

Literature Review for *School year 2023-2024*

RubbleScout,
"Navigating Chaos, Saving Lives"

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1. Introduction

Inspired by the micro VGTV (*Variable Geometry Tracked Vehicle*), which were deployed in the aftermath of the September 11 attacks in 2001, this project aims to design and build a semi-autonomous search and rescue robot. The primary objective is to create a robot capable of assisting human operators in navigating complex terrains, identifying obstacles and hazards, and providing real-time data to rescue teams.

The need for such a robot arises from the inherent limitations and risks associated with manual search and rescue operations. Human rescue teams face challenges such as limited accessibility, the risk of aftershocks, and exposure to hazardous materials. Robotic technology can augment human capabilities, making rescue operations safer and more efficient, thereby potentially saving more lives.

In this project, the focus will be on semi-autonomous operation. While fully autonomous systems have their advantages, the serious implications of deploying an entirely self-operating unit in life-critical scenarios necessitate a cautious approach. Therefore, the robot will primarily be operated by a human agent, with autonomous systems taking over for more straightforward tasks. This balanced approach aims to harness the benefits of automation while minimising risks and allowing for human oversight.

As an academic project, the goal is to build a functional semi-autonomous search and rescue robot that could have real-world applications. Given the educational setting, the project serves as a hands-on introduction to the challenges of integrating human oversight with automated systems in potentially critical situations.

2. Review of Existing Solutions

The development of robotic solutions, especially in the realm of search and rescue, has seen considerable advancements over the past decades. The increasing complexities of urban environments and the unpredictable nature of natural disasters have necessitated innovative solutions to assist in rescue operations. In this context, several robotic designs and mechanisms have been proposed and implemented.

2.1 State-of-the-Art Developments and Innovations

2.1.1 Teleoperated Robots

Most current search and rescue robots are teleoperated. These robots allow human operators to control them remotely, which offers immediate adaptability in unpredictable situations. However, the downside is that it requires continuous human attention, which may not always be feasible in crisis conditions.



PackBot Scout: Developed by iRobot, PackBot Scout is a highly versatile, teleoperated robot that has been deployed in various military and civilian search and rescue operations.

Fig 2.1: PackBot Scout

2.1.2 Semi-Autonomous Robots

Recent innovations have produced semi-autonomous robots capable of executing certain tasks independently while still allowing for human intervention. Such systems combine the best of both worlds: the efficiency of automation and the adaptability of human control.



Fig 2.2: Guardian S

Guardian S: Developed by Sarcos Robotics, this snake-like, semi-autonomous robot is designed for search and rescue in tight spaces. It navigates tricky terrains, provides real-time video, and can autonomously avoid obstacles.

2.1.3 Fully Autonomous Robots

While still under development and not widely deployed in emergency scenarios, fully autonomous robots represent the cutting edge of robotics research. These robots use complex algorithms and sensory data to make real-time decisions. However, ethical and technical constraints have limited their immediate application in search and rescue missions.



DJI Matrice 300 RTK: Developed by DJI, this drone is tailored for search and rescue missions. Equipped with advanced sensors and thermal imaging from the Zenmuse H20 series, it offers both autonomous and manual flight modes, making it a versatile tool for expansive search areas.

Fig 2.3: DJI Matrice 300 RTK

2.1.4 Multi-Agent Systems

Another emerging area is multi-agent systems where a fleet of robots collaborates to accomplish tasks more efficiently. Each robot in the system specialises in a particular function, making the entire system more resilient and adaptable.



SwarmDiver: Developed by Aquabotix, SwarmDiver is a system of small aquatic drones that can work in coordination. Specifically designed for applications including oceanography, monitoring, and search & rescue, these drones can cover vast areas quickly.

Fig 2.4: SwarmDiver

2.2 Rationale for Selecting a Semi-Autonomous Approach

In the landscape of search and rescue robotics, various modes of operation have demonstrated their respective strengths and challenges. Teleoperated robots offer direct human control but can be limited by the need for constant human intervention. Fully autonomous systems, while efficient, might carry risks in life-critical situations due to the absence of human judgement.

On the other hand, semi-autonomous robots harmoniously blend human oversight with machine efficiency. By combining the adaptability and decision-making prowess of humans with the precision and stamina of robots, a semi-autonomous approach offers a balanced solution, especially for unpredictable search and rescue missions.

Drawing design inspiration from proven systems like the PackBot Scout (*Fig 2.1*), the goal is to create a robot that capitalises on effective design elements while integrating semi-autonomous functionalities. This combination is anticipated to enhance its capabilities and applicability in various scenarios.

For an academic project, focusing on semi-autonomous robotics strikes the right balance between innovation, real-world applicability, and manageable complexity. Thus, it is a fitting direction for this endeavour.

3 Project Specifications

3.1 Expected outcomes and Deliverables

- **Functional Prototype:** A working model of the semi-autonomous robot demonstrating all the required features and functionalities as per the criteria.
- **Software & Code:** Any software or code developed for the robot's operation.
- **Project Presentation:** A comprehensive presentation detailing the design, development, and deployment process, highlighting challenges faced and solutions implemented.

3.2 Criteria and Requirements

Criteria	Requirements
Purpose & Environment	<ul style="list-style-type: none"> - Designed for academic demonstration - Ability to traverse various terrains
Physical Dimensions	<ul style="list-style-type: none"> - Maximum size of 30×30×20 cm
Maneuverability & Mobility	<ul style="list-style-type: none"> - Tracked propulsion system (Refer to Section 4) - Capable of basic terrain navigation
Power & Operation Time	<ul style="list-style-type: none"> - Functional duration: >10mins
Sensory & Detection Systems	<ul style="list-style-type: none"> - Real-time camera feedback to operator - Ultrasonic sensors for obstacle identification - LIDAR or Stereo Camera for environment scanning - Illumination lamps for dark scenarios
Communication & Interface	<ul style="list-style-type: none"> - Live video streaming capability - Direct computer interface (possibly wired)
Autonomy & Navigation	<ul style="list-style-type: none"> - Independent area mapping - Navigate to specified waypoints
Potential Additional Features	<ul style="list-style-type: none"> - Pitch and Roll detection sensor - Option for thermometers or infrared camera - GPS module for location tracking - Microphone for detecting sounds - Speaker for communication with individuals

4. Design Foundations

The basis for the creation of any robotic system lies in the foundational choices made during the design phase. These decisions shape not only the robot's physical attributes but also its functional capabilities, resilience, and effectiveness in fulfilling its intended tasks.

4.1 Chassis and Mechanical Components

At the core of the robot's mechanical design is its chassis – the framework that houses all its components. The design of the chassis determines the robot's movement capabilities, sturdiness, and how efficiently it can accommodate other components like sensors, power units, and more.

4.1.1 Material Selection

- **Polymer Plastics (PLA/PET)** : Given the prototypical nature of the project, using 3D-printed parts made from PLA or PET is an ideal choice. These materials are cost-effective and provide adequate strength for an academic setting. Their ease of fabrication makes them suitable for rapid prototyping, allowing for design iterations.
- **Wood/Plexi** : For parts that might require larger sizes or specific design intricacies, laser-cut wood or plexiglass can be employed. These materials provide structural integrity and allow for quicker fabrication times compared to other methods.
- **Aluminium** : Aluminium is lightweight yet strong, offering durability and corrosion resistance. While we're not set up for custom aluminium machining, we can integrate pre-made aluminium parts as needed.

4.1.2 Structural Design

The structural design of the robot will consider the requirements of search and rescue operations. Given the complex terrains these robots might encounter, it's crucial to design a structure that provides stability, flexibility, and adaptability. The design should ensure easy integration of the various components such as cameras, sensors, and power units. The form factor should also be compact, given the size restrictions, yet provide enough space for potential upgrades or modifications.

4.1.3 Weight Estimation

For our search and rescue robot, an accurate estimation of weight is pivotal for performance and durability. It informs decisions regarding power management, motor selection, and structural stability.

- 1. Prebuilt Chassis with motors :** As mentioned, the combined weight of the aluminium chassis and the two motors is approximately 2.2 kg.
- 2. Vision System :**
 - a. Camera or Stereo Camera : Depending on the make and model, a standard stereo camera system can weigh between 50 to 200 grams.
 - b. Lamp/Flashlight : A small LED flashlight suitable for robot applications might weigh around 50 to 150 grams.
- 3. Sensors :**
 - a. Basic LiDAR: A compact LiDAR module suitable for robotics can weigh anywhere from 100 to 400 grams.
 - b. Ultrasonic Sensors: Ultrasonic sensors are generally light, with each weighing around 10 to 20 grams. Assuming you use four sensors, this would total to about 40 to 80 grams.
- 4. Power Source :** Li-Po or Li-ion Battery: The weight will largely depend on the capacity. For a battery providing 10 minutes of autonomy to a medium-sized robot, it could range from 300 to 800 grams.
- 5. Computational Components :**
 - a. NVIDIA Jetson Nano: The Jetson modules weigh roughly 250 grams, depending on the specific version.
 - b. Arduino Uno/Mega: An Arduino Uno weighs about 25 grams, while the Mega is slightly heavier at around 37 grams.
- 6. Miscellaneous Components :** Any other parts, wires, fasteners, and structural components not listed above need to be considered.

Total Estimated Weight: Summing the minimum and maximum weights of each component, the robot's total weight might range between approximately 3.1kg to 4kg. This is a rough estimate and the actual weight can vary based on specific component choices.

4.2 Locomotion and Mobility

Choosing the right mode of locomotion is crucial in robotics, especially when the robot's intended purpose is search and rescue. The landscape of terrains and obstacles it might face makes this decision integral to its effectiveness.

Here's a breakdown:

Type of Mobility	Description	Advantages	Drawbacks	Example
Wheeled	Consists of circular components rotating about a central axis.	Simple mechanics, efficient for flat terrains, easier to control.	Limited in uneven or soft terrains like sand or mud.	NASA's Perseverance Rover (Fig 4.1)
Tracked	Continuous track laid over wheels.	Enhanced stability, distributes weight, good in rough terrains.	Slower, more mechanical parts.	iRobot's PackBot Scout (Fig 2.1)
Legged	Multiple legs for movement.	Versatile, can navigate complex terrains, mimics natural organisms.	Extremely complex mechanics, energy-consuming.	Boston Dynamics' Spot (Fig 4.2)
Snake-like	Mimics the movement of snakes.	Can access tight spaces, versatile in motion.	Complex to design and control.	Sarcos Robotics' Guardian S (Fig 2.2)

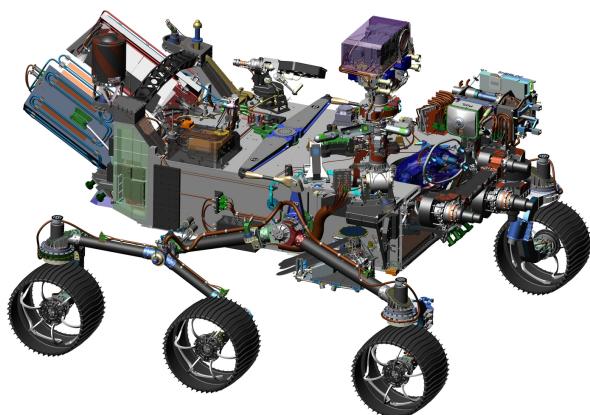


Fig 4.1: NASA's Perseverance Rover



Fig 4.2: Boston Dynamics' Spot

For search and rescue missions, navigating diverse terrains is paramount, and the **tracked** mode of locomotion emerges as the prime candidate. The prebuilt chassis we chose offers the adaptability to manoeuvre through various environments while maintaining inherent stability, aligning perfectly with the goals of a semi-autonomous robot. Furthermore, the ease of incorporating a tracked system and the option to utilise pre-built chassis make it a pragmatic and time-efficient solution for our endeavour. An example of the ready-to-use chassis we're considering can be found [\[here\]](#).

4.3 Motors and Actuators

Choosing the right motors is essential for achieving the desired movement and operational efficiency. The choice of motors often revolves around the nature of tasks, the weight of the robot, and the terrain it will navigate.

4.3.1 Types of Motors

- **Brushed DC Motors** : Simple in design, cost-effective, and provide good torque for their size. However, they wear out faster due to brush friction.
- **Brushless DC Motors** : More efficient than brushed motors and have a longer lifespan as they don't have brushes that wear out. They are commonly used in high-end robots due to their efficiency and durability.
- **Stepper Motors** : Precise control of position and velocity without a feedback sensor. Suitable for applications where precision is a priority.

4.3.2 HM-GM-37-3429 12V DC Motors (*Prebuilt Chassis Motors*)

1. **Voltage and Current** : These motors operate at 12V and have a rated current of less than 2A, ensuring that they won't excessively drain the battery. With a stall current of less than 3.8A, it indicates that the motors can handle load surges without consuming a huge amount of power.
2. **Reduction Gear** : The 1:30 reduction gear is crucial for providing the motor with more torque. This increased torque, at 784 mN.m per motor, ensures that the robot can move efficiently, even on uneven or challenging terrains typical in search and rescue missions.
3. **Hall Sensors** : Having hall sensors is an added advantage, as it allows for precise speed and position control of the motor, essential for semi-autonomous operations.
4. **Torque** : A torque of 784 mN.m per motor ensures that the robot can carry the required equipment without struggling in terms of speed or stability. The higher torque ensures smoother movement, especially when navigating obstacles or inclines.

4.3.3 Consideration for Future Upgrades

While the HM-GM-37-3429 12V DC motors seem apt for our initial design, robotics is an iterative process. Based on real-world testing, there might be scenarios where we realise that the motors are either overpowered or underpowered for our specific application. If the robot struggles with mobility or is unable to navigate certain terrains, we may consider upgrading to a motor with a higher torque or different reduction gear ratio. Conversely, if we find that the robot is moving too fast and sacrificing stability, a motor with a lower speed might be more appropriate. It's essential to remember that motor selection isn't just about raw power but achieving the right balance between speed, torque, and power consumption to best suit our robot's mission profile.

4.3.2 Actuation Mechanism

For tracked or wheeled robots, motors directly power the motion. In legged or snake-like robots, complex actuation mechanisms such as servos, hydraulics, or pneumatics might be needed to control the limbs or segments.

4.4 Energy and Power Management

Selecting the right battery is critical for ensuring uninterrupted operation, especially in a search and rescue mission where reliability can mean the difference between success and failure.

- **Type of battery :** Li-Po and Li-ion batteries are the most popular choices for robotics due to their high energy density and light weight. For our application, considering the power needs and operational time of over 10 minutes, a Li-Po or Li-ion battery would be ideal.
- **Voltage and Capacity :** The voltage of the battery should match or exceed the requirements of the most power-hungry component, in this case, the 12V DC motors. The capacity, often measured in milliamp-hours (mAh), determines the operational time. A higher mAh value would provide a longer run time, but also increase the weight.
- **Components' Power Consumption :** Different components of the robot, such as the motors, Nvidia Jetson, Arduino board, sensors, and lighting, each have their power requirements.
- **Operational Efficiency :** Ensuring that the robot's software and mechanical components work efficiently can significantly reduce energy wastage. For instance, optimising motion algorithms can prevent unnecessary movements, conserving power.

- **Power Management Strategies :** Implementing power-saving modes, like reducing sensor polling rates or dimming lights when not necessary, can extend battery life. Additionally, monitoring battery levels in real-time can help in making informed decisions about the robot's operations, ensuring that it doesn't run out of power in critical situations.

Taking all these criteria into consideration, an 11.1V LiPo battery with a capacity of 5000mAh to 10000 mAh would be the ideal solution.

A battery corresponding to these criteria can be found [\[here\]](#).

In addition, thanks to an 11.1V LiPo battery, we can directly power our motors and the arduino board.

However, we will still need a converter to power the nvidia Jetson nano card.

5. Sensory Systems and Data Management

Search and rescue robots are required to have a heightened sense of their surroundings to navigate effectively and locate targets. The choice of sensors and their integration, along with how the data they produce is managed, is critical. Let's delve into this aspect of the robot:

5.1 Sensor Selection and Integration

LIDAR :

- **Purpose :** LiDAR systems are used to map surroundings in 3D, making them crucial for obstacle avoidance and mapping in unknown terrains.
- **Integration :** It must be placed in a position that provides an optimum field of view, and a system must be created that allows the lidar to be moved to take 3D measurements. To do so heliocentric configuration can be considered.
- **Specification :** LIDAR-Lite V3 [\[link\]](#)

Stereo Camera :

- **Purpose :** Provides depth perception, which aids in navigation and object recognition. Can also be used in 3D mapping.
- **Integration :** Draws around 1W of power and will need to be positioned to get a wide field of view of the surroundings.
- **Specification :** IMX219-83 [\[link\]](#)

Ultrasonic Sensors :

- **Purpose :** These sensors determine distances by emitting sound waves and measuring the time it takes for the echo to return. They can help with close-range obstacle detection.
- **Integration :** These sensors will be scattered around the robot's frame to ensure detection of obstacles from all angles.
- **Specification :** HC-SR04 [\[link\]](#)

Hall Effect Sensors (on motors) :

- **Purpose** : To provide feedback on the motor's rotation, which can be used for precise movement control and odometry.
- **Integration** : These will be integrated with the motor system and will provide feedback to the robot's main processing unit.
- **Specification** : Already integrated into the pre-built chassis

5.2 Data Collection and Processing

NVIDIA Jetson Nano :

- The Nvidia Jetson Nano will serve as the primary processing unit. Its high computational capacity makes it suitable for processing data from multiple sensors in real-time.
- The collected data will be used to generate a map of the surroundings, detect obstacles, and plot the robot's path.
- Algorithms for SLAM (Simultaneous Localization and Mapping) can be implemented to create and update maps in real-time.

Arduino Uno/Mega :

- The arduino board will perform the most basic tasks ordered by the operator or the nvidia jetson nano board.

Data Storage :

- Given the volume of data generated, especially from the LiDAR and stereo camera, it's essential to have adequate storage. An external SD card or SSD can be used for this purpose.
- Periodic data offloading might be necessary to ensure continuous operation without storage constraints.

5.3 Real-time Monitoring and Feedback

To ensure the mission's success and the safety of the robot, real-time monitoring is essential. The robot will be equipped with:

Telemetry Systems : Transmits real-time data back to the control station. This includes sensor readings, battery status, and system health metrics.

Feedback Mechanism : Any anomalies detected (like sensor malfunctions or significant drops in battery power) trigger alerts to the control station. This immediate feedback allows operators to take corrective actions promptly.

Live Feed Video : The stereo camera, apart from aiding in navigation and victim detection, provides a live video feed to the control station. This assists human operators in understanding the environment and guiding the robot when necessary. Through the combination of advanced sensory systems and efficient data management, our robot will be well-equipped to handle the challenges of search and rescue missions, ensuring both its safety and the success of the operation.

6. Development Approach

Developing a semi-autonomous robot for search and rescue is a complex endeavour that requires a systematic approach. Breaking down the development process into manageable phases ensures better control, streamlined integration, and thorough testing.

6.1 Initial Control and Functionality

Base Framework: Before diving into advanced functionalities, it's essential to have a solid foundation. This phase focuses on the core controls of the robot – basic movement, turning mechanisms, and stability. Utilising the prebuilt chassis we chose, we'll ensure the robot can navigate simple terrains without any sensory input.

Programming Interface: Using platforms like Arduino and the NVIDIA Jetson Nano, initial control algorithms will be developed. This includes basic commands for forward, reverse, left, and right movements, as well as speed control.

Safety Protocols: Even at this early stage, basic safety mechanisms, such as emergency stop commands, will be implemented to ensure the robot can be halted if unexpected behaviours arise.

6.2 Incremental Integration of Sensory Systems

Single Sensor Integration: Instead of integrating all sensors simultaneously, they will be added one by one. This modular approach ensures that each sensor's functionality can be tested and verified independently, reducing complexities.

Data Fusion: As multiple sensors are onboarded, the focus shifts to how their data can be merged to create a coherent understanding of the robot's environment. Platforms like the Jetson Nano play a crucial role here, handling multiple data streams and ensuring seamless integration.

Feedback Mechanisms : With each sensor addition, feedback loops will be established, ensuring the robot can adjust its behaviour based on the sensory data it receives.

7. Project Roadmap

Embarking on a project of this magnitude requires meticulous planning and clear milestones to ensure the development proceeds smoothly and efficiently. This section outlines the phases of the project and anticipates possible challenges.

7.1 Initial Phases and Milestones

Phase 1: Research and Procurement (0-5 hours)

- **Objective :** Understand the requirements and procure essential components.
- **Milestones :**
 - Detailed understanding of the robot's mission and capabilities.
 - Finalising the list of components required.
 - Placing orders for the chosen parts.

Phase 2: Basic Assembly (5-10 hours)

- **Objective :** Assemble the robot's primary framework and integrate the primary systems.
- **Milestones :**
 - Assembly of the tracked chassis.
 - Integration of the power system.
 - Initial testing of basic motion.

Phase 3: Sensor Integration (10-20 hours)

- **Objective :** Integrate sensory systems and validate their functionality.
- **Milestones :**
 - Installation of LiDAR, stereo camera, and ultrasonic sensors.
 - Integration of sensors with the NVIDIA Jetson Nano.
 - Basic data collection and validation tests.

Phase 4 : Software Development and Testing (20-30 hours)

- **Objective :** Develop control algorithms and conduct preliminary testing.
- **Milestones :**
 - Writing and optimising control algorithms.
 - Conducting tests in controlled environments.
 - Iterative improvements based on test feedback.

7.2 Anticipated Challenges and Contingencies

In the design and deployment of a semi-autonomous search and rescue robot, several challenges are anticipated. It's crucial to be prepared for these hurdles, ensuring the robot remains efficient and effective in its mission. Below are some potential challenges and their respective contingencies:

Power Limitations :

Challenge: The robot's battery might drain faster than anticipated, especially during prolonged missions or when dealing with energy-intensive tasks.

Contingency: Optimise power consumption by employing power-saving modes during idle times. Ensure real-time monitoring of battery levels and signal for recharging or replacement when levels are low.

Data Overload:

Challenge: With multiple sensors working simultaneously, the robot could get overwhelmed by the sheer volume of data.

Contingency: Implement efficient data processing algorithms on platforms like NVIDIA Jetson Nano. Store non-essential data for later processing and prioritise real-time processing for mission-critical data.

Communication Interruptions:

Challenge: Loss of communication with the robot, especially in areas with signal interference.

Contingency: If communication is lost, program the robot to either halt its operations and wait or to return to a predefined 'safe' location.

7.3 Component list

Pre-Built Chassis	1	TS100N	[link]
LiDAR	1	LIDAR-Lite V3	[link]
Ultrasonic Sensors	3	HC-SR04	[link]
Stereo Camera	1	IMX219-83	[link]
LiPo Battery	1	11.1V 5-10Ah	
NVIDIA Jetson Nano	1		
Arduino Uno/Mega	1		
Lamp/Flashlight	X		

8. Conclusion

The quest to design a semi-autonomous search and rescue robot is fraught with challenges and opportunities. This literature review aimed to distil the vast landscape of research and developments in this field to guide the design and implementation of such a robot.

8.1 Summary of Key Findings

Choice of Locomotion : Tracked robots emerged as the optimal choice for navigating varied terrains, offering both stability and adaptability.

Power Management : Efficient energy utilisation is paramount. Balancing between battery capacity, weight, and the power demands of various components is a critical aspect of the robot's design.

Sensory Systems : A blend of LiDAR, stereo cameras, and ultrasonic sensors provides a comprehensive view of the environment, allowing the robot to make informed decisions and navigate efficiently.

Data Management : The use of platforms like the NVIDIA Jetson Nano ensures efficient data processing, while onboard storage solutions provide room for data collection for further analysis.

8.2 Gaps in Current Literature and Potential Areas of Exploration

Alternative Locomotion Techniques : While tracks are preferred for their adaptability, there's limited literature on hybrid locomotion mechanisms that might offer additional benefits in specific terrains or scenarios.

Advanced Sensing : Current literature predominantly focuses on visual and distance sensing. There's potential for research into sensors that can detect biochemical signals or heat, enhancing the robot's ability to locate humans in disaster scenarios.

Machine Learning and AI : While many semi-autonomous robots leverage basic algorithms for navigation and decision-making, there's room for exploring deep learning techniques that can adapt and learn from environments in real-time.

Human-Robot Interaction : Ensuring seamless communication between the robot and its human operators or potential survivors is an area that requires more in-depth exploration. This includes understanding psychological factors, trust-building, and efficient feedback mechanisms.

In light of the above findings, it's evident that the journey towards designing and implementing a semi-autonomous search and rescue robot is both intricate and enlightening. This literature review has provided a foundational understanding, consolidating key aspects of design, energy management, sensory systems, and data handling. As we proceed with the prototype for our school project, we recognize the importance of this theoretical groundwork. It not only informs our decisions but also highlights areas where innovation can be applied, drawing from the latest research and technological advancements. As we transition from research to application, the insights gleaned from this review will be instrumental in shaping our robot's design and functionality.

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