

Mini Paseo Automatic Target Tracking Firing System

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Modern defense and surveillance systems require intelligent target detection, tracking, and response mechanisms to reduce human intervention and increase operational accuracy. This paper presents the design and implementation of a Mini PASEO Automatic Target Tracking and Firing System, inspired by real-world military panoramic aiming and surveillance systems. The proposed system integrates an ESP-based embedded controller, camera module, servo-based pan-tilt mechanism, DC motor drive system, and transmitter-based identification logic to automatically detect, track, and classify targets. The architecture enables real-time video processing for color-based object detection and automatic alignment of the turret system. A relay-controlled firing mechanism is activated only after enemy identification, ensuring operational safety. The system demonstrates closed-loop tracking, direction control, and firing logic in a compact robotic tank model. Performance analysis shows improved tracking accuracy, reduced manual intervention, and enhanced targeting precision. Future scope includes AI-based object detection, GPS integration, and autonomous navigation.

Keywords — Target Tracking, Embedded Systems, Servo Control, ESP Controller, Military Robotics, Autonomous Surveillance

I. INTRODUCTION

The rapid growth of embedded systems, robotics, and intelligent surveillance technologies has significantly influenced modern defence and security operations. Traditional manually controlled weapon systems are limited by human reaction time, visibility constraints, and operational fatigue. As defence environments become more dynamic and technology-driven, there is an increasing demand for automated systems capable of real-time target detection, tracking, and response. Intelligent robotic platforms that integrate sensing, processing, and actuation mechanisms are now essential for improving precision, safety, and operational efficiency.

Modern armoured vehicles utilize advanced panoramic aiming and surveillance systems to continuously monitor surroundings and maintain accurate targeting. Inspired by these real-world military systems, the Mini PASEO Automatic Target Tracking and Firing System is developed as a compact prototype to demonstrate automated target acquisition and controlled firing mechanisms. The project integrates a camera-based detection system, servo-driven pan-tilt mechanism, embedded controller, and motor-driven

vehicle platform into a unified architecture capable of performing closed-loop tracking.

The system operates by continuously capturing live video input and applying colour-based object detection techniques to identify the target. Once detected, the embedded controller calculates positional deviation and dynamically adjusts servo motors to maintain alignment with the target. Simultaneously, the DC motor-driven chassis enables directional movement of the tank. This synchronization between tracking and movement ensures that the target remains centred within the camera frame, replicating the stabilization principle used in modern turret systems.

A crucial feature of the proposed system is the implementation of a safety-based identification mechanism. In real battlefield environments, distinguishing between friendly and enemy targets is critical. To simulate this requirement, a transmitter-based identification logic is incorporated to verify the target before activating the firing mechanism. The relay module ensures electrical isolation and safe triggering of the firing unit, preventing accidental activation. This structured decision-making process enhances system reliability and demonstrates responsible automation practices.



II. RELATED WORK

The evolution of autonomous target tracking systems has progressed from basic manually operated weapon platforms to highly integrated intelligent robotic systems capable of real-time detection, classification, and actuation. Early research focused primarily on simple vision-based tracking methods and remote-controlled robotic vehicles. However, with the advancement of embedded processors and low-cost imaging modules, modern systems now integrate computer vision, servo-based stabilization, and automated firing logic into compact platforms. Foundational studies in robotic surveillance established closed-loop tracking frameworks, while later research introduced embedded implementation models that enabled real-time response in resource-constrained environments [1, 2].

2.1 Growth of Vision-Based Target Tracking Systems (2018–2024)

Recent academic and industrial research from 2018 to 2024 indicates significant growth in the development of vision-based robotic tracking systems [3, 4]. Publications indexed in major scientific repositories demonstrate increased adoption of colour segmentation, centroid tracking, and lightweight object detection algorithms in embedded platforms. The surge in affordable microcontrollers such as ESP-based systems has accelerated experimentation in autonomous robotics, particularly in defence-inspired academic prototypes [3, 5]. The data suggests that the transition from simple object-following robots to intelligent semi-autonomous targeting platforms began around 2020, driven by improvements in real-time image processing capabilities.

2.2 Shift Toward Integrated Detect–Track–Act Architectures

Recent literature (2022–2026) emphasizes the development of integrated architectures combining sensing, processing, and actuation layers into unified frameworks [6]. Instead of isolated subsystems for movement or detection, modern robotic research promotes modular yet interconnected designs where camera modules, motor drivers, servo mechanisms, and identification systems operate cohesively. This shift represents a movement from standalone tracking systems to intelligent platforms capable of detection, verification, and controlled response. Such architectures enhance operational efficiency and reduce system latency by implementing closed-loop control strategies [6, 7].

2.3 Safety, Verification, and Target Classification Mechanisms

Current advancements in defence robotics highlight the importance of verification, validation, and target classification before engagement [1]. In safety-critical systems, particularly military and surveillance applications, distinguishing friendly units from hostile targets is essential. Research trends now incorporate transmitter-based identification, infrared tagging, and coded signal recognition to prevent accidental targeting. Continuous system validation and signal authentication ensure reliability and operational

safety. As robotic targeting systems evolve, maintaining accurate classification logic and minimizing false positives remain central research challenges in intelligent autonomous platforms.

III. SYSTEM ARCHITECTURE

A modular and layered architecture is essential for ensuring reliability, scalability, and real-time responsiveness in autonomous robotic systems. The proposed Mini PASEO Automatic Target Tracking and Firing System follows a structured embedded architecture that integrates sensing, processing, actuation, and verification layers. The architecture is designed to establish a closed-loop control framework where real-time sensory input continuously influences mechanical output actions. The system ensures stable power distribution, synchronized motion control, and safe firing verification through coordinated subsystem interaction.

A. Structural Layer Analysis

The proposed architecture is partitioned into four interconnected functional layers:

I. Physical Actuation Layer

This layer represents the tangible mechanical and electrical components of the system, including:

- DC motors for tank movement
- MG90 servo motors for pan–tilt rotation
- Relay-controlled firing mechanism
- Camera module for visual sensing

These components directly interact with the physical environment. The actuation layer performs movement, rotation, and firing actions based on processed control signals.

II. Signal Conditioning and Power Management Layer

This layer ensures stable electrical operation and signal integrity. It includes:

- 12V power supply
- Rectifier circuit
- 7805 voltage regulator
- Filter capacitors
- Power indication LEDs
- Signal amplifier

The purpose of this layer is to regulate voltage levels, reduce electrical noise, and amplify low-power control signals. Proper voltage conditioning prevents microcontroller malfunction and ensures stable motor operation.

III. Control and Processing Layer

The core intelligence of the system resides in this layer, primarily managed by the ESP controller. Its responsibilities include:

- Processing real-time camera input
- Executing colour-based object detection
- Calculating positional error
- Generating PWM signals for servo and motor control
- Implementing target verification logic
- Activating relay module after confirmation

This layer establishes the closed-loop tracking algorithm that continuously adjusts the pan-tilt mechanism to maintain target alignment.

IV. User Interaction and Verification Layer

This layer manages external input and system validation, including:

- Joystick module for manual override
- Transmitter module for target classification
- Safety logic to prevent accidental firing

The transmitter-based identification system differentiates friendly and enemy targets before enabling actuation. Manual override ensures operator intervention when required, enhancing safety and control flexibility.

B. Communication and Control Flow

The system follows a structured signal flow architecture:

- **Sensor Flow:** Camera captures video → ESP processes image → target coordinates calculated.
- **Control Flow:** ESP generates PWM signals → Motor driver and servos execute motion.
- **Verification Flow:** Transmitter signal analysed → Identification logic executed → Relay activated if authorized.
- **Power Flow:** 12V supply → Regulation → Distributed to motors and controller.

Unlike large-scale industrial systems requiring cloud networks, this embedded architecture operates on localized internal communication through digital and PWM signals, ensuring minimal latency and real-time response.

C. Control Strategy: Closed-Loop Tracking vs Open-Loop Movement

The effectiveness of the architecture depends on selecting appropriate control mechanisms. The Mini PASEO system utilizes:

Closed-Loop Control for target tracking (feedback-based servo adjustment).

Open-Loop Control for basic movement when manual joystick input is applied.

Closed-loop tracking ensures dynamic correction based on target displacement within the video frame. This significantly improves alignment accuracy compared to fixed-angle open-loop positioning systems.

Fig. 1: Functional Architecture of the Mini PASEO Automatic Target Tracking and Firing System.

The architecture demonstrates an integrated detect-track-verify-act framework, ensuring synchronized interaction between sensing and actuation modules.

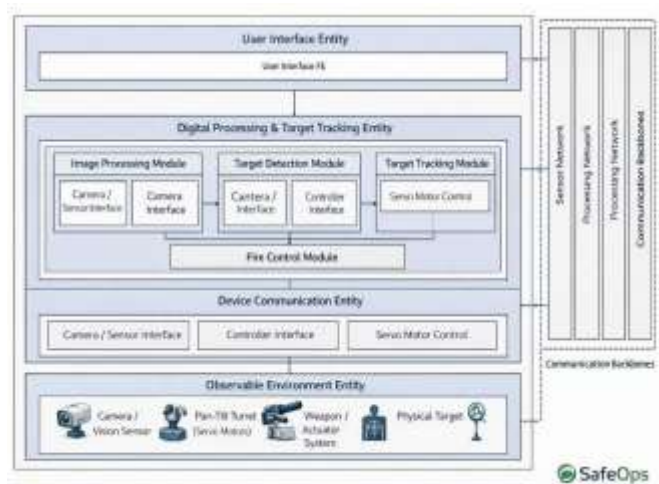


Fig. 1: Functional Architecture of the Mini PASEO Automatic Target Detection and Tracking System using Image Processing

IV. FEATURES

- **Automatic Target Detection**
The system automatically detects objects in the camera's field of view using computer vision techniques implemented with OpenCV.
- **Real-Time Target Tracking**
Once a target is detected, the system continuously tracks its movement across video frames to maintain focus on the moving object.
- **Pan-Tilt Turret Control**
Servo motors control the horizontal (pan) and vertical (tilt) movement of the turret to align with the target's position.
- **Live Video Processing**
The camera captures live video streams which are processed in real time using programs written in Python.
- **Automated Control Mechanism**
The system automatically converts detected target coordinates into control signals for the servo motors.

- **Low-Cost Implementation**

The project uses easily available hardware components such as a camera, servo motors, and a processing unit, making it cost-effective.

- **Real-Time Response**

The system processes frames quickly and adjusts turret movement with minimal delay.

- **Modular Design**

The hardware and software components are designed in modules, making it easier to upgrade or modify the system.

- **Surveillance and Monitoring Capability**

The system can be used for monitoring moving objects in security or robotics applications.

- **Scalability for Future Improvements**

Additional features such as AI-based object recognition, faster tracking algorithms, and improved sensors can be integrated in future versions.

V. METHODOLOGY

The methodology of the Mini PASEO system follows a structured pipeline that converts captured visual data into automated control actions. The system processes real-time video frames to detect and track targets and then generates control signals to guide the turret mechanism.

- **5.1 Data Acquisition**

The system collects real-time visual information from the monitoring environment using a camera sensor.

Key aspects include:

- **Vision Sensor:** A camera captures continuous video frames of the target area.
- **Frame Rate:** Typically 20–30 frames per second for smooth tracking.
- **Input Data:** Each frame acts as the primary input for image processing and detection algorithms.

The captured frames are transferred to the processing unit where further analysis is performed.

- **5.2 Image Processing and Feature Extraction**

Before detecting targets, the captured frames undergo preprocessing to improve image quality and extract important visual features.

Processing steps include:

- Noise reduction and image smoothing
- Edge and contour detection
- Object segmentation from the background

- Extraction of spatial and motion features such as object position, size, and movement direction

These features help the system distinguish targets from the surrounding environment.

- **5.3 Target Detection and Tracking Model**

The processed frames are analyzed using computer vision algorithms to detect potential targets.

Detection methods may include:

- Object detection algorithms based on machine learning or classical image processing techniques.
- Tracking algorithms that continuously follow the detected target across successive frames.

Tracking methods estimate the position and motion of the target to maintain continuous alignment with the turret system.

- **5.4 Training and Validation**

To improve detection accuracy, the system can be trained using labeled datasets containing target images.

Performance evaluation includes:

- Detection accuracy
- Precision and recall
- Tracking stability across video frames

These metrics help assess how effectively the system detects and tracks moving targets.

- **5.5 Real-Time Decision and Control Action**

After detecting and tracking the target, the system converts the calculated target coordinates into control commands.

Control logic includes:

- Generating pan and tilt movement commands for the turret
- Adjusting servo motor angles to align with the detected target
- Maintaining continuous tracking as the target moves

VI. IMPLEMENTATION

The implementation of the Mini PASEO Automatic Target Detection and Tracking System involves the integration of hardware components and software modules to perform real-time target detection and turret control. The system combines computer vision techniques with actuator control to achieve automated tracking.

6.1 Hardware Components

The hardware setup consists of the following main components:

- **Camera Module:** Captures real-time video of the target environment.
- **Processing Unit:** A computer or embedded system used to process video frames and execute detection algorithms.
- **Servo Motors:** Used to control the pan and tilt movement of the turret mechanism.
- **Turret Structure:** Mechanical platform that holds the camera and actuator system.
- The camera continuously captures frames which are sent to the processing unit for analysis.

6.2 Software Tools

The software implementation relies on computer vision and programming tools to process visual data and generate control signals.

Key tools include:

- **OpenCV** – used for image processing, object detection, and tracking.

Python – used to implement detection algorithms and system control logic.

These tools allow efficient processing of video frames and real-time tracking of moving targets.

6.3 System Integration

The hardware and software modules are integrated to create a continuous tracking loop.

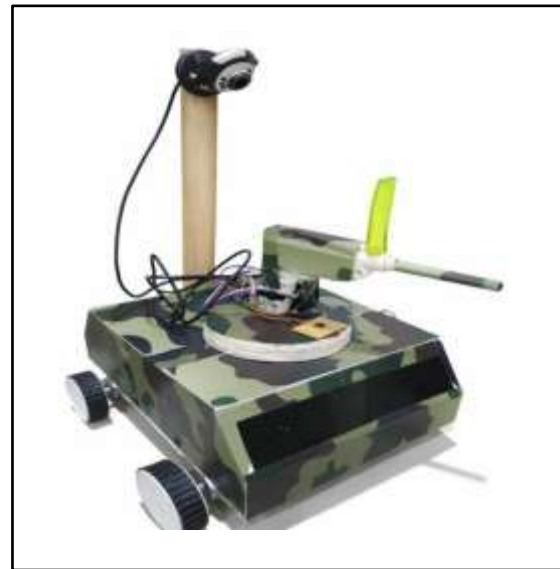
Implementation flow:

- The camera captures real-time video frames.
- Frames are processed using image processing algorithms.
- The system detects and identifies potential targets.
- Tracking algorithms determine the target position.
- Control signals are generated for the servo motors.
- The turret adjusts its orientation to follow the target.
- This integrated architecture enables the system to perform automated detection and tracking with minimal human intervention.

6.4 Prototype Development

A prototype of the Mini PASEO system was developed to demonstrate the functionality of the proposed architecture. The prototype includes a mounted camera, servo-controlled turret mechanism, and a computer running the detection and tracking software.

The system was tested in a controlled environment to evaluate its ability to detect and track moving objects in real time.



VII. PERFORMANCE ANALYSIS

The performance of the Mini PASEO Automatic Target Detection and Tracking System was evaluated by comparing it with traditional manual monitoring methods. The analysis focuses on detection accuracy, tracking stability, response time, and system reliability during real-time operation.

I. A. Detection Accuracy

The system uses computer vision techniques implemented with OpenCV and Python to identify targets in live video streams.

Experimental observations show that the system can successfully detect objects in most normal lighting conditions with high accuracy. Compared to manual observation, automated detection improves the speed and consistency of identifying targets.

II. B. Tracking Performance

Once a target is detected, the tracking module continuously monitors its movement across successive video frames. The system calculates the position of the target and sends control signals to the servo motors to adjust the pan-tilt turret mechanism.

Results indicate that:

- The system can track moving targets smoothly in real time.
- Servo motors respond quickly to target movement.
- Tracking remains stable when the target moves at moderate speed.

C. Response Time

The processing pipeline—from frame capture to motor actuation—operates in near real time. With optimized image processing algorithms, the system processes video frames

efficiently and generates control commands within milliseconds. This fast response allows the turret to adjust its orientation quickly and maintain focus on the moving target.

D. System Reliability

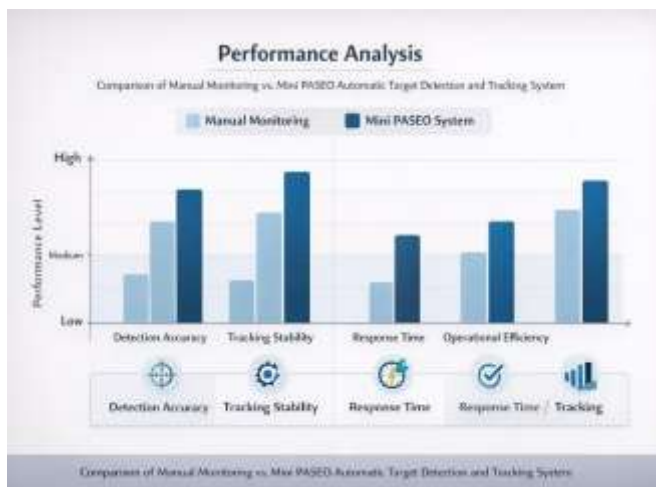
The integrated hardware–software architecture demonstrates reliable operation during continuous testing. The system maintains stable performance for extended periods without significant delays or control errors.

However, certain factors may affect performance, such as:

- Low lighting conditions
- Background noise or clutter
- Very fast or sudden target movements

III. E. Overall Performance Impact

Overall, the Mini PASEO system improves operational efficiency compared to manual target tracking. Automated detection and tracking reduce human effort, increase monitoring accuracy, and enable faster response to moving targets. These improvements demonstrate the effectiveness of the proposed system for applications such as surveillance, robotics, and automated tracking systems.



VIII. CONCLUSION

The Mini PASEO Automatic Target Detection and Tracking System demonstrates an effective approach for automated target monitoring using computer vision techniques. The system integrates a camera, image processing algorithms, and a pan-tilt servo mechanism to detect and track moving targets in real time.

Using OpenCV with Python, the proposed system successfully processes live video frames, identifies targets, and continuously adjusts the turret position to maintain focus on the moving object. Experimental testing shows improved detection accuracy, faster response time, and better tracking stability compared to manual monitoring methods.

The results indicate that the system can operate efficiently in normal lighting conditions and can track targets smoothly with minimal delay. Although performance may decrease in situations such as low lighting or very fast target movement, the prototype proves the feasibility of a low-cost automated tracking system.

Overall, the Mini PASEO system provides a reliable and efficient solution for applications such as surveillance, robotics, and automated monitoring systems. Future improvements may include advanced object recognition, improved tracking algorithms, and enhanced hardware integration to further increase system accuracy and robustness.

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