Jean Lucas Rothstein Machado

SIMPATIA: System for Identification and Monitoring for Assured Protection of Workers using AI

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Jean Lucas Rothstein Machado

SIMPATIA: An AI-Powered System for Automated Monitoring of Personal Protective Equipment in Industrial Environments

Final Course Project submitted to the Institute of Technology and Leadership (INTELI), to obtain a bachelor's degree in Computer Engineering.

Advisor: Prof. Rodrigo Nicola

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Resumo

Machado, Jean. **SIMPATIA: Sistema de Identificação e Monitoramento para Proteção Assegurada dos Trabalhadores usando IA**. 2025. nº de folhas. TCC (Graduação) – Curso Engenharia da Computação, Instituto de Tecnologia e Liderança, São Paulo, 2025.

O projeto SIMPATIA (Sistema de Identificação e Monitoramento para Proteção Assegurada do Trabalhador por IA) foi desenvolvido para automatizar a verificação do uso de Equipamentos de Proteção Individual (EPI) em ambientes industriais da empresa parceira, Atvos. O objetivo central foi aumentar a segurança e a eficiência operacional, substituindo a observação manual, suscetível a inconsistências, por um sistema de monitoramento contínuo e automatizado. Para alcançar este objetivo, foi implementada uma solução de visão computacional utilizando modelos de deteção de objetos da família YOLO, sobre uma infraestrutura baseada em Python com processamento multithreaded para garantir a escalabilidade. O sistema opera de ponta a ponta, desde a captura de vídeo até a geração de insights acionáveis, integrando-se com ferramentas corporativas como OneDrive, SharePoint e Power BI. Os resultados chave incluem a entrega de um protótipo técnico (MVP) validado e a demonstração de alta performance do modelo de IA. Através de estratégias avançadas de dados, como a fusão de datasets para generalização e o treino progressivo para especialização, o modelo alcançou métricas de precisão de alto nível, superando significativamente os benchmarks iniciais. Conclui-se que o projeto demonstrou com sucesso a viabilidade técnica de utilizar inteligência artificial para resolver um problema crítico de segurança industrial, fornecendo uma base robusta e de baixo custo para futuras expansões.

Palavras chave: visão computacional; inteligência artificial; segurança industrial; monitoramento; YOLO

ABSTRACT

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The SIMPATIA project (System for Identification and Monitoring for Assured Protection of Workers using AI) was developed to automate the verification of Personal Protective Equipment (PPE) use in the industrial environments of the partner company, Atvos. The central objective was to increase operational safety and efficiency by replacing manual observation, which is susceptible to inconsistencies, with a continuous and automated monitoring system. To achieve this goal, a computer vision solution was implemented using object detection models from the YOLO family on a Python-based infrastructure with multi-threaded processing to ensure scalability. The system operates end-to-end, from video capture to the generation of actionable insights, integrating with corporate tools such as OneDrive, SharePoint, and Power BI. Key results include the delivery of a validated technical prototype (MVP) and the demonstration of high-performance AI modeling. Through advanced data strategies, including dataset merging for generalization and progressive training for specialization, the model achieved top-tier accuracy metrics, significantly surpassing initial benchmarks. It is concluded that the project successfully demonstrated the technical feasibility of using artificial intelligence to solve a critical industrial safety problem, providing a robust and low-cost foundation for future expansions.

Key words: computer vision; artificial intelligence; industrial safety; monitoring; YOLO.

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Summary

1. Introduction

Workplace safety is a paramount concern in industrial settings, where adherence to safety protocols directly correlates with the prevention of accidents and the promotion of a secure operational environment. Ensuring the consistent use of Personal Protective Equipment (PPE) is a foundational element of these protocols. This project introduces the SIMPATIA (System for Identification and Monitoring for Assured Protection of Workers using AI), a technological intervention designed to enhance safety compliance at industrial plants. By leveraging artificial intelligence and computer vision, SIMPATIA automates the monitoring of PPE usage, transforming a traditionally manual and often inconsistent process into a reliable, data-driven system. This introduction provides the context, motivation, and objectives that guided the development of this innovative solution.

1.1. Partner Company Context & Motivation

The SIMPATIA project was developed in partnership with Atvos, a major player in the industrial sector. Atvos operates large-scale industrial plants where stringent safety standards are critical. The primary motivation for this project stemmed from the company's strategic goal to increase operational safety and efficiency. The manual process of monitoring PPE compliance across vast facilities is labor-intensive and prone to human error, leading to potential gaps in safety enforcement. Atvos sought an automated solution to reduce the manual effort required, improve the consistency of compliance checks, and create a safer working environment for its employees.

1.2. Problem Definition (Corporate Pain Point) and Baseline

The core business problem, or "corporate pain point," addressed by this project is the inherent challenge of ensuring consistent and reliable PPE compliance through manual observation. Human-led monitoring can be subjective, sporadic, and difficult to scale across multiple locations and shifts, resulting in incomplete safety oversight.

This inconsistency poses a direct risk to worker safety and regulatory compliance. As no quantitative baseline metrics for the existing manual process were available, the project's objective was defined as a qualitative and functional improvement over the unquantified consistency and reliability of the current manual monitoring system.

1.3. Proposed Solution and Expected Contribution

The proposed computational solution is the SIMPATIA system, an AI-driven platform that uses computer vision for real-time, automated identification of PPE compliance violations. The system is designed to analyze video streams from industrial cameras, detect workers who are not wearing required protective gear (e.g., helmets), and generate immediate alerts. The specific, quantifiable contribution of this project is demonstrated by the high performance of its core AI component. Through advanced data curation and a progressive training strategy, the final object detection model achieved the accuracy of 0.839, demonstrating exceptional results in identifying "no-helmet" violations within the target environment. This result represents a significant improvement over initial benchmarks and validates the solution's technical efficacy.

1.4. Business Objectives and Structure of the Thesis

The expected business results for Atvos from the implementation of SIMPATIA include enhanced workplace safety through proactive violation detection, improved compliance reporting through automated data collection, and the creation of actionable safety insights from the analysis of violation trends. This data-driven approach empowers safety managers to identify high-risk areas or times and implement targeted interventions.

This document is structured to provide a comprehensive overview of the project. The following chapter, "Solution Development," details the strategic rationale, technical architecture, implementation process, and business impact of the SIMPATIA system. The final chapter, "Conclusion," summarizes the project's achievements, reiterates its value proposition, and offers recommendations for future evolution. This structured approach moves from the project's foundational goals to the detailed technical and strategic rationale that guided its successful development.

2 Solution Development

This chapter constitutes the technical core of the thesis, detailing the journey from conceptual design to a validated prototype. It outlines the strategic and technological decisions that shaped the SIMPATIA system, describes its architecture and implementation, and assesses its final impact and contribution to the business. This section provides a comprehensive account of how the project's objectives were translated into a functional and valuable solution for the partner company, Atvos.

2.1 Applied Rationale

A robust and effective solution requires a foundation built upon both a sound business strategy and appropriate technological choices. This section justifies the project's direction by examining the external market landscape, defending the selection of core technologies, and outlining the management methodology that guided its execution. These elements collectively form the rationale that ensured the project remained aligned with both business needs and technical best practices.

2.1.1 Business Area Rationale

The strategic positioning of the SIMPATIA project was informed by a thorough analysis of its operational environment. A PESTEL analysis identified key external factors, including increasing regulatory pressure for workplace safety and the need to navigate privacy considerations under regulations like the LGPD. Concurrently, a Porter's Five Forces analysis revealed a strategic niche for a proprietary solution, characterized by limited direct rivals and low buyer power due to the high compliance pressure in the industry, which makes effective monitoring solutions a necessity rather than an option.

Furthermore, a market benchmarking study was conducted against two commercial alternatives, Minsait and Mob Conduta. This analysis highlighted that while off-the-shelf solutions offered faster deployment, developing a proprietary system like SIMPATIA provided full ownership of the data pipeline, lower long-term implementation costs, and greater customizability. This evaluation was instrumental in justifying the decision to develop an in-house solution tailored to Atvos's specific needs.

2.1.2 **Technological rationale for the solution**

The selection of technologies was driven by the need for a scalable, efficient, and integrable system. YOLO (You Only Look Once) models, specifically YOLOv8 models, were chosen for object detection due to their excellent balance of accuracy and real-time performance. An internal benchmark study confirmed that YOLO offered the right capabilities for this specific use case.

The system's backbone was built using Python, leveraging its extensive libraries for AI and data processing. OpenCV was used for image and video stream manipulation, while multi-threading was implemented to handle multiple camera feeds in parallel, ensuring the solution's scalability. For the data pipeline, integration with enterprise tools already in use at Atvos was prioritized. This included using OneDrive and SharePoint for secure cloud storage of evidence images and Power BI for creating an interactive data visualization dashboard, allowing for seamless integration into the company's existing IT ecosystem.

2.1.3 **Fundamentals of Management and Development Methods**

The project was executed using an Agile framework, which provided the flexibility to adapt to evolving requirements and technical challenges. The development process was structured into a series of sprints distributed across several modules, allowing for an iterative and incremental approach. This methodology facilitated continuous progress and regular feedback loops, enabling the project to evolve from initial feasibility studies and proofs-of-concept to a fully validated Minimum Viable Product (MVP) in a structured and predictable manner

2.2 Specification and Development

This section translates the project's strategic and technical rationale into a concrete implementation. It details the system's functional and non-functional requirements, presents its end-to-end architecture, chronicles the development process of the Minimum Viable Product (MVP), and summarizes the results of the final technical validation. This provides a clear blueprint of what the SIMPATIA system does and how it was built.

2.2.1 Requirements and Specifications

The system's design was guided by a clear set of requirements to ensure it met the core business needs.

Functional Requirements:

• Real-time detection of "no-helmet" violations from live or recorded video streams.

• Automated capture of image evidence at the moment a violation is detected.

• Generation of real-time desktop notifications to alert operators of compliance failures.

• Secure storage and automatic synchronization of evidence files to a cloud platform (OneDrive/SharePoint).

• Data visualization on a Power BI dashboard, with capabilities for filtering events by date and time.

Non-Functional Requirements:

• Scalability to handle multiple camera feeds simultaneously, achieved through a multi-threaded architecture.

• System stability for continuous, long-duration operation, as validated in the final testing phase.

• Traceability of all detected events through standardized, timestamped filenames for auditing and analysis.

2.2.2 **Architecture and Technology**

The SIMPATIA system features an end-to-end architecture designed for automation and integration. The data flow begins with video capture from sources simulating RTSP streams or local video files. Each stream is assigned to an independent processing thread to ensure parallel execution and scalability. Within each thread, frames are passed to the YOLO-based inference engine for PPE violation detection.

Upon a positive detection, the system triggers a sequence of automated actions: evidence generation, where the specific frame is captured and saved as an image; alerting, through a desktop notification sent to the operator's machine; and cloud synchronization, where the image evidence is saved to a local OneDrive folder that syncs with SharePoint. The final stage is data consumption, where the Power BI dashboard connects to the SharePoint data source, extracts metadata from the image filenames, and presents the information in an interactive dashboard for analysis. This architecture provides a seamless flow from raw video data to actionable business intelligence, integrating directly into the company's IT ecosystem.

2.2.3 **Development and Implementation (MVP)**

The development of the MVP followed an iterative lifecycle, with a focus on strategic data handling to maximize model performance. A key innovation was the creation of a merged dataset combining a small, high-quality internal Atvos dataset with a larger, more diverse public dataset from Roboflow. The rationale for this was to improve generalization, creating a model capable of performing reliably across varied environmental conditions, not just the specific context of the Atvos training data. This required a meticulous data pipeline for cleaning, label normalization, and remapping.

Building on this, a progressive training strategy was implemented to achieve the best of both worlds: robustness and precision. The model was first trained on the large, merged dataset to learn general features and become resilient to variations. Subsequently, it was fine-tuned on the smaller, highly specific Atvos dataset. This second stage specialized the model, significantly increasing its precision within the target operational context. This two-step approach was critical to developing a model that was both broadly capable and highly accurate for its primary mission.

2.2.4 **Testing and Technical Evaluation**

The project culminated in a comprehensive validation phase to ensure the system's reliability and performance. A full end-to-end system flow validation was conducted to confirm that the entire pipeline—from video input to dashboard visualization—operated continuously and deterministically without data loss or critical failures.

The performance of the AI model, a critical component of the system, was rigorously evaluated. The table below presents the key performance metrics for models trained on the Atvos-only dataset versus the merged dataset, demonstrating the effectiveness of the data strategy.

Model Dataset	Precision	Recall	mAP@0.5	mAP@0.5:0.95
Atvos Only	0.785	0.884	0.905	0.580
Merged Dataset	0.661	0.882	0.908	0.541

- *Table 1 - models results*

These results confirmed the technical success of the modeling approach, showing high precision in the specialized model and strong, generalized performance in the merged model. This validated that the system met the high performance standards required for a functional MVP.

2.3 Assessment of Impact and Contribution to the Business

This subsection evaluates the project's value and return on investment for the partner company, Atvos. It moves beyond technical validation to measure the tangible and intangible benefits the SIMPATIA system delivers, analyzing its performance against business-centric metrics, its financial viability, and the key lessons learned throughout its development.

2.3.1 Defining Corporate Success Metrics and Results

The project's Key Performance Indicators (KPIs) were directly tied to the model's detection accuracy metrics, including Precision, Recall, and Mean Average Precision (mAP). The primary quantitative result was the achievement of an exceptionally high mAP@0.5 of 0.905 with the model fine-tuned on the Atvos-specific dataset. This result confirms the system's capability to identify PPE violations with a high degree of reliability, far surpassing initial developmental benchmarks.

Qualitatively, the solution delivers significant business impact. It provides substantial gains in monitoring agility and consistency, replacing sporadic manual checks with continuous, automated oversight. Furthermore, the integration with Power BI enables data-driven safety management, allowing supervisors to analyze trends, identify high-risk areas, and make informed decisions to improve safety protocols.

2.3.2 Cost-Benefit Analysis

The financial viability of the SIMPATIA project was established through a financial feasibility model that proposed a B2B Software-as-a-Service (SaaS) model. This model projected a positive Return on Investment (ROI) within the first year of deployment for small and medium-sized industrial plants. When compared to the commercial alternatives (Minsait and Mob Conduta), the proprietary SIMPATIA solution demonstrated a significantly lower implementation cost, offering a more cost-effective path to achieving automated safety monitoring while retaining full ownership and control over the technology and data.

2.3.3 **Critical Success Factors and Lessons Learned**

Several key lessons emerged from the project's development lifecycle. A critical learning was the importance of managing the trade-off between dataset size and annotation quality. While larger datasets improve generalization, a smaller, highly curated dataset proved essential for achieving high precision in the specific target environment.

A key factor contributing to the project's success was the implementation of the progressive training strategy. Training the model first on a broad, merged dataset and then fine-tuning it on a specialized internal dataset proved to be a highly effective method for developing a model that is both robust and precise. This approach stands as a critical success factor for future AI projects in similar industrial contexts. The successful completion of the development phase now leads to the final conclusions and recommendations for the project's future.

3 **Conclusion**

The SIMPATIA project successfully achieved its primary objectives, culminating in the delivery of a complete and validated technical prototype. As confirmed through rigorous end-to-end testing, the developed Minimum Viable Product (MVP) demonstrates a functional, integrated system capable of automating the detection of PPE violations in an industrial setting. The project's journey from concept to validation has proven the technical feasibility of using AI-powered computer vision to address a critical business need in workplace safety.

The impact of SIMPATIA on the business is significant. It provides Atvos with a scalable, low-cost solution for automated safety monitoring that enhances operational efficiency, improves the consistency of compliance checks, and generates actionable data for proactive safety management. The system's architecture, built on open-source tools and integrated with existing enterprise platforms, offers a solid foundation for a full-scale production deployment.

Based on the project's outcomes and lessons learned, the following recommendations are proposed for the future evolution of the solution:

• Expand PPE Detection Capabilities: Refine the model to support additional PPE classes beyond helmets, such as safety boots, goggles, and gloves, to provide more comprehensive safety monitoring.

• Transition to Live Deployment: Deepen the integration with the on-site HikVision camera system to move from simulated video feeds to real-world, live monitoring within Atvos's industrial plants.

• Formalize Knowledge Transfer: Create a formal knowledge transfer plan, including comprehensive technical documentation and user manuals transferring for developers in future projects , to empower Atvos's internal team to maintain, operate, and further develop the system.

In conclusion, the SIMPATIA project stands as a successful demonstration of how targeted AI solutions can solve tangible business problems. It has not only delivered a functional system but also laid the strategic and technical groundwork for a new era of data-driven safety management at Atvos.

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