Soil Scooping Robotic Arm

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ABSTRACT

This project focuses on the development of an articulated robotic arm designed to collect soil samples in desert regions, particularly for applications in the defence sector. As chemical warfare becomes a growing concern, frequent soil analysis is essential to ensure the safety of armed forces. Leveraging advancements in robotics, this system provides a reliable solution for remote soil sampling, reducing human exposure to potentially hazardous environments. The articulated robotic arm can manoeuvre precisely to gather samples, enabling detailed environmental assessments. This approach showcases the integration of robotics in defence operations, offering enhanced operational efficiency, safety, and adaptability for soil analysis in challenging terrains.

Keywords:

1. Robot Arm
2. Soil Sampling
3. Hazardous Areas

1. INTRODUCTION

The field of robotics has seen significant advancements, expanding its applications across various sectors, from manufacturing to healthcare. This project explores the development of an articulated robotic arm specifically designed for soil sample collection in desert environments, catering to the defense sector's growing need for environmental analysis. With the increase in chemical warfare risks, it is essential to frequently analyze soil for contaminants to ensure the safety of armed forces. By automating the sampling process, this robotic arm reduces human exposure to potentially hazardous areas while ensuring precise and consistent sample collection.

The robotic arm utilizes advanced sensing technology to accurately identify and retrieve samples from challenging terrains. This automation enables timely and effective soil analysis, offering substantial improvements in operational efficiency, safety, and data accuracy. As robotics technology continues to evolve, the application of robotic arms for environmental monitoring in defence is expected to become even more reliable, adaptable, and efficient, enhancing the ability of defence forces to monitor and respond to chemical threats in diverse environments.

2. LITERATURE REVIEW AND OBJECTIVE

Soil testing remains an essential component of sustainable agricultural practices, helping farmers make informed decisions about fertilizer application and crop rotation. Olson [1] underscores its importance in maximizing crop yields and protecting the environment from nutrient runoff. More broadly, concerns about soil degradation—driven by erosion, compaction, and chemical depletion—highlight the need for accurate, ongoing soil monitoring [2].

To address these challenges, recent advances in robotics and automation have yielded several innovative soil sampling systems. Kitić et al. [3] developed *Agrobot Lala*, a fully autonomous robotic system capable of real-time, in-field nitrate analysis and soil sampling. Similarly, Edulji et al. [4] proposed a mobile semi-autonomous robot designed to increase sampling efficiency while reducing labor requirements. Lukowska et al. [5] contributed to this trend with a mobile platform tailored for Agriculture 4.0, aiming to optimize agricultural input through smart soil analysis.

Automation through unmanned ground vehicles (UGVs) has also been a focus of research. Vaeljaots et al. [6] presented a soil sampling system that leverages UGVs to automate the collection process in varied terrain. Olmedo et al. [7] expanded this concept with a modular robotic manipulator mounted on a UGV, capable of both sampling and terramechanics investigations, thus combining data acquisition with mechanical property assessment of soil.

From a mechanical standpoint, Mori and Ishigami [8] provided a detailed excavation model for soil sampling tools, employing particle image velocimetry to study soil-tool interactions. This modeling supports the design of more efficient and accurate sampling mechanisms. In hazardous or inaccessible environments, Ghaari et al. [9] demonstrated the application of autonomous robots to safely conduct soil sampling, emphasizing resilience and remote operation.

Complementing ground-based efforts, Huuskonen and Oksanen [10] explored the use of drones integrated with augmented reality for soil data acquisition in precision agriculture. Such hybrid systems can enhance coverage and data richness. Additionally, Chiodini et al. [11] introduced *Morpheus*, a field robotics testbed enabling autonomous navigation and soil sampling, primarily intended for experimental and educational use.

3. Methodology

The robotic arm was developed using Fusion 360 CAD software with a focus on modularity, reachability, and structural integrity. Designed with four degrees of freedom—base rotation, shoulder, elbow, and wrist—the arm emulates human arm movement. A custom-designed soil gripper serves as the end effector for scooping and collecting particulate samples. Stress analysis and motion simulations were performed to validate joint configurations, load-bearing capacity, and motion range. PLA+ was selected for prototyping due to its mechanical strength, UV resistance, and ease of 3D printing. Fabrication was done using FDM printing with a 0.2 mm layer height and 30% infill for strength-to-weight optimization. Post-processing steps included sanding, annealing for thermal resistance, and dimensional fit checks to ensure proper assembly.

The actuation system utilized MG996R and MG995 servo motors for arm movement, controlled via a PCA9685 servo driver and an Arduino microcontroller, with manual operation through a joystick module. A 5V SMPS provided stable power to the servos. The soil gripper was actuated by a compact MG90S motor, offering sufficient torque for lightweight material handling. Torque calculations showed that for two 180 mm arm segments (each 150 g) and a 50 g payload at the gripper, the shoulder joint required approx. 5.39 kg·cm torque.

a. Formula to calculate torque is:

$$T1 = T2 + (Flink2 \times L1) + (Fload \times (L1+L2)) + (Flink1 \times L1/2)$$

b. Formula to calculate gripping force is:

Digging Force (F) = force range (N/cm^2) x contact area(cm^2)

MG996R servos, rated at 15 kg·cm, easily handled this load. The MG90S motor at the gripper provides about 2.5 kg·cm, sufficient for gripping soil and small samples. The integrated mechanical and electronic system proved to be responsive and efficient for real-world soil sampling tasks.

Requirements:

Hardware	Software
1. Arduino Uno	1.Arduino IDE
2. MG995 Metal Gear Servo Motor	2.Fusion 360
3. PCA9685 16-Channel Servo Motor Driver	3.Robo DK
4. 3D printed parts	
5. Wires	
6. Push Buttons	
7. Joysticks	

Table.1 Requirements

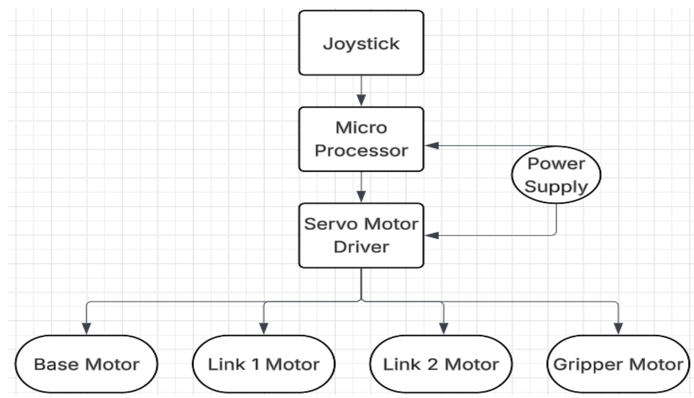


Figure1. Schematic Architecture of Robotic Arm

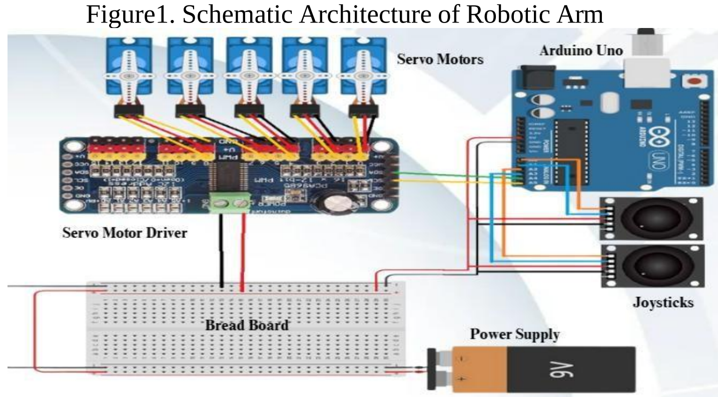
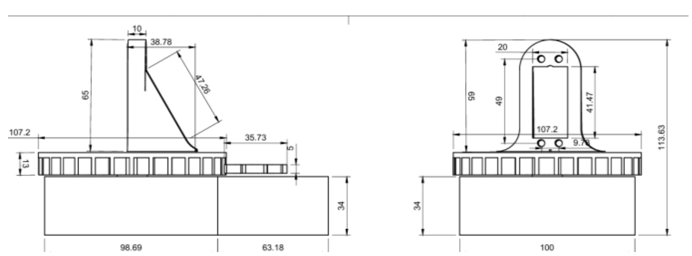


Figure 2. Block Diagram for Working of Robot Arm

Mechanical Designs: 1. Base



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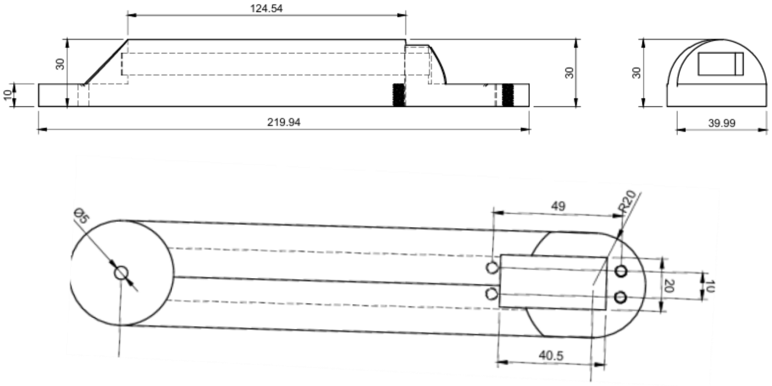
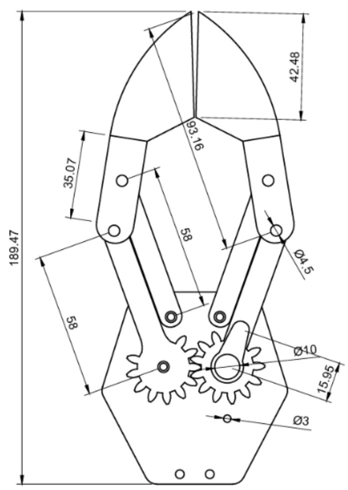
2. Link



3. Gripper



Link	Length	Link Weight	Motor Weight	Torque
Base	0.07 m	0.1 kg	0.05 kg	0.348 Nm
Link 1	0.18 m	0.15 kg	0.05 kg	0.79461 Nm
Link 2	0.18 m	0.15kg	0.05 kg	0.220725 Nm

Table.2 Calculations

 # Torque Calculation

Link 1 supports:

1. The torque for link 2
2. The weight of link 1 & link 2 and load at full length Flink1 = M1 x g = 0.15 x 9.81 = 1.4715 N

Torque for Link1 is:

T1= T2+ (Flink2 x L1) +(Fload x (L1+L2)) + (Flink1 x L1/2)

T1= 0.220725 + (1.4715 x 0.18) + (0.4905 x (0.18+0.18)) + (1.47145 x 0.09)

T1= 0.79461 Nm

#Lifting Force Calculation:

1. **Second Arm:**

F_arm2= (0.15×9.81) =1.47

Acting at its center of mass, d=0.18/2=0.09m

T_arm2=1.47×0.09=0.1323

2. **Gripper + Payload:**

F_gripper= (0.12+0.05) ×9.81=1.66 N

Acting at the end of the second arm (d = 0.18 m):

T_gripper=1.66×0.18=0.2988 Nm

Tjoint2=0.1323+0.2988=0.4311Nm

3. **First Arm:**

F_arm1= (0.15×9.81) =1.47 N

Acting at its center of mass, i.e., d=0.18/2=0.09m

T_arm1=1.47×0.09=0.1323

Torque from Joint 2 Load

T_joint2=0.4311Nm

Acting at

d=0.18d=0.18m

T_joint1=0.1323+(0.4311×0.18) =0.2099 Nm

Soil Type	Force Range (N/cm^cm2)
Sand	5-20 N/cm^2
Clay	20-50 N/cm^2
Loam	10-30 N/cm^2
Gravel	30-60 N/cm^2
Silt	10-25 N/cm^2
Peat (Organic)	5-15 N/cm^2
Desert Sand	20-40 N/cm^2

Table.3 Force Ranges for Lifting the Soil

4. RESULT

The development of the robotic arm demonstrated significant improvements in both safety and operational efficiency during soil sampling tasks in desert environments. Through successful field simulations, the system was able to collect soil samples remotely, minimizing the risk of exposure to hazardous substances for personnel. Additionally, the robotic arm showed potential in secondary applications such as handling and loading of artillery shells, highlighting its versatility in military scenarios. The results confirm that automation in hostile and high-risk areas can greatly enhance mission effectiveness while safeguarding human lives. This validates the system's dual-role capability and its relevance for defence-related operations in challenging terrains.

5. CONCLUSIONS

This project aims to create a robotic arm that can safely and efficiently collect soil samples in desert areas, especially for the defence sector. The robot will help protect soldiers from harmful chemicals by automating the sampling process. It can also assist in loading artillery shells, making it useful for multiple tasks in military operations. This solution shows how robots can improve safety and efficiency in dangerous environments.

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