Open Scout Build and Extend (Mechanical Design)

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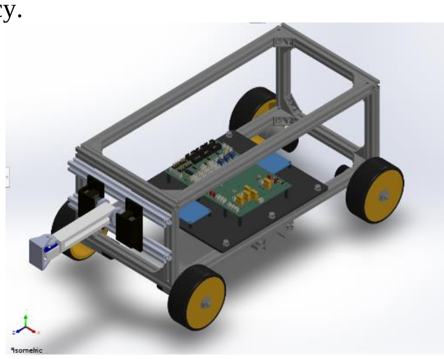
Abstract*— This report outlines the progress and improvements made to the Open Scout robot, an open-source hardware platform, by a group of MSc students from the University of Lincoln. The initial work conducted by previous MSc students involved the design of the Open Scout robot and its integration with ROS2 through the OSHR4 interface board. Expanding upon their contributions, the current team incorporated a 2 DOF robot arm to enable flexible sensor placement and explored the integration of whisker sensors and the ROS2 navigation stack. The report emphasizes the project's objectives, the integration of the 2 DOF arm and R4 interface board, and the new design considerations. To ensure precise design, Computer-Aided Design (CAD), specifically SolidWorks, was employed by the team. The report provides detailed insights into the mechanical design of the crane assembly, including the selection of components such as servo motors and micro-servos, as well as the utilization of aluminum extrusion profiles and 3D printing. The goal of enhancing the Open Scout robot is to optimize its performance and functionality for specific tasks, with a strong emphasis on careful planning and precision.

***Keywords*—Robot arm, 3D Design and Modelling, Versatility, Open Scout, Build and Extend, Component Selection, Simulation.**

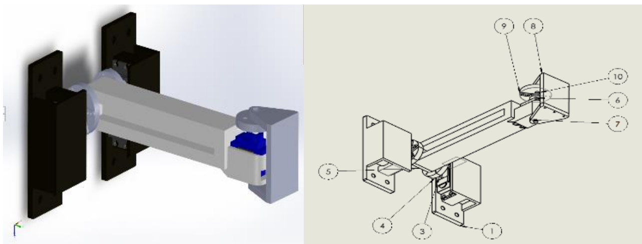
I. Introduction

The Open Scout robot, known for its versatility in the field of robotics, has been developed further by a team of MSc students. Previous contributions by other MSc students involved the initial design and integration of the robot with ROS2, sourced from their GitHub repository, Open Scout. The current team expanded the robot's capabilities by adding a 2 DOF robot arm, allowing for the attachment of sensors and improved interaction with the environment. They also incorporated the R4 interface board to enhance system control and communication between components. The team opted for an innovative design to optimize the robot's performance and functionality for specific tasks. The report provides an overview of the project's objectives, the integration of the 2 DOF arm and R4 board, and the reasoning behind the new design. The crane assembly of the robot includes a 2 DOF mechanism, enhancing flexibility, range of motion, lifting capacity, and space efficiency.



The team utilized Computer-Aided Design (CAD), particularly SolidWorks, to ensure accurate design and modeling of the robot's components. SolidWorks is considered a leading CAD software due to its extensive features, user-friendly interface, stability, and performance optimization. It is commonly adopted in professional settings, offering specialized tools for tasks like finite element analysis and motion simulation. The team aims to leverage CAD design expertise to create a robust and optimized Open Scout robot capable of excelling in its tasks. By using CAD, the team ensures precise measurements, simulations, and evaluation of the design's feasibility and functionality prior to physical implementation. This approach allows for identification of potential issues, design refinement, and verification of performance against intended specifications. The team's emphasis on CAD design reflects their dedication to meticulous planning and precision in creating a highly functional and efficient Open Scout robot. The subsequent sections of the report delve into the specific enhancements and considerations undertaken to further augment the capabilities of the Open Scout robot.

II. Mechanical Design of the Arm Assembly (Crane)



Bill of Materials (BoM):

Load-bearing robots require robust structures, often made of metal. Aluminum extrusion profiles are commonly utilized due to their strength, lightweight nature, efficiency, and ease of bolt attachment. In the specific design of an arm incorporating a crane profile, Polylactic Acid (PLA) was used.

When selecting the arm components, several factors were considered, including load capacity, available servo type and torque, lifting capability of the crane, crane weight and material for 3D printing, and the connection between the star horn and the crane profile.

The following is a list of the components and their respective functions:

1. Base Mount [2]: Used to vertically hold the servo and mount the entire assembly on the mobile robot's frame.
2. Servo motor (MG996R) [2]: Controls the vertical motion of the crane. Two servos are employed at each end of the crane to enhance torque and stability, distribute the load, provide precise control, improve reliability and safety, and reduce stress and wear on individual motors.
3. Servo_MG995_Star_horn [2]: Connects easily to the servo due to its threaded design. The star-shaped horn ensures smooth rotational force transmission during the crane's

movement, offering stability, torque transfer, load distribution, and resistance to stripping. A 6-star horn is preferred for its secure and stable connection, efficient power transmission, even load distribution, and reduced risk of stripping.

4. Motor and Crane connector [2]: This connector is bolted to the star horn and features a hexagonal shape that securely connects to the crane profile, enabling efficient transmission of rotary motion from the servo to the crane.
5. Crane profile [1]: Designed in the form of an I-beam, the crane profile provides strength, even when lifting weight at the end, while maintaining a lightweight structure to minimize overall assembly weight.
6. SG90 - Micro Servo 9g [1]: Used for the horizontal motion of the mount.
7. Mount [1]: A set piece facilitating the mounting of additional sensors on the robot and supporting the connection to the crane profile.
8. Top Mount [1]: Another set piece used for placing sensors, such as whiskers or cameras, on the robot.
9. Micro-servo connector [1]: This connector features a hexagonal key for a secure connection and is used to connect the micro-servo to other components in the assembly.
10. SG90 - Micro Servo 9g – horn [1]: This horn connects effortlessly to the servo due to its threaded design. The star shape ensures smooth rotational force transmission during the crane's movement, resulting in seamless motion.

Servo and Micro-servo

The crane assembly incorporates servo motors and micro-servos, essential components for controlling the crane's movement. The specific characteristics of these components, such as torque, speed, voltage, and control interfaces, play a significant role in determining the crane's performance and capabilities.

Here are the specifications of the servos used in the design[3],[5]:

Specifications	MG996R Servo motor	SG90 Micro Servo
Dimensions:	40.7*19.7*42.9mm	22*11.5*27mm
Operating Speed	0.19sec/60degree (4.8v); 0.15sec/60degree (6.0v)	4.8V no load: 0.12sec/60 degrees
Stall Torque:	9.4kg/cm (4.8v); 11kg/cm (6.0v)	1.2kg / 42.3oz(4.8V);1.6 kg / 56.4oz (6.0V)
Dead Band Width:	1usec	7usec
Operating Voltage:	4.8 ~ 6.6 Volts	3.0-7.2 Volts
Wire length:	32cm	15cm
Gear Type:	Metal gear	All Nylon Gear

The stall torque of a servo is the maximum torque it can exert without rotating. In this case, the MG996R servo has stall torques of 9.4kg/cm (4.8v) and 11kg/cm (6.0v), while the SG90 micro servo has a stall torque of 1.2kg / 42.3oz (4.8V) and 1.6 kg / 56.4oz (6.0V). The stall torque can be used to estimate the maximum weight that the servos can handle.

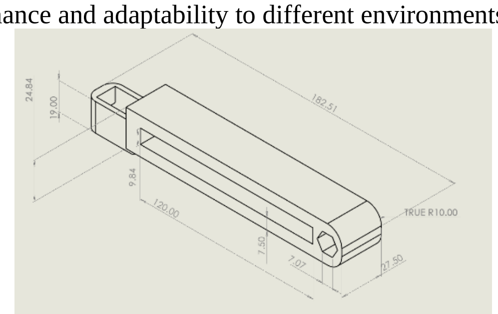
To calculate the maximum weight, the stall torque needs to be converted to force at the end of the servo arm using the formula: **Force = Torque / Distance**.

However, since the distance from the center of the servo to the end of the arm is not provided, an exact conversion is not possible. Based on the comparison of stall torque values, it can be inferred that the MG996R servo is stronger at 6.0 volts (11kg/cm), suggesting an estimated maximum weight handling capacity of approximately 11 kg. For the SG90 micro servo, the established method of calculating the maximum weight it can handle yields a value of 1.6 kg.

Crane Profile (I Extrusion)

The crane assembly is constructed using I extrusion as the main body, which provides structural support and stability while keeping the crane's weight to a minimum. The I extrusion serves as a robust framework for mounting the servo motors and other components. Utilizing I extrusions for crane design offers several advantages, including ease of 3D printing, lightweight construction, high strength-to-weight ratio, modularity, cost-effectiveness, and customizability.

These benefits enable rapid prototyping, customization, and the integration of additional features. The lightweight design reduces strain on the supporting structure and improves overall efficiency. The modularity simplifies assembly, maintenance, and reconfiguration processes. Cost-effective manufacturing and the ability to replace individual parts contribute to lower production and maintenance costs. Moreover, I extrusions offer a high level of customizability, allowing for optimized performance and adaptability to different environments.



In conclusion, the use of I extrusions for the crane design provides a compelling solution, particularly when flexibility, efficiency, and adaptability are essential considerations. A simulation was carried out on this frame to see the stress, deformation of the frame when the maximum weight permissible the servo is on it.

III. Partnership with the Whisker Team

Our partnership with the Whisker Team was established to enhance the capabilities of our mobile robot. Working together, we focused on designing a robust and modular mount for the end effector. The collaborative process involved brainstorming, prototyping, and continuous feedback to ensure optimal results. The resulting mount securely attaches to the end effector and accommodates various sensors and tools, significantly increasing the versatility of our mobile robot. This successful collaboration exemplifies the effectiveness of interdisciplinary teamwork in tackling complex challenges in the robotics field. We express our sincere gratitude to the Whisker Team for their invaluable contributions and collaborative spirit. This achievement highlights the power of teamwork and shared expertise in pushing the boundaries of robotics technology.

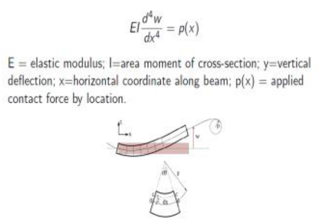
IV. Result and Build

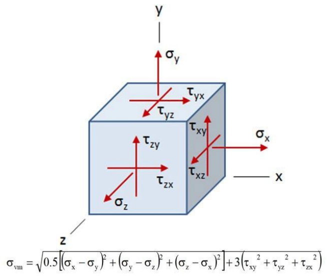
Results from the Simulation

Euler-Bernoulli Beam Theory and Von Mises Stress are concepts used in structural mechanics, but they address several aspects of material and structural analysis. Euler-Bernoulli

Beam Theory focuses on beam deformations, while Von Mises Stress is a measure of combined stresses in materials undergoing plastic deformation. In the Von Mises Stress equation, we have
- σx and σy are the normal stresses in the x and y directions, respectively.
- τxy is the shear stress in the xy plane.

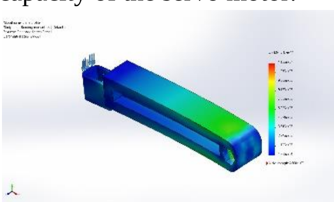
The Von Mises stress criterion is often used to evaluate the potential for yielding or failure of materials under complex stress states, where the individual normal and shear stresses may vary. By comparing the Von Mises stress to the yield strength of the material, engineers can assess whether the material is likely to deform or fail.

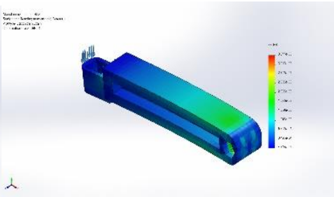


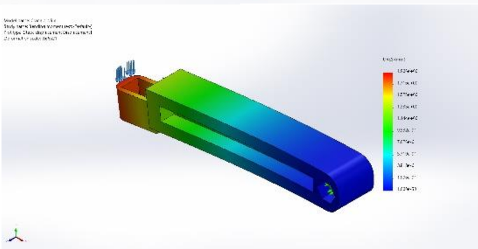


In SolidWorks simulations, the Von Mises stress criterion is commonly employed due to its ability to consider the combined effect of normal and shear stresses. SolidWorks utilizes Finite Element Analysis (FEA) to simulate the behavior of structures and materials, and Von Mises stress proves valuable in evaluating material failure, particularly in scenarios involving complex stress states. By providing a single value, Von Mises stress allows for direct comparison with the material's yield strength, facilitating safety assessments.

The utilization of Von Mises stress simplifies result interpretation in SolidWorks simulations, making it a practical choice for design and analysis purposes. In the specific simulation scenario mentioned, the Crane profile is fixed at both ends, where the servos are connected. The simulation considers a maximum weight of 11kg, aligning with the maximum weight capacity of the servo motor.







Name	Type	Min	Max
Stress	Von-Mises Stress	1.723e+04N/m^2	1.166e+07N/m^2
Strain	Equivalent Strain	4.746e-06	3.377e-03
Displacement	Resultant Displacement	0.000e+00mm	1.906e+00mm

PLA (Polylactic Acid) is a widely used 3D printing material renowned for its biodegradability and eco-friendly composition derived from renewable sources like cornstarch or sugarcane. While PLA may degrade over time when exposed to outdoor weather conditions, it offers notable environmental advantages in specific contexts. It should be noted that PLA has a lower heat resistance compared to certain materials, making it susceptible to deformation at lower temperatures. Recycling PLA can be more complex, and efficient breakdown is better achieved in industrial composting facilities.

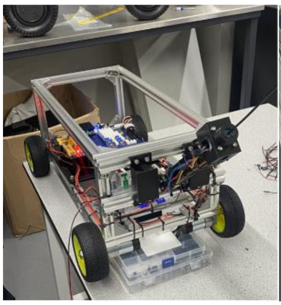
In the simulation, the following properties of PLA were considered [1]:
- Elastic Modulus: 3,500,000,000 N/m^2
- Poisson's Ratio: 0.36 (unitless)
- Shear Modulus: 128,900,000 N/m^2
- Mass Density: 1,240 kg/m^3
- Tensile Strength: 59,000,000 N/m^2
- Yield Strength: 26,082,000 N/m^2
- Thermal Conductivity: 0.111 W/(m·K)
- Specific Heat: 1,386 J/(kg·K)

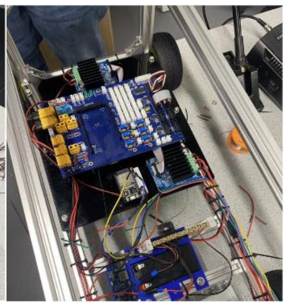
These properties provide vital information for analyzing the behavior and performance of PLA in the simulation. While PLA is favored for its environmental benefits and ease of use in 3D printing, its weather resistance, heat stability, and recycling considerations should be carefully evaluated to ensure suitability for specific applications.

Based on the results of the simulation, the crane profile has a severe displace at the end of it when the maximum load of 11kg was added to it, as such loads of that magnitude must never be added on it, else it would deform

V. Physical Assembly of the Robot

The physical construction of the robot commenced with meticulous placement of each part to assess their fit. Adjustments were made to accommodate wire pathways, and additional electrical components, including a switch, were integrated to ensure smooth current flow. The 12V battery, R4 board, motors, on-off switch, and other electrical elements were securely mounted onto the Aluminum frame prior to wiring, establishing a safe and reliable connection. Wiring was carefully arranged and secured with zip ties to prevent detachment during robot movement. The whiskers team attached their whisker to the robot's mount, and their microcontroller was installed on the board. Successful testing of the robot was carried out using a controller, with the code conveniently stored on a GitHub repository for easy access by team members. Notable considerations during the physical assembly included strategic part positioning for easy modification access, effective wire connections to prevent sparks and electrical faults, and insulation between naked wires and the aluminum frame. The alignment and secure attachment of each servo motor were also prioritized for smooth and reliable motion.





VI. Recommendation

Based on the conducted analysis, it is recommended to carefully select the locomotion system based on the specific requirements and operating environment of the vehicle or robot. For off-road applications with challenging terrains like uneven surfaces and muddy conditions, a tracked driving system is highly recommended due to its superior traction, stability, and maneuverability. On the other hand, for applications focused on smooth surfaces and higher speeds, a wheel driving system is recommended as it offers smoother turns, improved maneuverability, higher speeds, and greater energy efficiency.

It is important to consider the trade-offs between traction, stability, maneuverability, speed, and energy efficiency when deciding on the locomotion system. Additionally, integrating the Whisker onto the Open Scout and conducting further testing in real-world scenarios is advised to assess the robot's performance and identify areas for enhancement. This comprehensive approach will ensure that the chosen locomotion system and the integration of the Whisker meet the specific needs and objectives of the project.

VII. CONCLUSION

In conclusion, the collaborative efforts of the MSc student team from the University of Lincoln have significantly improved the Open Scout robot, enhancing its capabilities and functionality. The integration of a 2 DOF robot arm and the utilization of the R4 interface board have allowed for flexible sensor placement, improved interaction with the environment, and enhanced system control and communication between components. The meticulous mechanical design, carried out using CAD software such as SolidWorks, has ensured precise measurements, simulations, and evaluation of the robot's feasibility and functionality. Careful consideration has been given to the selection of components, including servo motors, micro-servos, and aluminum extrusion profiles, in order to optimize the performance and efficiency of the Open Scout robot.

The use of I extrusions in the crane design has provided a lightweight yet sturdy framework, offering advantages such as easy 3D printing, a high strength-to-weight ratio, modularity, and cost-effectiveness. The partnership with the Whisker Team has further enhanced the robot's capabilities, particularly through the design of a robust and modular mount for the end effector. The collaboration and continuous feedback with the Whisker Team have ensured optimal results and expanded the possibilities of the Open Scout robot.

The success of this project is attributed to the dedication, hard work, and expertise of various individuals and groups, and their contributions deserve recognition and appreciation.

The full documentation of this project is available on Github[4]

VIII. ACKNOWLEDGMENT

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   - Violet Mayne 28169620
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   - Maduabughichi hope Eze 28156651
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The successful development and enhancements of the Open Scout robot would not have been possible without the collective efforts, expertise, and support of the individuals and groups involved. I extend my sincerest gratitude to everyone involved and eagerly anticipate future advancements and collaborations in the field of robotics.

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