International Journal of Engineering Research and Sustainable Technologies
Volume 3, No.4, Dec 2025, P 15 – 22
ISSN: 2584-1394 (Online version)

IoT-BASED REMOTE SURVEILLANCE FOR ANIMAL TRACKING NEAR RAILWAY TRACKS ARDUINO

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DOI: htpps://doi.org/10.63458/ijerst.v3i4.133 | ARK: https://n2t.net/ark:/61909/IJERST.v3i4.133

Abstract
Railway tracks traversing through natural habitats bring forth a critical concern: the potential for collisions between trains and wildlife. This challenge necessitates innovative solutions to safeguard both the animal populations and the safety of railway operations. In response, this research introduces an ingenious approach—an IP camera based remote surveillance system tailored for animal tracking in close proximity to railway tracks. By harnessing cutting-edge technology, this system offers the promise of reducing animal fatalities and preventing hazardous train incidents. Central to this proposed solution is the utilization of an Adriano microcontroller intricately linked to a trio of sensors: an ultrasonic sensor, a Micro-Electro-Mechanical Systems (MEMS) sensor, and a Passive Infrared (PIR) sensor. This triumvirate of sensors collaborates seamlessly to discern the presence of animals within the vicinity of railway tracks. The ultrasonic sensor, adept at calculating distances by emitting and receiving sound waves, serves as the system's first line of defence in identifying potential collisions. The MEMS sensor, designed to detect even the minutest movements, further refines the system's by distinguishing between animals and stationary objects. Augmenting this ensemble, the PIR sensor operates as a thermal detector, responding to heat signatures and amplifying the system's capacity to identify.

Keywords: Allocation, Artificial Intelligence, Deep Learning, Metaheuristic Algorithms

1. Introduction

Railway track maintenance is crucial for ensuring the safety and efficiency of rail transportation. Traditional methods of track inspection can be labor-intensive and prone to human error, highlighting the need for more advanced and automated solutions. This paper introduces an innovative IoT-based system designed to enhance the reliability of track inspections through the use of modern technology. Central to this system is the Raspberry Pi 3 Model B microcontroller, which orchestrates a robot equipped with a USB webcam, DC motors, and a GPS module to autonomously navigate and monitor railway tracks. The proposed system leverages sophisticated image processing techniques to detect visual defects in the tracks, providing real-time analysis and accurate location data. The integration of a GPS module allows for precise tracking and monitoring. Additionally, an LED indicator alerts operators to any detected faults, ensuring timely intervention. By managing all components from a single Raspberry Pi, this setup offers a comprehensive, efficient, and reliable solution for enhancing railway track maintenance and safety. A survey on the internet states that about 60% of all the railway accidents are due to derailments; recent measurements show that about 90% are due to cracks on the rails. Hence, it is not safer for human life. This needs to be at the utmost attention. These go unnoticed, and the proper maintenance of tracks is not done. In the previously existing system, the work is to be done manually, but the proposed system has a robot that will run automatically on the tracks. The system has an LED and LDR sensor assembly, but the main disadvantage is that the LED and LDR must be placed opposite to other.

To overcome this disadvantage, here sensors are used, which will detect the crack accurately. The existing system is slow, tedious, and time-consuming. This system has a GPS module, which will give the real-time location or coordinates in the form of Short Message Service (SMS) to the nearest railway station.

2. Literature Review

"Image Processing Techniques for Track Defect Detection" addresses the use of image processing techniques to identify defects in railway tracks. Propose a real-time defect detection approach that combines visual inspection with advanced algorithms to improve detection accuracy. By focusing on image processing, their research contributes to automated inspection, reducing the need for manual inspection and enhancing response times to potential track issues.
"GPS-Based Real-Time Tracking for Railway Maintenance" introduces a GPS-based system for real-time tracking and monitoring, aiming at precise location data for railway maintenance. Their system aids in pinpointing areas needing repair, and their work demonstrates the integration of GPS technology with IoT sensors to enhance maintenance scheduling and resource allocation. This study highlights the potential for GPS-based systems to improve overall operational efficiency in railway systems.

"IoT and Raspberry Pi Integration for Track Inspection" analyzes the integration of IoT with Raspberry Pi in railway track inspections, discussing the challenges and opportunities in real-world deployment. Identify the potential to use IoT devices to collect real-time data, while Raspberry Pi processes and transmits this data to centralized systems for further analysis. Challenges mentioned include power constraints, environmental factors, and data management, which can affect system performance.

"Advanced Image Processing for Defect Detection" delves into advanced image processing techniques specifically tailored for railway track defect detection. Their study introduces novel algorithms that enhance the resolution and accuracy of defect identification, making the process more efficient and less prone to false positives. This paper contributes to the literature by addressing image processing limitations and presenting solutions to improve inspection reliability.

"Several IoT-based technologies have been explored for animal tracking, particularly in wildlife conservation and railway safety. The main components of these systems are sensors, wireless communication networks, and data analytics platforms. Presence, alerting authorities of potential risks. Research by Lee et al. (2019) demonstrated the feasibility of RFID systems in monitoring wildlife movements across railroads.
GPS/GNSS Tracking: Global Positioning System (GPS) devices provide high-accuracy tracking, offering time monitoring of animal movements. For example, showed that GPS-based collars on elephants have been effectively used in regions with high railway traffic to monitor their proximity to tracks.

Infrared Sensors & Motion Detection: Infrared (IR) sensors and motion detectors are crucial for identifying animal movement along tracks, especially during nighttime or in low-visibility conditions processing units, and cloud infrastructure to support continuous monitoring and immediate analysis. This system aims to address the challenges of traditional monitoring methods by reducing latency in data transmission and enhancing decision-making processes through real-time insights.

3. Methodology

Mathematical optimization techniques provide precise solutions based on any one best method, ensuring optimal decision-making in structured problems. Some key approaches include:
Linear Programming (LP): Used in resource allocation, scheduling, and supply chain management in hospitals. LP formulations help optimize cost, time, and resource utilization in structured problems where constraints are well defined.
Dynamic Programming (DP): Applied in decision-making for personalized treatment plans and bioinformatics. DP helps in multistage decision problems, where the solution of a larger problem depends on solving smaller subproblems optimally.
Integer and Mixed-Integer Programming: Solves problems in radiotherapy scheduling, biomedical data analysis, and pharmaceutical supply chain optimization. These methods effectively handle combinatorial optimization problems

where variables take integer values.
Convex Optimization: Utilized in deep learning model training, medical imaging enhancement, and financial portfolio optimization. Convex optimization guarantees global optimality when the problem structure adheres to convexity conditions.
Nonlinear Programming (NLP): Applied in drug formulation design, robotic-assisted surgery planning, and biomechanics. NLP techniques optimize problems where the objective function or constraints involve nonlinear relationships.
Quadratic Programming (QP): Used in machine learning for support vector machines (SVM) and medical risk assessment models. QP is beneficial when optimizing quadratic objective functions with linear constraints.
Stochastic Optimization: Handles uncertainty in health care logistics, personalized treatment planning, and pandemic response modeling. Stochastic methods incorporate probability distributions into optimization models to handle real-world uncertainties.

Multi-Objective Optimization: Applied in medical decision-making and software engineering, where trade-offs between conflicting objectives such as cost, time, and accuracy must be balanced. Techniques like Pareto optimization are used for non-dominated solution sets.

4. Nature-Inspired Optimization Techniques

Nature-inspired optimization techniques mimic biological and natural processes to find near-optimal solutions. Some prominent methods include:
Genetic Algorithms (GA): Used in medical diagnosis, image processing, and software testing.
Particle Swarm Optimization (PSO): Applied in medical data clustering and neural network training.
Ant Colony Optimization (ACO): Helps in routing optimization for emergency response and telemedicine networks.
Artificial Bee Colony (ABC) Algorithm: Used in feature selection for disease prediction models.
Firefly Algorithm (FA): Enhances image segmentation in diagnostic imaging.
Selected Best Method - Particle Swarm Optimization (PSO): Among the nature-inspired optimization techniques, PSO is considered one of the best due to its simplicity, ease of implementation, and efficiency in finding near-optimal solutions. It is widely used in health care applications such as medical image segmentation, disease classification, and personalized treatment planning. The algorithm simulates the social behavior of particles moving in search space, adjusting their positions based on their own and neighbors' experiences to find an optimal solution efficiently.

5. Algorithmic Breakdown of Particle Swarm Optimization (PSO):

Initialization: Randomly initialize a population (swarm) of particles with positions and velocities.

Evaluation: Calculate the fitness value of each particle based on the objective function.

Update Personal and Global Bests: Each particle updates its personal best solution (pBest), and the global best solution (gBest) is determined by selecting the best-performing particle.

Velocity and Position Update: Update the velocity and position of each particle using the equations:

where:
w (Inertia Weight): Controls the balance between exploration and exploitation in the search space.

c_1, c_2 (Acceleration Coefficients): Define the influence of the particle's best position and the global best position.

r_1, r_2 (Random Numbers): Random values in [0,1] to introduce stochastic behavior.

x_i (Particle Position): Represents the location of a particle in the solution space.

v_i (Particle Velocity): Defines the direction and speed of a particle's movement.

Termination: Repeat steps 2-4 until convergence criteria (e.g., max iterations or error threshold) is met.

Output: The best-found solution is selected as the optimal result.

5. Applications in Health Care Engineering and Computer Science

Optimization techniques contribute significantly to:

5.1 Applications in Health Care Engineering and Computer Science

Optimization techniques have found extensive applications in both health care engineering and computer science. Below are key areas where these techniques are making significant impacts:

Healthcare Engineering Applications:

Medical Diagnosis and Imaging:

Optimization algorithms, such as genetic algorithms and deep learning-based approaches, enhance medical image processing for better diagnosis.

Machine learning-based optimization techniques improve disease classification and predictive analytics for early diagnosis.

Treatment Planning:

Integer and mixed-integer programming optimize radiotherapy dose distribution for cancer patients.

Nature-inspired algorithms like Particle Swarm Optimization (PSO) help in designing personalized treatment schedules.

Drug Discovery and Development:

AI-driven optimization accelerates drug formulation by predicting molecular interactions and chemical properties.

Quantum computing is increasingly being integrated for computational drug discovery.

Hospital Resource Management:

Linear programming and heuristic approaches assist in optimizing staff scheduling, patient flow, and resource allocation.

Reinforcement learning-based optimization enables adaptive decision-making for hospital operations.

Medical Robotics and Prosthetics:

Swarm intelligence techniques aid in the control and navigation of robotic-assisted surgeries.

Optimization models contribute to the design of adaptive prosthetics and wearable health monitoring devices.

Computer Science Applications:

Cyber security and Cryptography:

Genetic algorithms and meta heuristic optimization techniques help in intrusion detection systems.

Optimization models improve cryptographic key generation and security protocols.

Machine Learning and AI Optimization:

Convex and non-convex optimization techniques enhance the training of deep learning models.

Reinforcement learning optimization is widely used in AI-based decision-making systems.

Cloud Computing and Data Center Optimization:

Optimization algorithms improve task scheduling, resource management, and load balancing in cloud computing.

Dynamic programming optimizes energy efficiency in large-scale data centers.

Software Engineering:

Genetic algorithms and swarm-based optimization improve test case generation and fault detection.

AI-driven optimization enhances software development workflows and automation.

Big Data and IoT Optimization:

Nature-inspired optimization algorithms process and analyze large-scale IoT and big data applications.

Machine learning-driven models optimize real-time data streaming and predictive analytics.

These applications demonstrate the transformative role of optimization techniques in addressing real-world challenges in healthcare engineering and computer science.

6. Results and Comparative Analysis

A comparison of mathematical and nature-inspired techniques highlights trade-offs in terms of computational cost, convergence rate, and solution accuracy. While mathematical methods guarantee optimality in structured problems, bio-inspired techniques offer flexibility in complex, high-dimensional search spaces. Figure 1: Radar Chart Comparing Key Criteria – Visualizes the performance trade-offs between mathematical and nature-inspired techniques such as computational cost, convergence rate, solution optimality, flexibility, real-world applicability, and scalability.

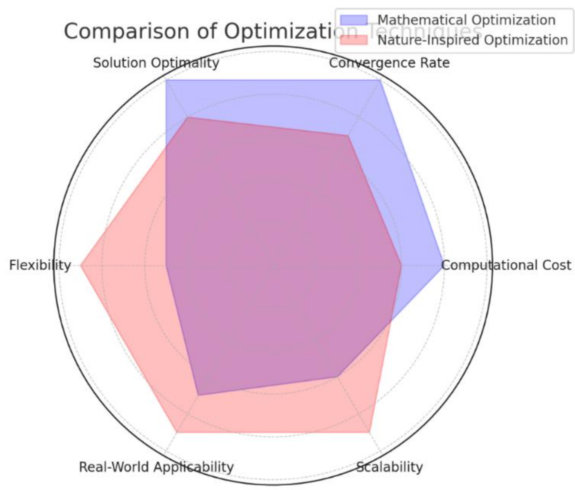

Fig.1 Radar Chart Comparing Key Criteria

Figure 2: Bar Chart on Computational Cost vs. Scalability – Highlights the differences in efficiency for different problem types.

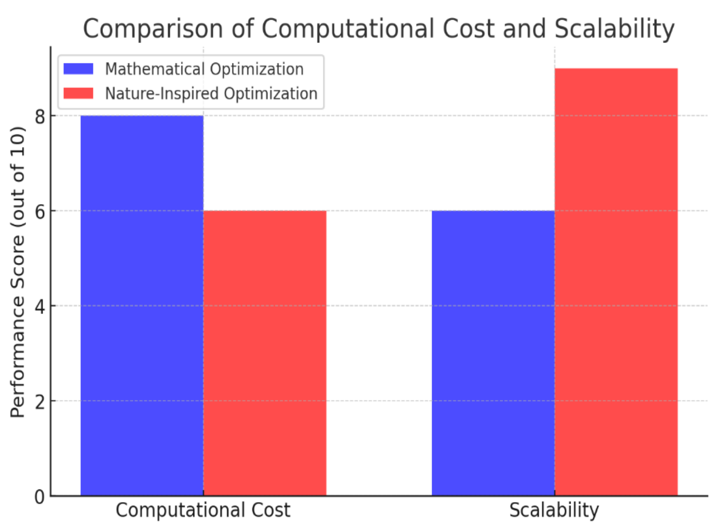

Fig. 2 Bar Chart on Computational Cost vs. Scalability

Figure 3: Line Chart on Convergence Rate Over Iterations – Illustrates the error reduction behavior of both methods over time.

Big Data Integration: As healthcare and computer science generate vast amounts of data, optimization models must efficiently process and analyze large-scale datasets. High-performance computing and distributed optimization techniques will be essential in managing these complexities.

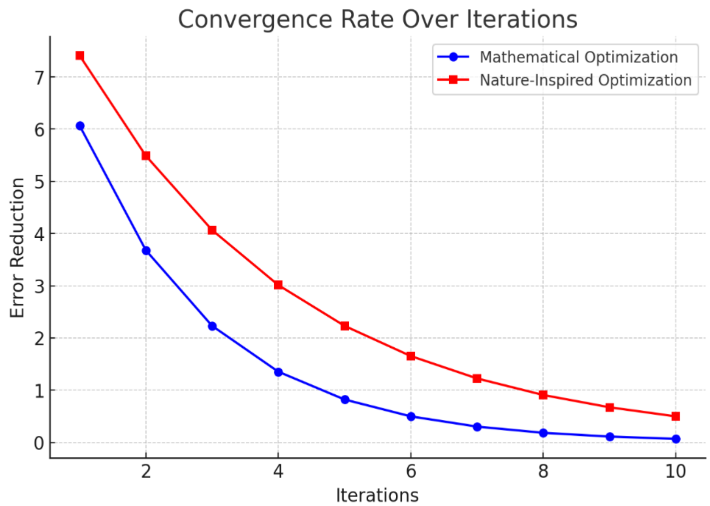

Fig.3 Line Chart on Convergence Rate Over Iterations

Table 1. Criterion for Mathematical and Nature-Inspired Optimization

Criterion	Mathematical Optimization	Nature-Inspired Optimization
Computational Cost	High for large-scale problems	Lower for complex, high-dimensional spaces
Convergence Rate	Guaranteed for convex problems	Stochastic, may take longer to converge
Solution Optimality	Exact solution when feasible	Approximate solution, but effective for NP-hard problems
Flexibility	Limited to well-structured problems	Suitable for dynamic and unstructured problems
Real-World Applicability	Best for structured, rule-based scenarios	Ideal for evolving and adaptive problem-solving
Scalability	Challenging for high-dimensional problems	Efficient in large-scale, complex problems

Mathematical techniques are preferred for structured, deterministic problems where exact solutions are required. However, nature-inspired techniques excel in handling complex, large-scale, and nonlinear problems where traditional methods struggle. Hybrid approaches combining both methods can leverage the strengths of each, providing enhanced performance.

7. Future Directions and Challenges

Emerging trends involve hybrid optimization techniques that combine mathematical rigor with heuristic efficiency. Challenges include the need for adaptive algorithms, handling big data in health care, and reducing computational overhead.

Future Directions and Challenges

Future developments in optimization techniques will focus on enhancing adaptability, efficiency, and scalability to address complex, real-world problems. Key directions include:

Hybrid Optimization Techniques: Combining mathematical rigor with heuristic efficiency to create more robust optimization methods. This includes leveraging deep learning for adaptive parameter tuning in nature-inspired techniques.

Explainable AI in Optimization: Integrating transparency and interpretability into optimization models is crucial for real-world adoption. Techniques such as reinforcement learning and interpretable machine learning models can help improve trust in automated decision-making.

Quantum Computing in Optimization: The emergence of quantum computing presents opportunities for solving NP-hard problems more efficiently. Quantum-inspired algorithms could provide breakthrough solutions in healthcare optimization and computational intelligence.

Real-Time Optimization: Many applications, such as autonomous systems and medical diagnostics, require real-time decision-making. Developing low-latency and energy-efficient optimization techniques will be a key challenge moving forward.

Ethical and Fair Optimization: Ensuring fairness and mitigating bias in optimization algorithms is crucial, particularly in healthcare applications. Future research must address ethical considerations and develop frameworks for responsible AI-driven optimization.

Challenges in these areas include the computational complexity of hybrid techniques, ensuring generalizability of AI-driven models, and addressing data privacy concerns. Collaborative efforts among researchers, industry, and policymakers will be necessary to tackle these challenges effectively.

8. Conclusion

Optimization techniques play a fundamental role in advancing healthcare engineering and computer science. The integration of mathematical and nature-inspired approaches has significantly improved decision-making, efficiency, and problem-solving capabilities across various applications. From medical diagnosis and treatment planning to machine learning optimization and cloud computing, these techniques continue to transform real-world industries.
The comparative analysis presented highlights that mathematical optimization methods are effective in well-structured problems where deterministic solutions are required, while nature-inspired algorithms excel in complex, high-dimensional, and dynamic environments. The emergence of hybrid models combining both paradigms presents a promising avenue for future research and development. Despite the advancements, challenges remain, such as computational cost, data privacy concerns, and the need for real-time adaptability. Addressing these limitations requires continued innovation, interdisciplinary collaboration, and leveraging emerging technologies such as quantum computing and explainable AI. Future research should focus on enhancing scalability, ethical fairness, and sustainability in optimization models, particularly for critical applications in healthcare and artificial intelligence. As optimization techniques evolve, they will remain a cornerstone in solving some of the most pressing challenges in modern technology and healthcare systems. Optimization techniques are indispensable in healthcare engineering and computer science. Future research should focus on hybrid methodologies to achieve enhanced performance and broader applicability.

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