractical global motion strategy	Redesign, time loss, unreliable motion stage until approach changed	24	Joint-space P2P global transfers; early feasibility validation; reduce unnecessary IK
Depth/PCA grasp pose estimation	Wrong or unstable grasp pose from depth noise or PCA ambiguity	Failed pick, retries, lower sort success	48	Grasp validation, depth filtering, pose and axis sanity checks
Perception–motion handoff	Frame, interface, or validation gap between perception and motion	Wrong pre-grasp, erratic execution, end-to-end unreliability	27	Explicit interface contract, frame checks, full integration tests

RPN = S × O × D (judgement estimates; full scoring in Appendix B).

These lessons are consistent with the broader argument of this report: reliable robotics engineering depends on integration, validation, and practical design decisions, not only on phenomenal practical work.

VII. CONCLUSION

This report has argued that the RoboCup ARM Challenge Project should be understood as more than a technical simulation exercise. Although the project focused on a UR5e-based pick-and-place system in MATLAB, ROS, and Gazebo, in the end it showed that its success depended not only on perception, motion planning, and grasp execution, but also on project organisation, communication, sustainability thinking, and risk awareness.

The clearest overall lesson from the project was that reliable integration mattered more than ambitious ideas. A robotics system can contain technically interesting components, but this has limited value if those components do not work together reliably in the end. The project also showed that teamwork and communication are not secondary concerns, but practical engineering requirements, since technical progress depends on people being able to cooperate effectively as well as on the quality of their work.

The reflective frameworks used in this report reinforced that lesson. The sustainability and ethics analysis showed that even a simulation-based robotics project sits within a wider educational, industrial, and societal context. The simplified LCA and FMEA further showed that design choices carry environmental and reliability consequences that are easier to address when they are considered early, rather than later.

From a personal perspective, the project taught me that better planning from the start would likely have improved the final result. If I were to repeat the project, I would organise team coordination earlier and validate the feasibility of key motion-planning choices before committing too much time to them. Finally, the project demonstrated that good engineering is not defined only by technical capability, but by the ability to combine design, reliable integration and effective teamwork.

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APPENDIX

TABLE IV
FULL SIMPLIFIED LCA INVENTORY.

Component	Proxy Type	Est. Mass/Power	Use-Phase Relevance	End-of-Life Note
Robot arm (UR5e-class)	Al/steel structure; motors; gearboxes	∼21 kg	100–350 W depending on speed/load	Metals recyclable; electronics via WEEE
Controller / cabinet	Steel enclosure; PCBs; power electronics	∼12 kg	∼100–200 W when energised	WEEE; some steel scrap
Gripper (parallel 2-finger)	Al fingers; steel fasteners; small actuator	0.5–1.8 kg	∼2–10 W	E-waste + metal mix
Vision sensor (RGB-D)	ABS/PC housing; glass; PCB	∼0.15 kg	∼2–5 W USB-powered	WEEE; small plastic
Mounting / cabling	Al extrusion; copper cables; PVC	∼1.5 kg	Negligible direct power	Mixed metals/plastics
Workstation / PC	Steel case; PCBs; PSU	∼12 kg	∼180 W mixed load	WEEE; PSU complexity
Operation electricity	Grid electricity (aggregate)	Sum of above × 1 h	Primary use-phase line	N/A

TABLE V
DETAILED LCA SCENARIO COMPARISON.

Scenario	Element	Baseline	Alternative	Direction
C: Sim-first vs hardware-heavy	Prototyping burden	Lower scrap/spares when iterating in simulation	Higher scrap from prints, spare fingers, revised brackets	Alt. higher
	Hardware wear	Lower joint/collision hours during early development	Higher stress cycles and collision risk during bring-up	Alt. higher
	Material waste (project phase)	Lower mass to landfill from fewer failed trials	Higher waste from discarded prototypes	Alt. higher
	1 h operation electricity	Set by metered kWh for chosen duty	Same FU definition	Neutral
A: Light vs robust gripper	Gripper mass	∼0.5 kg simple/light build	∼1.8 kg robust/COTS-class	Alt. higher embodied
	Durability trade-off	May slip; more mis-grasps; higher redesign risk	Better repeatability; fewer drop failures; longer service	Context-dependent
	Use-phase electricity	Negligible difference vs baseline	Negligible unless motion profiles change	Neutral

TABLE VI

FULL FMEA WORKSHEET.

Item	**Function**	**Failure Mode**	**Effect**	**S**	**Cause**	**O**	**Current Controls**	**D**	**RPN**	**Recommended Action**
Motion-planning method (global transfer)	Select and implement global transfer motions between task configurations in the integrated pipeline	Design-stage risk: persisting with an IK-intensive or over-decomposed global motion approach unsuitable for reliable integrated motion generation	Computational inefficiency; difficult integration; motion stage unreliable until replanned; project rework and schedule pressure	3	Underestimated IK/solve budget; late profiling; planner chosen before end-to-end constraints understood	4	Simulation profiling; design review; comparison to simpler P2P baseline; early integration tests	2	24	Adopt scalable joint-space P2P transfers; validate feasibility early; reduce unnecessary IK dependence
Depth/PCA grasp pose estimation	Estimate feasible pre-grasp pose from depth data and PCA-based geometric inference	Incorrect or unstable grasp position/orientation due to depth noise, PCA axis degeneracy or ambiguity, poor fit to object geometry	Failed pickup or slip; repeated attempts; wrong or missed sort; degraded demo performance	3	Noisy or incomplete depth; symmetric or slender objects; partial occlusion; weak PCA fit; residual calibration errors	4	Visual inspection in RViz/Gazebo; threshold tuning; repeated simulation trials; ground-truth checks where available	4	48	Pre-grasp validation (reachability, clearance); depth filtering and outlier rejection; sanity-check principal axes; conservative retry patterns
Perception–motion handoff	Pass perception outputs into motion generation and execution with consistent semantics and timing	Interface mismatch; incorrect frame; stale or unvalidated pose passed to motion module despite locally plausible perception	Wrong pre-grasp target; incorrect motion execution; intermittent end-to-end pipeline failure	3	TF/camera-to-base inconsistency; topic or message schema drift; missing NaN/range guards; async between MATLAB and ROS	3	Static TF checks; logging of intermediate poses; stepwise replay in simulation; manual inspection of published targets	3	27	Explicit interface contract (frames, units, timestamps); assert workspace limits; end-to-end integration tests; validate before execute

S: 1–5, O: 1–5, D: 1–6 (1 = almost certain detection, 6 = undetected). All scores are judgement-based coursework estimates.