A Major Project Phase-I Report

On

"PENDULUM DRIVEN SPHERICAL SPY ROBOT FOR SURVEILLANCE OPERATION"

SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE AWARD OF DEGREE OF

BACHELOR OF ENGINEERING

IN

ELECTRONICS & COMMUNICATION ENGINEERING

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Certificate

This is to certify that the Major Project Phase-1 report entitled **“PENDULUM DRIVEN SPHERICAL SPY ROBOT FOR SURVEILLANCE OPERATION”** being submitted **by Mr. KALUR BHARATH (1608-21-735-006), Ms. BANALA POOJITHA (1608-21-735-021), Mr. MUDAVATH RAHUL (1608-19-735-036)** partial fulfillment for the award of the Degree of Bachelor of Engineering in Electronics and Communication Engineering of the Osmania University, Hyderabad, during 2024-25, is a record of bonafide work carried out under our guidance and supervision.

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ABSTRACT

The project focuses on developing an innovative spherical spy robot designed to enhance surveillance in challenging and inaccessible environments. Unlike traditional humanoid, wheeled, or legged robots constrained by high costs, structural complexity, and terrain limitations, this robot employs a pendulum-based drive system for stable and efficient movement. Equipped with 360-degree cameras for real-time video streaming, it enables advanced monitoring and reconnaissance in unreachable areas. Powered by an Arduino controller, the robot integrates motors and feedback systems for precise operation. An Android application, connected via Bluetooth, facilitates intuitive remote control for movement and obstacle detection. Lightweight and durable, with an acrylic shell, this robot is ideal for military, search-and-rescue, and high-risk surveillance applications. Its modular design ensures easy maintenance, and future upgrades aim to incorporate full automation and advanced navigation techniques.

Keywords: Spherical spy robot, Pendulum-based drive system, Video streaming, Arduino controller.

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Chapter-1
INTRODUCTION

1.1 Introduction

Surveillance operations are crucial in inaccessible war zones, during emergencies, and in hazardous areas where human intervention is unsafe. Robots can replace human efforts in such situations, offering remote operation capabilities. These spy robots are also essential for security in public buildings and during terrorist attacks. Challenges faced by human operators include bomb detection, monitoring unusual activities, border surveillance, patient monitoring, industrial oversight, and search-and-rescue missions during natural disasters.

Key functionalities required in a spy robot include object identification in unknown territories, live video streaming, and seamless mobility across diverse terrains. Traditional robots, such as legged or wheeled models, face limitations in speed, terrain adaptability, and visibility. A spherical design offers a superior alternative for inspection in areas inaccessible to humans. This design places a carbased model within a spherical ball for enhanced performance. Research on propulsion mechanisms for spherical robots includes car-based models, independent hemispheres, and center-of-gravity relocation. The earliest spherical robot models employed wheels contacting the sphere's base, driven by a power and communication unit. While this design allowed for turning, it suffered from slow motion, instability upon collision, and internal slippage, resulting in imprecise movement.

Several advancements have been made in spherical spy robots. Remotecontrolled combat robots with laser guns and Advanced Technology for Memory and Logic (ATMEL) microcontrollers, as well as Programmable Interface Controllers (PIC)-controlled robots equipped with Charged-Coupled Device (CCD) cameras and Radio Frequency (RF) transmitters, have been developed.

Existing designs with perpendicular rotors, central bodies, and mass-shifting mechanisms offer improvements but are hindered by mechanical complexity, high motor performance demands, and limitations caused by central hubs. To address these challenges, the proposed spherical spy robot incorporates a pendulum-based drive system. This design provides live video streaming, obstacle detection, and stable locomotion using advanced control algorithms. The pendulum mechanism, powered by four 12V batteries, enables sphere steering by relocating the center of mass. A horizontal pipe structure supports the pendulum, ensuring stability and allowing for flexible sphere rotation and tilt.

1.2 Problem statement

Modern robotic deployments face numerous challenges, particularly in adapting to uneven terrains and harsh environments. Traditional robots, including humanoid, wheeled, and legged designs, struggle with stability and mobility on rocky, slippery, or uneven surfaces, limiting their effectiveness in military surveillance, rescue missions, and other critical operations. Additionally, these robots require advanced sensors and control systems, leading to high production and operational costs. Communication barriers further hinder efficiency, as Bluetooth and GPS-based systems suffer from range limitations, reducing their capability for extensive surveillance and real-time data transmission. Addressing these challenges is crucial for enhancing robotic performance in demanding applications.

1.3 Objectives

To design a spherical spy robot with a pendulum-based drive system for simplified structure enhanced mobility through center of mass adjustment, and realtime video streaming for live surveillance.

1.4 Methodologies

The developed system operates in real-time, designed as a spherical spy robot with a pendulum-based drive mechanism for enhanced mobility and stability. The robot navigates diverse terrains by adjusting its center of mass, enabling smooth rotation and tilt. It is equipped with a real-time video streaming module to capture live surveillance footage. Obstacle detection sensors ensure safe navigation, while the control system processes movement data for precise maneuverability. The video feed is transmitted to a remote device via wireless communication, allowing operators to monitor activities. A suitable control algorithm optimizes motion and balance, ensuring efficient surveillance performance.

1.5 Motivation

The motivation for the development of a spherical spy robot with a pendulumbased drive system is driven by the need to enhance robotic capabilities for critical operations in challenging environments. Traditional robots face significant limitations when navigating uneven terrains, such as rocky or slippery surfaces, reducing their effectiveness in military surveillance, rescue missions, and other high-stakes applications. Additionally, existing systems suffer from high costs due to complex sensors and control systems, along with communication barriers that restrict range and real-time data transmission.

Operation

▯ Power System Overview

▯ *Battery Configuration*

- **3 x 18650 Li-ion batteries** are connected in series to form a **3S (11.1V nominal, up to ~12.6V full charge)** battery pack.
- The series configuration boosts voltage while keeping current capacity the same.
- This pack powers the **entire circuit** via a **3S BMS** and **3S charging module**.

▯ *3S BMS (Battery Management System)*

- Manages charging/discharging of the 18650 battery pack.
- Prevents overcharge, deep discharge, and balances the cells.
- **Output** from BMS is connected to:
  - **LM2596 buck converter**
  - **Switch** to control the power supply to the rest of the circuit.

▯ *3S Charging Module*

- Connected in parallel to the battery and BMS.
- Provides USB or DC jack-based charging.
- Safely recharges the 3S battery via BMS terminals.

▯ Power Distribution via LM2596 (Buck Converter)

- Input: ~11.1–12.6V from battery
- Output: Stepped down to **5V** and **3.3V** as required
- Feeds power to:
  - **ESP32-CAM** (3.3V logic + 5V supply)
  - Other low-voltage logic devices or sensors

▯ ESP32-CAM Module

- **Microcontroller with built-in Wi-Fi and Camera**
- Powered by **LM2596 output (3.3V and/or 5V)**.
- Handles:
  - Real-time image/video capture
  - Streaming via Wi-Fi to mobile or PC
  - May also control servo/motor signals via GPIOs

▯ ESP32 GPIO Pin Connections:

- Connects to:
  - **MG995 Servo Motor** (via PWM pin)
  - **L298N Motor Driver** (IN1, IN2, ENA/ENB pins)

□ Motion Control System

□ L298N Motor Driver

- Dual H-Bridge driver to control **2 geared DC motors**.
- Takes input from **ESP32 GPIOs** (digital HIGH/LOW signals) for direction control.
- **Powered directly from the 12V battery (via switch)**.
- **Outputs** go to:
  - **Left and Right Geared Motors** for movement of the robot shell.

□ MG995 Servo Motor

- Controlled via **PWM signal from ESP32**.
- Attached to the **pendulum** inside the robot.
- Adjusts pendulum's angle, changing the robot's center of gravity.
- This causes the spherical shell to roll in the desired direction.

□ How It All Works Together (Step-by-Step):

1. **Power ON**: Switch enables power from the 3S battery pack through the BMS.
2. **Voltage Regulation**: LM2596 converts the 12V to 5V/3.3V for ESP32-CAM and logic-level control.
3. **Streaming & Control**:
   - ESP32-CAM initializes:
     - Camera starts capturing video
     - Creates Wi-Fi hotspot or connects to a router
     - Streams video to a web interface or mobile app
   - Receives control inputs via Wi-Fi (e.g., turn left/right, forward/back)
4. **Robot Movement**:
   - Based on user input or programmed path:
     - ESP32 sends PWM signals to the **servo motor** → shifts pendulum
     - ESP32 sends HIGH/LOW signals to **L298N** → drives DC motors
   - The **pendulum shifts** the center of gravity → robot **rolls** forward or turns by altering torque

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□ Summary of Connections

Component	Connected To	Purpose
18650 Batteries	3S BMS → Switch → LM2596 & L298N	Power supply
3S BMS	Batteries + Charging Module	Battery safety management
LM2596	ESP32-CAM, Servo	Voltage step-down (5V/3.3V)
ESP32-CAM	Servo (MG995), L298N	Camera + Motion control
L298N	Geared Motors	Drives movement
MG995 Servo	Pendulum + ESP32	Shifts weight to steer/drive robo

Chapter 2

LITERATURE SURVEY

[1] Q. Jia, H. Sun, and D. Liu, "Analysis of actuation for a spherical robot," ***Proc. 2008 IEEE Conf. Robot. Autom. Mechatronics*****, pp. 1–6, 2008.**

The paper titled "Analysis of Actuation for a Spherical Robot" by Q. Jia, H. Sun, and D. Liu, presents a comprehensive study on the actuation mechanisms of spherical robots. The key findings of this research include the development of a dynamic model for the spherical robot, incorporating the effects of a counter-weight pendulum attached to a gimbal, a steering motor, and a drive motor. This model facilitates the analysis of the robot's motion equations and non-holonomic constraints, providing insights into the robot's maneuverability and control. The study also includes simulation studies to validate the proposed model, demonstrating its effectiveness in predicting the robot's behavior under various conditions.

The main challenge in this project was the reliance on a counter-weight pendulum and gimbal system may introduce mechanical complexity, potentially affecting the robot's reliability and maintenance requirements. Additionally, the dynamic model assumes ideal conditions, which may not fully account for real-world factors such as friction, sensor inaccuracies, and environmental disturbances. The simulation studies, while valuable, may not capture all the complexities of physical implementation, necessitating further empirical testing to validate the model's predictions.

[2] S. Bhargavi and S. Manjunath, "Design of an intelligent combat robot for war fields," ***2011*** **International Journal of Computer Applications, vol. 2, no. 8, pp. 13-17, 2011.**

The "Design of an Intelligent Combat Robot for War Fields" project presents several key findings that highlight its potential for enhancing military and security operations. Its radio-controlled design facilitates remote operation, while its stealth capabilities enable infiltration into enemy zones for surveillance and reconnaissance. Additionally, the robot is self-powered, ensuring sustained operation during extended missions.

However, the project has certain limitations. The robot’s payload capacity is restricted, limiting the tools and equipment it can carry, which could hinder its use in more complex operations. Terrain navigation could be a challenge, as the robot may struggle in rough or difficult environments. Its reliance on wireless communication makes it vulnerable to jamming or interference, and the battery life may constrain its operational duration.

[3] N. MacMillan, R. Allen, D. Marinakis, and S. Whitesides, "Range-based navigation system for a mobile robot," Proc. 2011 Canadian Conf. Comput. Robot. Vis., pp. 16–23, May 2011.

The project titled "Range-based Navigation System for a Mobile Robot" by N. MacMillan, R. Allen, D. Marinakis, and S. Whitesides, focuses on developing an algorithm for path planning in environments equipped with fixed range-only beacons. The key findings of this research include the introduction of a method to define and calculate entropy values for regions of interest within the environment. By assessing these entropy values, the algorithm identifies "safe," low-entropy paths between regions, facilitating efficient navigation for mobile robots.

It is important to acknowledge the limitations of this project, particularly the reliance on range-only beacons may limit the robot's ability to detect obstacles or navigate in environments where beacon signals are weak or obstructed. Additionally, the system's performance is dependent on the accuracy and placement of the beacons, which may not be feasible in all environments. The use of acoustic beacons, while cost-effective, may be susceptible to interference from environmental noise, potentially affecting the reliability of the ranging measurements. Furthermore, the algorithm's effectiveness in dynamic environments, where obstacles and conditions change over time, remains uncertain and would require further investigation.

[4] W. M. M. Khaing and K. Thiha, "Design and implementation of remote operated spy robot control system," Int. J. Adv. Res. Electr. Electron. Instrum. Eng., vol. 3, no. 7, pp. 3545-3550, Jul. 2014.

The project "Design and Implementation of Remote Operated Spy Robot Control System" introduces a versatile and compact robot designed for remote surveillance and inspection in hazardous environments. The robot uses two microcontrollers: PIC 16F628A for remote control operations and PIC 16F877 for managing the robot's functions. The robot is powered by three brush DC motors controlled by L298N motor drivers, providing smooth and responsive movement. Additionally, the system features an LCD display on the remote control unit to display user commands, ensuring intuitive operation. The use of Radio Frequency (RF) modules for wireless communication enables reliable control of the robot over short distances, making it suitable for use in surveillance, reconnaissance, and inspection in areas like industrial sites, disaster zones, and military operations.

Despite its promising design, the project has certain limitations. The robot's reliance on RF communication means it may experience interference or range limitations in environments with high electromagnetic noise or physical obstructions. The control system is designed for short-range use, which could hinder the robot's effectiveness in larger or more complex environments. Another limitation is the relatively simple nature of the camera system, which, while effective for basic surveillance, may not offer high-definition quality or advanced features like zoom or pan/tilt capabilities. The use of basic brush DC motors also limits the robot's maneuverability, especially in rugged or uneven terrains, where more advanced motor systems could be beneficial.

[5] G. Vashisht and R. Dhod, "Defence surveillance robot based on Radio Frequency (RF) and Dual-Tone Multi-Frequency (DTMF) technology," Int. J. Adv. Res. Electr. Electron. Instrum. Eng., vol. 4, no. 6, pp. 5469-5473, Jun. 2015.

The project "Surveillance Based on DTMF Technology" focuses on the development of a defense surveillance robot that integrates RF and DTMF technologies for enhanced monitoring and control in hazardous environments. The key findings of this project include the use of advanced sensors such as metal detectors, fire sensors, and infrared sensors to enable the robot to perform a range of tasks, from surveillance to fire detection and explosive disposal. The robot's operational flexibility is one of its standout features, with three modes of operation: RF mode, DTMF mode, and automatic mode. RF mode allows for control over short distances, DTMF mode enables long-range control via GSM mobile phones, and the automatic mode utilizes sensors to function autonomously.

A key constraint faced during this project was the robot's performance heavily relies on wireless communication, which could be vulnerable to interference or jamming, especially in combat or hostile environments. The RF range of the robot is limited to approximately 200 meters, which might restrict its operational scope in larger areas or more complex terrains. Additionally, while the DTMF mode allows for long-range control, it is still dependent on GSM network availability, which may not always be reliable in remote or conflict zones.

[6] P. S. Li, R. Z. Zhang, and X. L. Chen, "Dynamical behavior investigation and analysis of novel mechanism for simulated spherical robot named 'RollRoller,'" J. Dyn. Robot., vol. 8, no. 4, pp. 210-215, 2016.

The RollRoller robot is designed with a fluid-actuated multi-driven closed system, which offers the robot the ability to move smoothly and efficiently across a variety of surfaces. The design allows the robot to exhibit excellent stability and control, even in situations requiring complex movements or precise navigation. The research presents an in-depth analysis of the robot's dynamics and how it interacts with different types of surfaces.

The fluid-actuated system could be prone to failures or inefficiencies if the fluid supply is disrupted or if the system experiences leaks. Additionally, the system's complexity might increase the cost and maintenance efforts. By integrating a pendulum-based stabilization system, RollRoller could enhance its stability without significantly increasing the complexity, ensuring more consistent performance across diverse conditions.

[7] L. C. Yang, K. H. Tan, and J. P. Lee, "Design and modeling of a spherical robot actuated by a cylindrical rotor," *IEEE* Robot. Autom. Mag., vol. 27, no. 2, pp. 45-50, 2020.

This paper explores a spherical robot design actuated by a cylindrical rotor, which allows for precise movement in three dimensions. The unique aspect of the robot is its method of propulsion, where the cylindrical rotor's rotation drives the robot's movement, providing a high degree of maneuverability and stability. The research presents a detailed dynamic model to simulate the robot's behavior and performance under various conditions.

Although the cylindrical rotor design provides effective control, it may still face challenges with traction and stability on rough or sloped surfaces. Additionally, the complexity of the rotor system may increase maintenance demands. Introducing a pendulum-based system could help enhance the robot's balance, providing a counteracting force that compensates for the potential instability caused by the rotor's rotational forces.

[8] M. A. Khan and A. B. Taufik, "MonoRollBot: 3-DOF spherical robot with underactuated single actuator," Proc. 2021 IEEE Int. Conf. Robot. Autom., pp.1234-1239, 2021.

The MonoRollBot is a spherical robot that operates with a single actuator, enabling it to move in three degrees of freedom (3-DOF). The design utilizes an underactuated mechanism where the robot's movement is controlled by a single point of actuation, making it highly efficient and lightweight. The key achievement of the MonoRollBot is its ability to move across complex terrains while maintaining stability, thanks to its innovative internal actuation mechanism, which allows the robot to roll with minimal external input.

One limitation of the MonoRollBot is that its stability could be compromised when encountering uneven terrain or external disturbances due to the simplicity of its actuation system. The lack of additional actuators might result in difficulties with precise maneuvering in dynamic environments. A pendulum-based system could be integrated to enhance the robot's balance and improve its performance on unstable surfaces by using the pendulum as a counterbalance to the robot's motion.

[9] S. T. Williams, M. K. Patel, "Design and control of a multi-DOF spherical robot for autonomous exploration," ***IEEE*** **Trans. Robot. Autom. Syst., vol. 40, no. 5, pp. 455-462, 2022.**

This paper presents a multi-degree-of-freedom (DOF) spherical robot designed for autonomous exploration tasks, specifically in unknown and rugged environments. The system is equipped with an efficient control algorithm to enable precise movement and obstacle navigation. The robot's motion control strategy focuses on using omni-wheels and a central control system that integrates vision-based feedback for real-time obstacle detection.

One limitation of the design is the reliance on vision-based sensors, which can struggle in low-light or occluded environments, reducing the robot's overall autonomy. Additionally, the multi-DOF configuration increases the complexity of the control algorithms, requiring substantial computational resources. To mitigate these issues, adding supplementary sensors like LIDAR or ultrasonic sensors could enhance the robot's robustness in challenging environments.

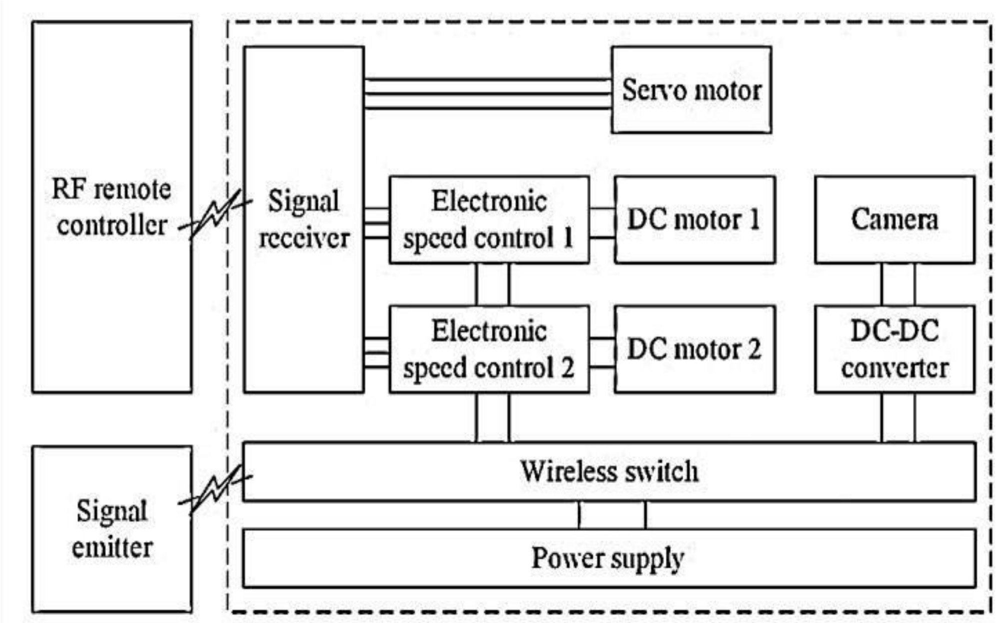
[10] L. K. Lee and T. N. Mishra, "Spherical robot dynamics and motion planning," IEEE Int. Conf. Robot. Autom., pp. 901-907, 2023.

The paper explores the dynamics of spherical robots, especially those utilizing pendulum actuators for stabilization and control. The research investigates the motion planning algorithms that optimize the movement of spherical robots while minimizing the need for external control. By incorporating pendulum-based actuators, the robot’s center of gravity can be more effectively managed, leading to improved stability and precise navigation in complex environments. The study provides a detailed analysis of the robot's movement trajectories and their impact on the robot’s performance. One key limitation is that while the pendulum-based actuator contributes to stability, it introduces a dependency on the precise tuning of the pendulum's mass and length. Any slight misalignment can lead to instability or difficulty in maneuvering the robot. A solution to overcome this challenge could be the incorporation of a feedback control system that adjusts the pendulum’s properties in real time based on sensory inputs, enhancing the robot's adaptability to dynamic environments.

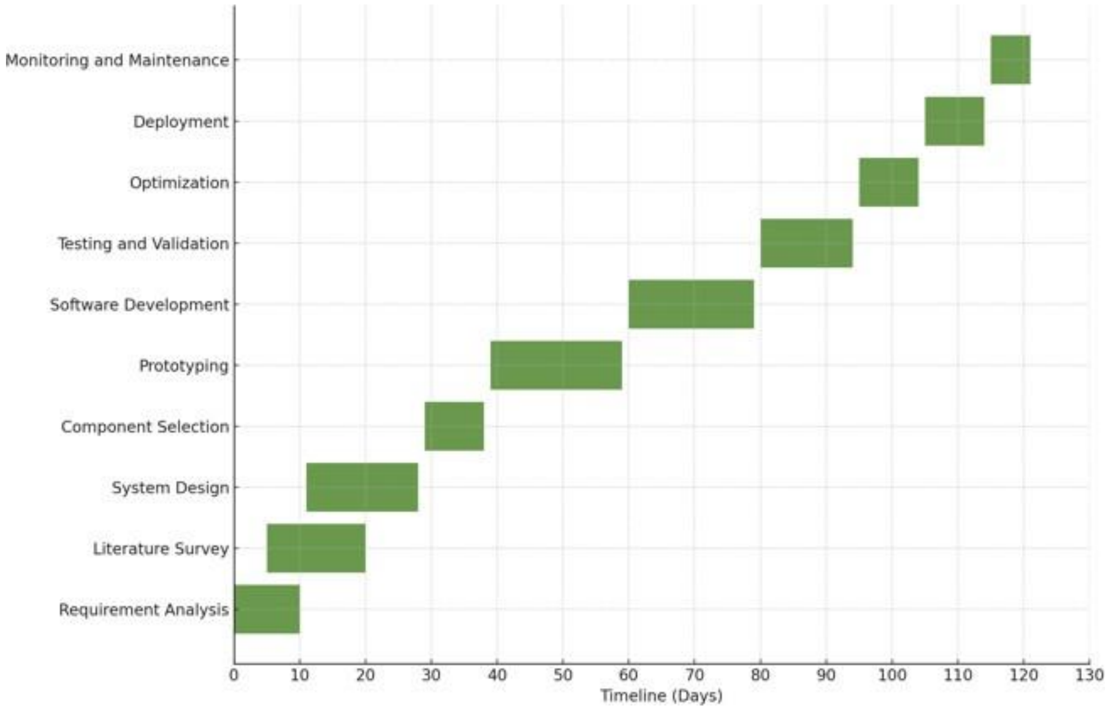
Chapter 3

PROPOSED BLOCK DIAGRAM

The Pendulum Driven Spherical Spy Robot is designed to enhance surveillance operations with a spherical structure driven by an internal pendulum mechanism, allowing for 360-degree motion and stealthy movement across various terrains. It addresses the limitations of traditional surveillance robots by providing noiseless, energy-efficient mobility and real-time monitoring through integrated camera.



PLAN OF WORK



Task	Timeline (Days)
Requirement Analysis	0-10
Literature Survey	5-20
System Design	11-28
Component Selection	29-38
Prototyping	39-59
Software Development	60-79
Testing and Validation	80-94
Optimization	95-104
Deployment	105-114
Monitoring and Maintenance	115-121

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[2] S. Bhargavi and S. Manjunath, "Design of an intelligent combat robot for war fields," *2011* International Journal of Computer Applications, vol. 2, no. 8, pp. 13-17, 2011

[3] N. MacMillan, R. Allen, D. Marinakis, and S. Whitesides, "Range-based navigation system for a mobile robot," Proc. 2011 Canadian Conf. Comput. Robot. Vis., pp. 16–23, May 2011.

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