Group number: 7
The Traverser Robot

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Please specify if you attempted the Bonus tasks in Task 3.

- Yes, our group attempted

1 COMPONENT LIST & PURCHASED ITEMS
2 OUTSOURCED DESIGN/LIBRARY/SOFTWARE
3 MECHANICAL DESIGN AND FABRICATION

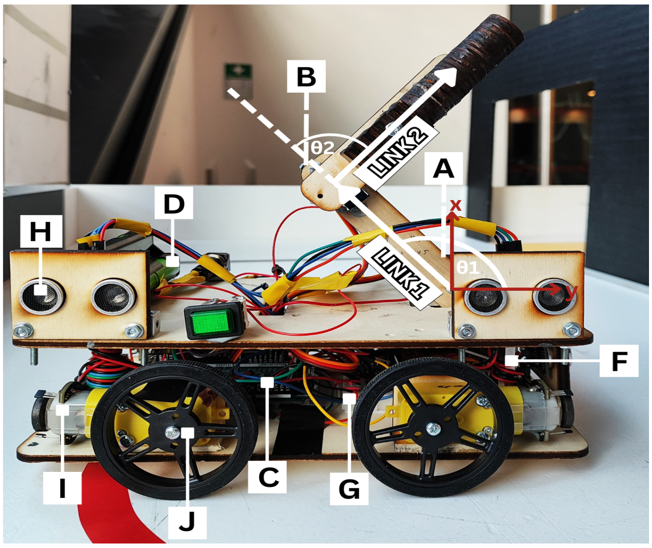

Fig. 1 - The developed robot. A: MG996 RC servo motor, B: SG90 servo motor, C: Arduino Mega, D: Batteries, F: Spacers, G: Breadboard, H: HC-SR04 Multicomp Ultrasonic Sensor, I: DFRobot Micro DC Motor with Encoder, J: Skinny Wheels

Key mechanical aspects and components

The robot features a stable and modular rectangular chassis designed for efficient component organisation. The dimensions of the chassis, with a width of $140mm$ and a length of $226mm$ based on the golden ratio, ensure both compactness and optimal movement. The robot employs two plates: the bottom one houses electrical components and the top accommodates batteries and an arm. Spacers, which are easily removable, support the plates and facilitate access to components while providing enclosure. Skinny wheels are chosen for minimal ground contact, reducing friction and enhancing agility for efficient movements.

Workspace of the Arm

The robotic arm comprises two links featuring two rotating joints. The first joint is restricted to a movement range of $0° - 100°$, while the second link can move within the range of $0° - 90°$. These limitations were determined based on the required range of motion for the robot. The resulting shape of the workspace is illustrated in the figure below.

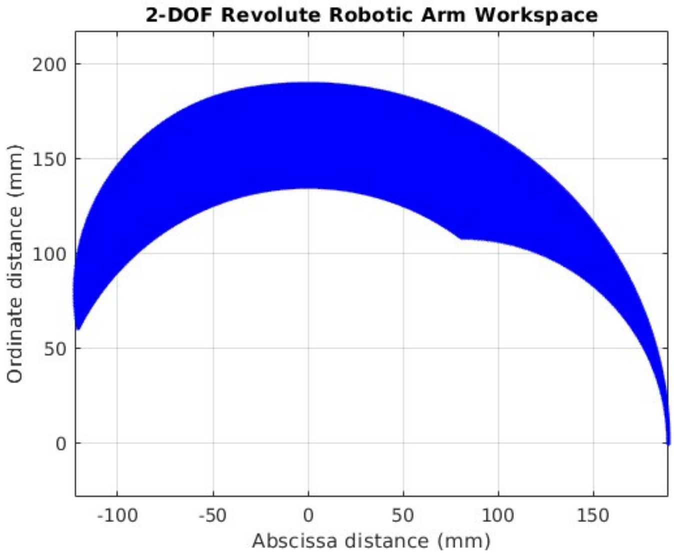

Fig. 2 - The workspace of the robot arm.

For a serial two-link manipulator, the number of degrees of freedom (DOF) is determined by the formula:

$$DOF_{total} = DOF_{joint1} + DOF_{joint2}$$

Both joints in the robot are revolute, and thus,

$$DOF_{total} = 1 + 1 = 2$$

Therefore, the robotic arm has two degrees of freedom. The arm is mounted on top of a mobile robot, completing the entire system. The robot can translate forward and backward in one direction and rotate within a planar surface as it moves. Therefore, its total degrees of freedom in a planar space are 2.

Carriable load

The payload is calculated using the equation shown below, which uses torque, gravitational forces, and moment of inertia.

$$\tau_{max} = g.(m_{l1}r_{l1} + m_{l2}j_{l2} + m_{l3}r_{l3} + m_{payload}r_{payload})$$

where the terms in the equations are described as:

- τ_{max} is the maximum torque exerted on the robotic arm.
- m_{l1}, m_{j2}, m_{l2} are the masses of the individual links and joints.
- r_{l1}, r_{j2}, r_{l2} are the distances from the joint axis to the COG (centre of gravity) of the corresponding links and joints.
- $m_{payload}$ is the maximum mass that the robotic arm can handle.

- $r_{payload}$ is the distance from the joint axis to the COG of the payload.

In the calculation of the payload, the term τ_{max} is replaced with the Stall torque value of the base servo motor, and the masses of each component are derived from the model, incorporating the area, thickness, and density of the material used. Upon implementation of these values, the Maximum Payload of the robotic arm is determined to be 703.18g. Simultaneously, the servo motor's payload near the end effector can effectively handle is calculated to be 34.28g. Additionally, we specified the arm's length to reach the board, with the width chosen arbitrarily. Evaluating the payload under these conditions, we found it to be sufficient to support 34g, resulting in a factor of safety of 1.7.

.Stability

The robot has been designed to ensure that its Center of Gravity (COG) consistently resides within its support polygon, regardless of its configuration. This has been verified through mathematical analysis.

The support polygon, shaped as a rectangle with $87mm \times 142mm$ dimensions, is a critical factor in maintaining stability. The mass distribution of various components, including encoder motors, Arduino Mega, breadboard, arm components, servo motors, and the battery, has been considered. These components have been evenly distributed, with identical motor placements at four corners and the arm and battery strategically positioned at two ends. The robot's centre serves as the reference frame for calculating the coordinates of its components. The following equation is employed to determine the system's Center of Gravity along the X-axis, where m_1 to m_8 represents the masses of individual components and x_1 to x_8 corresponds to their respective X-axis coordinates.

$$\overline{X} = \frac{m_1 x_1 + m_2 x_2 + \ldots\ldots\ldots + m_n x_n}{m_1 + m_2 + \ldots\ldots\ldots + m_n}$$

$$\overline{Y} = \frac{m_1 y_1 + m_2 y_2 + \ldots\ldots\ldots + m_n y_n}{m_1 + m_2 + \ldots\ldots\ldots + m_n}$$

Taking into account the collective mass of all components, the system's Center of Gravity has been determined to be at $\overline{X} = 19.56mm$ along the X-axis from the origin. Importantly, this Center of Gravity consistently remains within the defined support polygon of $87mm \times 142mm$ throughout the robot's range of configurations. This calculation ensures that the robot remains stable and does not fall outside the designated polygon at any point.

Fabrication method, cycle time, sustainability

The robot was designed using Fusion 360, and the entire design and fabrication process, including iterations, spanned a duration of three weeks.The chosen material for the design is plywood, primarily selected due to its cost-effectiveness, sustainability, and ease of processing. Plywood, being 77% cheaper than acrylic, offers a significant economic advantage. Plywood is also easy to work with, allowing for convenient hole placement and modifications during fabrication.

In terms of fabrication details, the assembly of the robot is achieved through the use of nuts and bolts, ensuring a sturdy and reliable structure. The pen holder component employs a combination of gum and waste materials. The waste material, cut into circles and squares, is repurposed to create an innovative and functional pen holder to emphasise the environmentally conscious approach of the design.

Equipment

CO2 laser cutting serves as the primary fabrication method, as it is more precise, with total material removed $(kerf)$ being 0.1mm. In addition, CAD models are strategically positioned closely during cutting to optimise material usage. This comprehensive approach ensures that fabrication methods align with environmentally conscious principles, contributing to a sustainable project lifecycle.

4 ELECTRONICS

Here, we use an external supply of $7.2V$ by serial chaining six $1.2V$ batteries across two motor drivers assembled in a breadboard. A steady supply of $5V$ is given to the motor drivers for power, two encoders, the two servos present in the arm, and the three ultrasonic sensors.

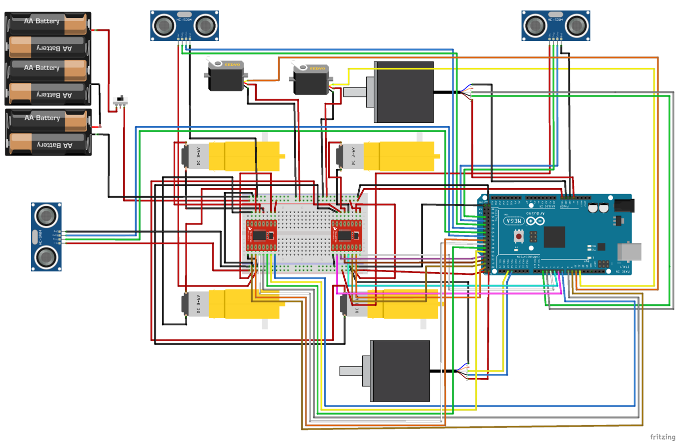

Fig. 3 Schematic of the electronic circuit

- **Microcontrollers**: - The Arduino Mega is being used as the computing unit of the robot. This is due to the increasing number of pins required by using four DC motors.

Additionally, since each encoder requires a pair of interrupts (one interrupt can be used, but the resolution is halved), the UNO was unsuitable, given that the entire system mandates a minimum of four interrupts.

- **Sensors**: - The encoders are used to develop and measure the odometry of the robot. The ultrasonic sensors on the side correct the drift and the overshoot, whereas the rotation points are determined by the front ultrasonic sensor. IR is not used because of its susceptibility to sunlight in comparison to stable sonar reflections.
- **Actuators**: DC motors with a $1:120$ gear ratio are employed to provide the adequate torque needed. The larger servo MG996 is used at the base to provide greater torque in comparison to the SG90 servo for actuating the blackboard marker.
- **Batteries and robot's operation time**: The components require a power source with a current rating of at least $3.45A$, a voltage rating of $5-6V$, and a maximum power draw of roughly 7W to 8W when the two motor drivers are operating. Because each battery has a voltage rating of $1.5V$, after calculating, 6 batteries must be connected in series, giving the power rating of around $9W$ for the components to work without overpowering any of them, and this power supply configuration can power the robot for $1.5hrs$. The robot takes around 3 minutes to complete one cycle; thus, with these power supply parameters, it can be powered for 30 cycles.
- **Circuit board, wires and connectors:** Solid core wires were prioritised throughout, reserving jumper wires exclusively for the ultrasonic components due to their known reliability. The breadboard serves the dual purpose of managing two distinct power lines $7.2V$ and $5V$ and housing the two motor drivers. The system's inability to accommodate additional components influenced the decision to forgo protoboards. Additionally, PCBs were not employed, primarily due to cost considerations.

5 CONTROL

The entire control algorithm of the robot relies on encoders for rotation and a side panel of ultrasonics for error correction. The front ultrasonic provided input for when the robot needs to rotate to traverse to the next wall and an indication of when the robot crosses the gate. Zero radius turns proved essential as part of the differential steering mechanism.

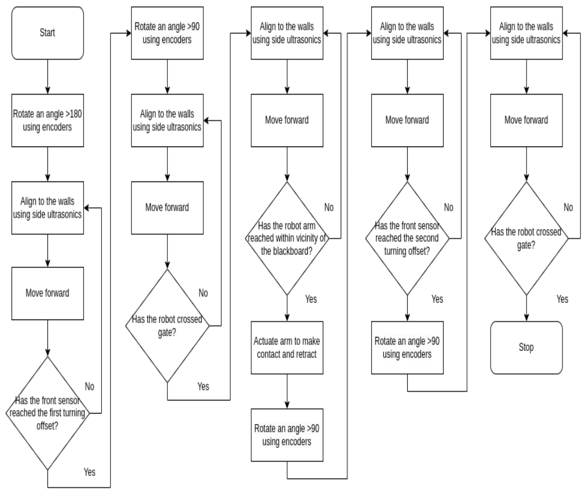

Fig. 4. Flowchart of the operational logic

Kinematics

$$q_1 = tan^{-1}(\frac{y}{x}) - tan^{-1}(\frac{a_2 sin(q_2)}{a_1 + a_2 cos(q_2)})$$

$$q_2 = cos^{-1}(\frac{x^2+y^2-a_1^2-a_2^2}{2a_1a_2})$$

Inverse kinematics was implemented on the robotic arm using the set of equations above, where q_1, q_2, x, y are the individual joint angles and the position coordinates of the end effector, while a_1 and a_2 are the link lengths. Since the end effector lies inside the workspace of the robot but not on the circumference, this gives rise to two possible configurations of the end effector, namely known as 'elbow up' and 'elbow down'. The solutions are obtained by implementing the equation in MATLAB, which derived the values of the joint angles as:

$$(q_1, q_2) = (32.39, 29.03)$$

$$(q_1, q_2) = (67.07, -29.03)$$

The solution is verified using forward kinematics in MATLAB using the function

$$x = a_1cos(q1) + a_2cos(q1 + q2)$$

$$y = a_1sin(q1) + a_2sin(q1 + q2)$$

and the solutions x and y are found to be $(12, 14)$ for both the joint configurations. Thus, these elbow configurations can be obtained by actuating the servo motors to these specific angles.

6 ADVANCED MECHANISM

The pen holder element utilises a mix of adhesive and recycled materials. The reused materials, shaped into circles and squares, are creatively transformed into a practical pen holder, highlighting the eco-friendly ethos of the design. Furthermore, CAD models are tactically placed in close proximity during the cutting process to maximise material efficiency.

Appendix (it is preferable to fit the content within two pages, though not mandatory). You may remove the explanatory text, retaining only the tables filled with the requisite information.

Table 1: Mechanical and electronic components and material list

component name/model	count	weight	current/power consumption	total price excl. VAT	link	Labels in Fig.1
Arduino Mega	1	37 g	250 mA max.	(included in the kit)	-	C
MG996 RC servo motor	1	55 g	500 mA	(included in the kit)	-	A
SG90 servo motor	1	9 g	220 mA	(included in the kit)	-	B
DFRobot Micro DC Motor with Encoder	4	200 g	0.14A to 2.8A	(included in the kit)	-	I
Jumper wires (solid core, ??AWG)	30	ignorable	N/A	(included in the kit)	-	not labelled
Bolts/nuts/screws/washers/adhesives	25	ignorable	N/A	(included in the kit)	-	not labelled
6 batterys (max discharge current XXA) (LiPo&Li-ion prohibited)	1	180g	2600mAh/1.2V	£ 12	-	D
Battery holder	1	ignorable	N/A	£ 2	-	not labelled
Plywood	2	150 g	N/A	£ 4.26	-	-
Male header pins	25	ignorable	N/A	(included in the kit)	-	not labelled
L298N motor driver	2	ignorable	36mA / 20W	(included in the kit)	-	not labelled
Spacers	4	ignorable	N/A	(included in the kit)	-	F
Breadboard / Protoboard	1	20 g	N/A	(included in the kit)	-	G
HC-SR04 Multicomp Ultrasonic Sensor	3	ignorable	5V	£7.5	-	H
Skinny Wheels	4	11.7g	N/A	£7.6	-	J
	Total	662.7 g	6 A / 9 W (excl. batteries)	£ 33.36		

Table 2: Outsourced design/library/software materials

material name	description	link
Arduino Mega 2560	Open source 3d model (.igs) for dimensional reference for designing the base.	https://grabcad.com/library/arduino-mega-2560--1
SG90 Servo Motor	Open source 3d model (.step) for dimensional reference for designing the base.	https://grabcad.com/library/sg90-micro-servo-9g-tower-pro-1
MG996 RC servo motor	Open source 3d model (.step) for dimensional reference for designing the base.	https://grabcad.com/library/servo-mg996r-3

Peer assessment

Table 3: Peer assessment

	Leander Stephen Desouza (230118120)	Shakir Abdul Rasheed (230118119)	Varun Krishna Vasthupurakkal Radhakrishnan (230228739)	Vivek Kamble (230118142)	Total
1 COMPONENT LIST & PURCHASED ITEMS	25%	25%	25%	25%	100%
	• Assisted in selection of electronics components.	• Assisted in selection of mechanical components	• Assisted in selection of mechanical components	• Assisted in selection of electronics components.	
2 OUTSOURCED DESIGN/LIBRARY/SOFTWARE					
3 MECHANICAL DESIGN AND FABRICATION	25%	25%	25%	25%	100%
	• Assembled the components	• Analysed the workspace and DOF	• Calculated the robot's stability	• Calculated the carriable load	
4 ELECTRONICS	25%	25%	25%	25%	100%
	• Calibrated the components	• Checked actuators are in alignment with	• Assembled the connections	• Power, voltage, and current requirements	

		task requirements		are calculated	
5 CONTROL	25%	25%	25%	25%	100%
	• Programmed the robot	• Analysed inverse kinematics	• Cross checked with forward kinematics	• Assessed the code logic with the components	
Report writing and Video recording&editing	25**%**	25**%**	25**%**	25**%**	100%
	• Control part	• Mechanical part	• Mechanical part	• Sensors part	