EASTERN MEDITERRANEAN UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

Course Code: MENG233
Course Name: DYNAMICS
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Assessment: Project
Submission Date:

PROJECT: Design and Development of a Robotic Arm

GROUP NO. : .....
STUDENT NO: ..... NAME, SURNAME: .....
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SECTIONS:

No.	STUDENT OUTCOMES	COURSE LEARNING OUTCOMES	WEIGHT OF SECTION /100	MARKS OBTAINED	REMARKS
S-0	1, 5, 7	5	10		Abstract, References, Appendices
S-1	1, 5, 7	5	10		
S-2	1, 5, 7	5	10		
S-3	1, 5, 7	5	10		
S-4	1, 5, 7	5	10		
Simulation	1, 5, 7	5	25		
Prototype	1, 5, 7	5	25		
TOTAL:(Out of 100)					

Course Learning Outcomes		Student Outcomes						
		1	2	3	4	5	6	7
1	Analyze the kinematics of particles	X						
2	Analyze the kinetics of particles using: (force and acceleration, principle of work and energy, or principle of impulse and momentum)	X				X	X	
3	Analyze the planar kinematics of rigid bodies (Relative motion analysis: velocity and acceleration)	X				X	X	
4	Analyze the planar kinetics of rigid bodies using: (force and acceleration, principle of work and energy, or principle of impulse and momentum)	X						
5	Use the techniques learned to model and analyze a dynamic system.	X				X	X	X

Instructions:

1. Late submissions will be penalized with 10 marks/ day.
2. Draw neat, labeled diagrams where necessary.
3. Write relevant equations and write your Assumptions where necessary.
4. Be clear and specific and include units. Give explanatory notes where necessary. Please carry out each step explicitly.
5. Please provide the references using APA Style of Referencing.
6. References should be from the Textbook or from an authentic source.
7. Please include the equations, diagrams, plots and figures in the report.
8. All figures and Tables must be numbered and captioned.
9. Please submit the pdf Soft copy of the report via the MOODLE LMS/ Microsoft Assignment along with the MATLAB codes, Simulink. AVI File. Code/ Simulation etc.
10. The file/ folder uploaded should be named as [MENG233-PROJECT-GROUP NO]. Files with any other name or format will be disregarded. Do not forget the cover page Files with any other name or format will be disregarded. Do not forget the cover page.

ABSTRACT

Abstract and Keywords

An abstract summarizes, usually in one paragraph of 300 words or less, the major aspects of the entire paper/report in a prescribed sequence that includes: 1) the overall purpose of the study and the research problem(s) you investigated; 2) the basic design/approach of the study; 3) major/key findings or trends found as a result of your analysis; and, 4) a brief summary of your interpretations and conclusions.

SECTION 1 - INTRODUCTION

Introduction of the Mechanism
History of the Mechanism
Applications of the Mechanism
*Please provide reference information i.e. using proper citation.

SECTION 2 – MODEL

Working of the Mechanism - Working Principle
*Mathematical Model (Kinematics and/or Kinetics Models) used with reference to the equations in the textbook and other reliable sources.
Model of the Mechanism (can be modelled, designed in CAD Software, SIMSCAPE etc)
Prototype of the Mechanism
Materials and Manufacturing Process
*Prototype can be modelled, designed in CAD Software and manufactured using Plexiglass, Balsawood or 3D Printing.
*Hydraulic, Pneumatic or Motor Actuators can be used accordingly to demonstrate the working of the Mechanism.
*Please use labelled Diagrams, Figures, Graphs, Tables, etc.

SECTION 3 – ANALYSIS

Results - Results of the Velocity, Acceleration, Force, analysis etc. using Figures, Graphs, Tables, etc.
Discuss the Kinematics, Kinetics pf the system.

SECTION 4 - CONCLUSION

The conclusion is intended to help the reader understand why your research should matter to them after they have finished reading the report/paper. A conclusion is not merely a summary of the main topics covered or a re-statement of your research problem, but a synthesis of key points and, if applicable, where you recommend new areas for future research.

REFERENCES

All references on APA Style Format and must also be cited in text in Author (Year) format.

APPENDIX

CAD MODELS, Drawings, Sketches
Prototype of the Mechanism
Simulation (if any)
MATLAB CODES (if any)
SIMULINK MODELS (if any)
SIMSCAPE MODELS (if any)

USE OF ARTIFICIAL INTELLIGENCE

Generative AI tools may be used in this project as learning and drafting aids. They do not replace your own engineering judgement. This course follows the **AI Fluency Framework** (Dakan & Feller, 2025), which describes four connected competencies for working with AI effectively, efficiently, ethically and safely: **Delegation, Description, Discernment and Diligence** (the "4Ds").

Apply the 4Ds every time you use an AI tool for any part of the project. The free-body diagrams, assumptions, calculations, simulation set-up, measurements, interpretation and conclusions must be your own work, and you must be able to explain and defend all of it at the individual viva voce. The companion handout, *AI Fluency Step-by-Step Guide – MENG233*, gives a worked example of all four Ds for every section of this report. Read it before you write your first draft.

How AI use is assessed

- **Disclosure:** a complete "Use of Artificial Intelligence" section and the AI Use & 4D Log, placed immediately after the References.
- **Verification:** each log entry states what you checked and what you checked it against.
- **Ownership:** every team member explains the work, including any AI-assisted parts, in the individual viva voce.
- **Limit:** AI-generated content must not exceed 20% of the total word count of the report.

The 4Ds applied to this project

Table 1. *The four AI Fluency competencies and what each one requires in MENG233.*

Competency	Question to ask	What to do in this project	Evidence you provide
Delegation	Should AI do this task at all, and how?	Decide **before** opening an AI tool which tasks to hand over (outlines, code templates, checklists, formatting) and which to keep (free-body diagrams, assumptions, equations, design choices, measurements, interpretation, conclusions).	Log entry marked "Delegation" with a one-line reason.
Description	Have I given the AI enough accurate context?	Give your real configuration: joints, link lengths, servos, budget and data. State the task, the constraints, the output format and what the AI must **not** do (for example, "do not interpret the cause"). Refine the prompt and repeat.	Keep the main prompts and replies you rely on; you may be asked to show them.
Discernment	Is the output correct, relevant and complete?	Check results against your own hand calculations, the textbook, datasheets, the simulation and your measurements. Open every suggested source. Check units, zero-angle cases and joint limits.	Log entry stating what you checked and against what.
Diligence	Am I ready to take responsibility for the result?	Disclose every use, log it as you go, own the final text, code and numbers, and make sure each team member can explain them. Do not share other people's work or personal data with AI tools without permission.	"Use of Artificial Intelligence" section, the log and the viva voce.

What AI may and may not be used for

Table 2. Permitted, conditional and prohibited uses of AI tools.

Permitted (disclose and log)	Permitted only after you verify	Not permitted
• Brainstorming alternative arm configurations • Explaining a concept you find unclear • Outlines for the abstract, results tables and test logs • Template code (Arduino, MATLAB) that you then test and tune • Debugging help and language editing of text you wrote • A second opinion on a derivation you did yourself	• Equations and derivations (DH parameters, kinematics, torque) • Component data (servo torque, mass, price) • Historical facts, dates and application examples • Simulation parameters and joint limits • Any reference or link the AI suggests	• Submitting AI-written analysis, discussion or conclusions as your own • AI-generated or invented data, plots, test results or prototype photographs • References you have not opened and read • Using AI during the viva voce • Uploading other people's work or personal data to AI tools without permission

AI use by report section

The table shows, for each graded part of the project, what you may hand to an AI tool as a starting point, what you must keep for yourself, and what you must verify before using any AI output. Examples for every row are in the AI Fluency Step-by-Step Guide.

Table 3. AI use, ownership and verification for each section of the report.

Section	May delegate (starting point only)	Keep for yourself	Verify before use
S-0 Abstract, References, Appendices	A four-part abstract outline with placeholders; formatting of the APA list.	The final abstract, written after your results exist; the choice of every reference.	Open and read each source and confirm authors, year and DOI. Run every file in the Appendix and confirm it reproduces the reported results.
S-1 Introduction	General background and a list of typical pick-and-place applications to research further.	Choice of sources; the history and applications written in your own words.	Check every date, name and claim against a textbook, journal paper or reputable engineering source, and cite that source, not the AI.
S-2 §2.1 Working principle	A general explanation of how a serial arm turns servo rotations into end-effector motion.	The description of your own joint arrangement (base, shoulder, elbow, wrist pitch, gripper).	Confirm the AI describes your joints in your order and DOF, not a different arm.
S-2 §2.2 Mathematical model	Template code for a DH table and transformation matrices, after you define joints and link lengths.	Free-body diagrams, assumptions (rigid links, negligible friction), equations from the textbook, link lengths.	Zero-angle test; singular configurations; compare the hand derivation with the Simscape result.
S-2 §2.3 CAD and simulation model	A general checklist for importing a CAD assembly with smimport.	The CAD design, joint definitions and constraints.	After import, rotate every joint in Mechanics Explorer and confirm its type, axis and limits.
S-2 §2.4 Prototype, materials, manufacturing	A first comparison of materials (acrylic, balsa, 3D-printed PLA) and actuator types.	The final selection, supported by your own torque calculation and cost.	Ask for the worst-case torque calculation and check the servo rating against the datasheet.
S-3 Analysis	The layout of results tables and charts.	All values (from your simulation and tests), their interpretation and the discussion.	Investigate any discrepancy yourself (joint limits, saturation, units) before accepting an AI explanation.
S-4 Conclusion	A typical structure for a conclusion.	The conclusions: what worked, what did not, why, and what to do next.	Every statement can be traced to your own measured results.

Section	May delegate (starting point only)	Keep for yourself	Verify before use
Simulation (25%)	General guidance on the Simscape Multibody workflow, such as torque input versus motion input.	The model, joint set-up, actuator inputs and trajectories.	Match every joint limit and actuator parameter to the real servo; compare with your forward-kinematics hand calculation.
Prototype (25%)	An Arduino code outline with named motion states; the layout of the test log.	Servo angles and timing tuned by testing; all measurements; the build itself.	Test any suggested timing or tuning value on your own hardware. Every member can explain the code.

Worked example: a strong prompt and the check that follows

Weak prompt (avoid)
"Derive the kinematics for my robot arm." The result is a general textbook derivation that may not match your joints or your DH convention.

Strong prompt (use instead)
"For a planar arm with shoulder, elbow and wrist-pitch joints, link lengths L_1 = 0.11 m, L_2 = 0.11 m, L_3 = 0.06 m, and an extra base rotation ϕ, derive the forward kinematics using the standard DH convention. Show the transformation matrix for each joint and the final end-effector position. State every assumption."

Discernment check you must carry out
Set $\theta_1 = \theta_2 = \theta_3 = 0$ in the AI's result. The end-effector must lie 11 + 11 + 6 = **28 cm** from the shoulder axis. Any other value means the derivation contains an error. Then compare it with your hand calculation and with the Simscape result.
Log entry: ChatGPT · S-2, §2.2 · Discernment · "Verified AI-derived DH matrices against the zero-angle configuration by hand."

Common AI pitfalls in this project

Table 4. *Typical failure modes and how to catch them.*

Pitfall	Why it happens	How to catch it
Sign or joint-order errors in DH matrices	A swapped joint order can still give a plausible-looking Jacobian.	Check the zero-angle case and the singular configurations against your own derivation.
Invented historical or technical claims, or references	AI states dates, facts and citations with the same confidence whether they are accurate or not.	Verify against a real, checkable source before citing. Open every reference and read it.
Servo chosen without a torque margin	AI may recommend a servo without showing the calculation behind it.	Ask for the worst-case moment-arm calculation and repeat it yourself.
Simulation limits that do not match the hardware	AI-suggested joint and actuator parameters may be general defaults.	Match every simulation parameter to the real servo's specification.
Explained-away test or analysis results	AI writes a believable explanation for a result it never saw tested.	Investigate against your own set-up and data before accepting any explanation.

Disclosure: the "Use of Artificial Intelligence" section

Students must explicitly state the use of AI-generated text, data analysis, visuals, code or other content in their report under the heading "Use of Artificial Intelligence", placed **immediately after the "References"** section. The statement must name each AI tool used (for example ChatGPT, Claude, Gemini, DeepSeek or Midjourney) and the purpose for which it was used, and it must be supported by the AI Use & 4D Log below. AI-generated content must not exceed **20%** of the total word count of the report.

> **Example statement**
> "In this study, [AI tool] was used for [purpose, e.g., drafting an initial abstract structure and an Arduino code outline]. [What you verified and how, e.g., all equations were re-derived by hand and checked against the Simscape model; every reference was opened and read.] The authors reviewed and edited all content and take full responsibility for the report."

AI Use & 4D Log

Record every meaningful AI interaction **as you go**, straight after it happens, not at submission time. Add rows as needed. The first row is an example; replace it with your own entries.

Table 5. *AI Use & 4D Log (to be completed by each group and placed after References).*

S. No.	AI Tool Used	Section	Section No.	Page No.	4D Competency	Purpose of use and what you verified
Ex.	*ChatGPT*	*S-2: Model (Kinematics)*	*2.2*	*5*	*Discernment*	*Derived DH transformation matrices; checked them by hand against the zero-angle configuration*
2						
3						
4						
5						
6						
7						
8						

Viva voce and academic integrity

- Each team member is questioned individually and must be able to explain any part of the report, simulation, code or prototype, including parts that AI helped to produce.
- Content that you cannot explain, results that you cannot reproduce, or references that do not exist may be reflected in your individual marks.
- Undisclosed or misrepresented AI use may be handled under the university's academic integrity regulations.

PROJECT GUIDELINES:

Design and Development of a Low-Cost Multi-Degree-of-Freedom Robotic Arm for Ping-Pong Ball Pick-and-Place

1. Project Overview

This project challenges undergraduate engineering students to **design, build and experimentally validate a low-cost multi-degree-of-freedom (DOF) robotic arm** that can grip, lift, transfer and place a ping-pong ball with reasonable repeatability and accuracy. The complete system must be developed under a **strict budget of approximately 100 USD**. This encourages cost-effective solutions, efficient mechanical designs and creative problem solving.

The project is the applied part of MENG233 Dynamics. Its central task is to model and analyse the motion of a multi-link rigid-body system with the kinematics and kinetics taught in the course (Beer et al., 2019; Hibbeler, 2016), and then to check the model by simulation and by experiment. It also brings together:

- mechanical design and structural analysis
- actuator selection and torque estimation
- robot kinematics and motion planning
- embedded system programming
- control implementation and experimental validation

A **4-DOF arm with a simple 1-DOF gripper** is recommended. It is capable enough for pick-and-place work and still feasible within the cost and time limits. Low-cost manipulators are widely used in undergraduate teaching of kinematics, motion control and system integration (Čehovin Zajc et al., 2023; Markvicka et al., 2023).

MATLAB Simscape Multibody lets you build, simulate and test mechanical systems, including robotic manipulators, in a virtual environment (MathWorks, n.d.-a). Simulating the arm before fabrication lets you examine link motion, actuator loads and joint trajectories, which reduces design errors and improves reliability.

Supplementary video tutorials

The videos below are learning aids that show similar systems. They are not technical sources: in your report, cite textbooks, journal papers, datasheets or manufacturer documentation instead.

Table 6. *Supplementary video tutorials.*

Title	What it shows	Link
Build a 4 DOF Robotic Arm with Arduino | Servo + Joystick Control	A 4-DOF arm with servo motors and Arduino control performing pick-and-place.	youtube.com/watch?v=o89WD4vNm5U
Pick and Place Robot using Arduino | DIY Arduino Project	Four servo motors coordinating a simple pick-and-place operation.	youtube.com/watch?v=ew--i5Sx-hU
Pick-and-Place Arm Robot Simulation | MATLAB Simulink Simscape Multibody	How to simulate an arm before building it.	youtube.com/watch?v=cg6XhRoXxd4

2. Project Aim

The primary aim is to develop a robotic manipulator that can:

- reach a defined pickup location
- grasp a ping-pong ball without damaging it
- transport it to a designated drop location
- release it accurately in a target zone

The final system should demonstrate **reliable and repeatable pick-and-place operation** while keeping cost low and the mechanism simple.

3. Learning Objectives

On completing this project, students should be able to:

- apply the kinematics and kinetics of rigid bodies from MENG233 to a real multi-link mechanism
- design articulated robotic mechanisms with several joints
- perform basic torque calculations and select actuators
- model robotic arms with CAD tools
- apply forward and inverse kinematics
- develop embedded control software for servo motors
- design grippers for fragile objects
- simulate robotic systems with MATLAB Simscape
- evaluate system performance by experiment
- use AI tools responsibly, and document that use, following the AI Fluency Framework (Dakan & Feller, 2025)

The project assesses Course Learning Outcome 5 (use the techniques learned to model and analyse a dynamic system), which builds on Outcomes 1 to 4, and contributes to Student Outcomes 1, 5 and 7 as shown on page 1.

4. Recommended System Configuration

Table 7. *Recommended joints and degrees of freedom.*

Joint	Degrees of freedom	Function
Base rotation	1	Turns the whole arm about a vertical axis to select the pick and drop directions.
Shoulder	1	Raises and lowers the arm; carries the largest torque.
Elbow	1	Sets the reach by folding and extending the second link.
Wrist pitch	1	Keeps the gripper orientation suitable for picking and placing.
Gripper open/close	1	Holds and releases the ball.

This gives a **4-DOF manipulator plus a 1-DOF gripper**, enough for tabletop pick-and-place.

Suggested performance targets

Table 8. *Suggested performance targets.*

Parameter	Target
Object	Standard ping-pong ball (about 2.7 g)
Reach	20–30 cm
Placement accuracy	Within about 1–2 cm
Cycle time	10–20 s
Success rate	At least 80–90% during testing

5. Design Philosophy

Although the ping-pong ball is very light, the system must give:

- stable motion
- repeatable positioning
- gentle gripping
- structural rigidity

The design should therefore prioritise:

- lightweight links
- rigid joints
- balanced mass distribution
- smooth servo control
- compliant gripping surfaces

Low-cost arms usually use hobby servos because they are cheap and easy to control (Al Tahtawi et al., 2021). The **MG996R** (stall torque about 9.4 kgf·cm at 4.8 V and 11 kgf·cm at 6 V; mass about 55 g; TowerPro, n.d.-a) suits the base, shoulder and, if the torque calculation requires it, the elbow. The smaller **SG90** (about 1.8 kgf·cm; 9 g; TowerPro, n.d.-b) suits the wrist and the gripper. Check the figures against the datasheet of the servo you actually buy, because suppliers differ.

6. Role of Simulation Using MATLAB Simscape

Before fabrication, model the arm in **MATLAB Simscape Multibody**. The software builds 3-D multibody models of links, joints and actuators, so that you can simulate motion and judge mechanical behaviour under different operating conditions (MathWorks, n.d.-a). A typical workflow is:

1. Build the mechanical model (or import your CAD assembly).
2. Define the joint types, axes, limits and constraints.
3. Apply actuator torques or joint angles (motion inputs).
4. Simulate the motion trajectory for a full pick-and-place cycle.
5. Visualise the motion in 3-D and record joint angles, velocities, accelerations and torques.
6. Compare the results with your hand calculations and, later, with experiments.

MathWorks provides a pick-and-place example that uses forward and inverse kinematics inside a Simscape Multibody simulation. It models a delta robot rather than a serial arm, but the approach can be adapted (MathWorks, n.d.-b). If you build your arm in CAD, the *smimport* function converts the assembly into a simulation model (MathWorks, n.d.-c).

> **Simulation checklist**
> - Joint limits equal those of the real servo you selected.
> - Masses and inertias come from your CAD model or measured parts, not default values.
> - Units are consistent (SI) throughout.
> - Each imported joint has the correct type and axis (rotate it in Mechanics Explorer to confirm).
> - Zero-angle pose reproduces the fully extended reach from your hand calculation.

7. Dynamics Analysis Requirements

To earn credit for the Model and Analysis sections, your work must apply MENG233 theory. The minimum content is listed below; the textbook basis is Hibbeler (2016) and Beer et al. (2019), together with Craig (2005) for robot kinematics.

Table 9. *Minimum analysis content.*

Analysis	What to do	Where it appears
Forward kinematics and reach	Derive the end-effector position as a function of the joint angles. Plot the reach envelope (workspace).	S-2 Model; S-3 Analysis
Velocity and acceleration	Use relative-motion analysis for at least one complete pick-and-place trajectory. Compare with the simulation output.	S-3 Analysis; Simulation
Kinetics	Find the static torque at the worst-case posture (arm horizontal). Find the dynamic torque with the equations of motion for the rigid links. The work–energy method may be used as a check.	S-2 Model; S-3 Analysis
Actuator check	Compare the peak torque with the servo stall torque. A margin of at least 2 is recommended for dynamic loads and wear.	S-2 §2.4; S-3 Analysis
Experimental validation	Compare simulated and measured joint angles, cycle time and placement accuracy.	S-3 Analysis; Prototype

Forward kinematics of the arm

Let ϕ be the base rotation, h the height of the shoulder axis above the base, θ_1 the shoulder angle measured from the horizontal, and θ_2 and θ_3 the elbow and wrist angles measured relative to the previous link. The radial reach r and the height z of the gripper tip are

$$r = L_1 \cos\theta_1 + L_2 \cos(\theta_1+\theta_2) + L_3 \cos(\theta_1+\theta_2+\theta_3)$$

$$z = h + L_1 \sin\theta_1 + L_2 \sin(\theta_1+\theta_2) + L_3 \sin(\theta_1+\theta_2+\theta_3)$$

and the tip position is $x = r\cos\phi$, $y = r\sin\phi$. With all joint angles equal to zero, $r = L_1 + L_2 + L_3$. For L_1 = 11 cm, L_2 = 11 cm and L_3 = 6 cm this gives a maximum reach of **28 cm**, inside the 20–30 cm target. If your own numbers give 12 cm or 45 cm, revise the link lengths before going further.

Worked example: worst-case static torque at the shoulder

The worst case is the arm fully extended and horizontal. The masses and distances below are illustrative; replace them with the values of your own design. The torque of each item is its weight (m g, with g = 9.81 m/s²) multiplied by its horizontal distance from the shoulder axis.

Table 10. *Illustrative static torque calculation about the shoulder axis.*

Item	Mass (g)	Distance from shoulder axis (cm)	Torque (N·m)
Link 1 (own mass)	15	5.5	0.008
Elbow servo	55	11	0.059
Link 2 (own mass)	15	16.5	0.024
Wrist servo	45	22	0.097
Gripper and its servo	60	28	0.165
Ping-pong ball	2.7	28	0.007
Total shoulder torque			**0.36 (≈ 3.7 kgf·cm)**

A MG996R servo with a stall torque of 9.4 kgf·cm (4.8 V) corresponds to about 0.92 N·m, which is roughly **2.6 times** the required torque (3.0 times at 6 V, with its 11 kgf·cm rating). This is a reasonable margin for dynamic loads and

wear. If your own calculation gives a torque close to the servo rating, reconsider the link lengths, the materials or the servo before building.

8. Key Technical Challenges

The project exposes you to realistic engineering problems.

8.1 Torque and load distribution

Even with a light payload, the proximal joints must carry the downstream links, the motors and wiring, and the gripper components. Estimate the joint torques (Section 7) and select actuators accordingly.

8.2 Structural rigidity

Low-cost materials such as plywood or acrylic can flex, which reduces positioning accuracy. Measure the deflection at maximum reach (Test 2).

8.3 Servo backlash

Inexpensive hobby servos can have backlash, which affects repeatability.

8.4 Gripper design

The ping-pong ball is smooth and light, so reliable grasping is difficult. A recent systematic review notes that holding fragile objects with the correct force remains a limitation of many grippers (Hernandez et al., 2023). An effective gripper should have:

- curved finger surfaces
- soft rubber or foam padding
- moderate gripping force

8.5 Motion coordination

Joint movements must be coordinated to place the end-effector precisely. Use either inverse kinematics or predefined motion sequences (Al Tahtawi et al., 2021).

9. Recommended Materials and Components

Table 11. *Indicative component list and cost (USD).*

Component	Quantity	Unit cost (USD)	Subtotal (USD)
Arduino Nano or compatible	1	6–8	6–8
MG996R high-torque servos	2–3	8–10 each	16–30
SG90 micro servos	2	2–3 each	4–6
Power supply (5–6 V)	1	8–12	8–12
Structural materials (plywood, acrylic or PLA)	set	10–15	10–15
Mechanical fasteners and brackets	set	8–12	8–12
Rubber pads or foam for the gripper	set	3–5	3–5
Breadboard and wiring	set	5–7	5–7
Itemised subtotal			**60–95**

Together with a reserve for spare servos and replacement parts, the expected total project cost is **75–100 USD**. Prices are indicative; include your own bill of materials with actual prices in the report.

10. Mechanical Design Recommendations

Link lengths

Table 12. Suggested link lengths.

Link	Suggested length	Reason
Link 1 (shoulder to elbow)	10–12 cm	Shorter links reduce the torque requirement and improve stability.
Link 2 (elbow to wrist)	10–12 cm	Together with Link 1, gives the 20–30 cm target reach.
Wrist link	5–7 cm	Keeps the gripper mass close to the shoulder.

Base design

The base should be rigid and heavy enough to prevent tipping during arm motion.

Gripper design

A **two-finger parallel gripper** is recommended. Key features:

- curved gripping surfaces
- rubber padding for friction
- a closing angle large enough to cradle the ball

11. Control Strategy

Two control approaches can be used.

Option 1: predefined motion sequence

Define the joint angles manually for the key positions: **home → approach → pickup → lift → drop → release**. This method is simple and reliable.

Option 2: coordinate-based motion

Implement simplified inverse kinematics to compute the joint angles from Cartesian coordinates. Validate the method in MATLAB simulation before running it on hardware. MathWorks provides a video on designing a pick-and-place application with MATLAB and Simulink that can be adapted for an educational arm (MathWorks, n.d.-d).

12. Suggested Development Stages

Table 13. Development stages and the evidence each produces.

Stage	Activity	Evidence for the report
1 – Concept development	Develop alternative arm configurations.	S-2: concept comparison
2 – Preliminary analysis	Torque estimation, workspace analysis and servo selection.	S-2 and S-3: calculations
3 – CAD modelling	Model the arm in CAD software.	S-2 and Appendix: CAD models, drawings
4 – Simulation	Import the CAD assembly into Simscape with smimport (MathWorks, n.d.-c) and simulate.	Simulation: model files, plots
5 – Fabrication	Manufacture the structural parts and assemble the arm.	Prototype; S-2 materials and manufacturing
6 – Electronics integration	Install the servos and microcontroller.	Prototype: wiring diagram

Stage	Activity	Evidence for the report
7 – Programming	Implement the motion sequences and test each joint.	Appendix: control code
8 – Experimental testing	Run the repeatability and pick-and-place experiments.	S-3 and Prototype: test results

AI reminder: add an entry to the AI Use & 4D Log at the end of every stage in which an AI tool helped.

13. Testing Plan

Test in progressive stages. Record every trial in a table (trial number, result, measured error, time).

Table 14. *Testing plan and pass criteria.*

Test	Purpose	Procedure	Target / pass criterion
1 – Servo calibration	Verify the joint angle limits.	Sweep each joint through its full range and record the limits.	No mechanical binding at the limits.
2 – Static stability	Evaluate structural deflection.	Load the arm at maximum reach and measure the deflection.	Deflection within the placement-accuracy tolerance.
3 – Repeatability	Measure positional deviation.	Repeat the same motion sequence several times.	Within about ±1–2 cm.
4 – Gripper reliability	Test gripping without arm motion.	Grip and release the ball repeatedly with the arm stationary.	No drops across repeated trials.
5 – Integrated pick-and-place	Full-system performance.	Perform at least **10 complete** pick-and-place cycles.	80–90% success rate; 10–20 s cycle time.

Performance metrics: success rate, placement accuracy, cycle time and number of dropped objects.

14. Risk Mitigation and Cost Control

To keep the project feasible:

- minimise unnecessary sensors
- keep link lengths short
- prototype the gripper early
- maintain rigid structural connections
- reserve budget for replacement components

15. Possible Enhancements

Optional extensions, to be attempted only after the core requirements are met:

- joystick control interface
- ultrasonic object detection
- camera-based object recognition
- trajectory optimisation algorithms
- advanced simulation-based control

16. Expected Deliverables and Assessment

Table 15. Deliverables and how they are assessed (weights as on page 1).

Deliverable	Content	Assessed under
Engineering design report	Abstract, References, Appendices (S-0); Introduction (S-1); Model (S-2); Analysis (S-3); Conclusion (S-4); "Use of Artificial Intelligence" section and AI Use & 4D Log after the References.	S-0 to S-4: 10 marks each
Simulation	MATLAB Simscape Multibody model, simulation files and AVI video; results compared with hand calculations.	Simulation: 25 marks
Working robotic arm prototype	Physical arm with embedded control software and experimental test results.	Prototype: 25 marks
Final live demonstration	At least 10 complete pick-and-place cycles, followed by the individual viva voce of each team member.	Prototype: 25 marks

What earns marks in the Simulation and the Prototype

- **Simulation:** the model matches the physical design (link lengths, masses, joint limits); correct joint types and motion inputs; plots of position, velocity, acceleration and torque for a full cycle; agreement with the hand calculation; actuator limits consistent with the selected servos.
- **Prototype:** performance meets the targets, or the gap is honestly measured and explained; at least 10 complete cycles demonstrated; a rigid build within budget; test results recorded; every member can explain the code and the design.

Submission checklist

- ☐ Cover page completed (group number, student numbers and names).
- ☐ Report submitted as a PDF through the Moodle LMS or Microsoft Assignment, with the MATLAB code, Simulink/Simscape files and the AVI file.
- ☐ File or folder named [MENG233-PROJECT-GROUP NO]; any other name or format will be disregarded.
- ☐ All figures and tables numbered and captioned; units given; equations, assumptions and labelled diagrams included.
- ☐ APA references, each cited in the text, from the textbook or another authentic source, all opened and read.
- ☐ "Use of Artificial Intelligence" section and completed AI Use & 4D Log placed immediately after the References.
- ☐ Submitted on time (late submissions are penalised at 10 marks per day).

17. Project Outcome

Successful completion of this project produces a **functional low-cost robotic manipulator** that demonstrates the principles of robotic motion, manipulation and system integration. By combining hands-on prototyping, simulation and the dynamics theory of the course, you gain practical experience of designing a real robotic system within realistic engineering constraints, and of using AI tools in a responsible and transparent way.

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