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Rail Safe Vision: Real-Time Railway Track Hazard Detection and Signal Alert System

Dr. Akshita Chanchlani[1], Varad Pramod Nimbalkar[2], Vishu Kumar[3], Siddharth Bharadwaj[4] and Vedansh Gohil[5]
[1]Assistant Professor – Project Mentor Department of Computer Engineering and Technology, Dr. Vishwanath Karad MIT World Peace University Pune, India
Email: akshita.chanchlani@mitwpu.edu.in
[2-5]B. Tech Student Department of Computer Engineering and Technology, Dr. Vishwanath Karad MIT – World Peace University Pune, India
Email: varadnimbalkar08@gmail.com, vishu.singh8809@gmail.com, siddharthbharadwaj02@gmail.com, vedanshgohil2@gmail.com

***Abstract*— The RailSafe Vision project is aimed at achieving a novel solution by bringing in Computer vision and Machine learning methods to improve the safety in railway network. The system is dedicated to detecting on-track hazards in real-time as well as accurately interpreting railway signals, being able to greatly minimize chances of human errors and unforeseen obstacles. The solution makes use of machine learning models for object detection and image processing (Yolo, OpenCV) granting the system fast response times — all to help quickly alert train operators about potential obstacles. RailSafe Vision logs event data continuously, so it supports the work of post-incident investigations as well as ongoing safety improvement. This approach is putting Railtrack on a track toward better rail operations and service efficiency in Britain's railways (Swainston 2002).**

***Index Terms*— YOLO, Open CV, Python, Hazard Detection, Real-Time Processing, Signal Recognition.**

I. INTRODUCTION

Railway is an important part of modern infrastructure and has great national economic, military roles in the socialization. However, keeping the railways safe is still a major issue due to areas being prone human error and signal misreads (even though technology has advanced significantly from old days) with surprise track obstructions. This is indicative of the urgent requirement to improve safety measures given that 2022 alone saw over 13,000 fatalities in railway accidents only in India.

Also in 2020, the European Union recorded a total of 1,331 mainline railway accidents with 687 fatalities and also 476 people seriously injured. Many of these accidents involved trespassing plus level crossing incidents which emphasize the need for obstacle detection and intervention in good time.Recent advancements in sensor technology have led to the development of various systems aimed at mitigating such accidents. Sensors like LiDAR [19], ultrasonic, infrared, and thermal cameras have been employed in the automotive industry and adapted for use in railway safety systems. However, these sensors are often costly and require powerful computing hardware to process data in real-time, making them less feasible for widespread implementation in railway systems, particularly in resource-constrained environments.

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In response, the "RailSafe Vision" initiative suggests a creative way, using cameras of low cost and intelligent solutions that rely on artificial intelligence for perceiving road hazards in real time as well recognizing the signals. This significantly lowers costs and allows for a scalable computing solutions using tested machine learning models such as YOLO, OpenCV etc. unlike traditional sensor-based systems.
The goal is to identify potential track obstructions, such as animals, debris or vehicles in close proximity with the tracks and also correctly read railroad signals. The system offers real-time alerts to the train operators while it logs data for analysis post-incident, which not only increases safety but also supports investigations after an incident and improvement of railway operations.
The "RailSafe Vision" project aims to bridge the gap of existing research by focusing on AI-driven software solution that can be implemented on embedded devices, even challenging environments like Embedded object detection [3][11][14] applying Deep Neural Networks in railway domain. This project evaluates a combined approach that integrates machine learning [20] with traditional computer vision techniques, ensuring durable and dependable performance. By overcoming the shortcomings in existing approaches, and still providing real-time situational awareness to all stakeholders involved on railway networks, RailSafe Vision aims at reducing risk of rail accidents significantly & increasing overall efficiency and safety for railways.

II. LITERATURE SURVEY

This line of research has come a long way in the area of railway safety with sensor-based techniques for accident prevention, coupled with computer vision technology. In the following, we briefly present existing methods and technologies that have been developed for detection of obstacles or recognition signals in railway systems.

A. Sensor-Based Systems

A variety of sensor technologies have been explored for enhancing railway safety [5]. These systems are typically mounted on the front of trains and are designed to detect obstacles on the tracks at a distance. Key sensor technologies include:

- LiDAR (Light Detection and Ranging): LiDAR systems are widely used in obstacle detection due to their high accuracy in measuring distances and detecting objects. They work by emitting laser pulses and measuring the time it takes for the pulses to return after hitting an object. However, the high cost and complexity of LiDAR [11][19] systems limit their widespread adoption in railway applications
- Ultrasonic Sensors: Ultrasonic sensors emit sound waves to locate objects by measuring the time for their reflection back to it. They are cheap, but have low detection range and suffer environmental conditions such as fog or rain.
- Infrared and infrared camera: These cameras track the signature of heat, which is suitable. For recognizing dwelling (humans or animals) in tracks where there's insufficient light. But it needs high processing power and less helpful in spotting non-heat-emitting objects.
- A stereo or RGB cameras: A stereo is a type of camera that uses at least two lenses to capture the depth data, where as an RGB is who captures standard colour images. Such cameras can be employed for obstacle detection, but processing of the data in (quasi-) real-time usually demands substantial computational resources.
- Although these systems based on sensor offers good predictive potential but being expensive & demanding high computational hardware makes them not a practical choice for overall successful implementation among railway systems especially in resource-limited environments.

B. Approaches Based-on Computer Vision

Railway safety research has employed the use of computer vision (CV) techniques is an interesting field [5, 6]. These methods usually require cameras mounted on trains to take pictures or record video of the track. Key techniques include:

- *Traditional Image Processing:* These approaches are early works that focus on traditional image processing techniques, i.e. edge detection, color segmentation and template matching to detect obstacles as well as railway signals. For instance, you can detect rails and signals in an image by identifying noted geometric shapes using techniques like
  Hough Transform. It does have some drawbacks, of course — the effectiveness of these methods can be a bit more limited when it comes to shadows and varying environmental conditions.
- *Machine Learning and Deep Learning Models*: Until recently, research has predominantly used machine learning (ML) and deep learning models for detecting obstacles or recognizing signals. So as to detect object

on railway track accurately and in real time utilization of models like YOLO(You only look once) and SSD(Single Shot Multibox Detector) been done. Note that for the temporal domain, dynamic environments like railways require real-time processing of images and hence there are models.

Although CV methods made remarkable progress, the research mainly concentrated on vehicle-mounted sensors or classical CV technologies [7], less identification with AI solutions for railways that emerged later. Furthermore, these strategies often consist of high-cost hardware and may be limited in the case of more challenging environments like mountainous or vegetative areas.

C. Problems with Integrated Systems

In a similar attempt, few studies have been conducted for mixture of sensors and CV techniques to increase the robustness in railway safety applications. For example, a hybrid system of LiDAR with RGB cameras [11] or thermal imaging have been proposed to robustly detect obstacles in different environmental conditions. But such integrated systems have to deal with the problems of cost, computational complexity and real-time processing.

Moreover, research on AI software applications for trains remains underdeveloped. Despite some recent work on using AI for obstacle detection in other domains, e.g., autonomous vehicles [4] the application of similar techniques in railway industry have not been extensively explored.

D. Proposed Contribution

However, the project "RailSafe Vision" aims to overcome these drawbacks by providing a cost-effective AI-driven solution which depends on low-cost cameras and deep / generalized machine learning models. The system is intended to be run on embedded devices, which makes it portable and capable of being deployed in different scenarios like mountains. The project aims to improve safety on railway tracks with traditional CV techniques and adding ML capabilities, without having a high cost of sensors across the length of entire track or complex number crunching systems.

TABLE I

Paper	Task Perform	Result	Algorithm	Accuracy
Enhanced Few-Shot Learning for Intrusion Detection in Railway Video Surveillance	a) only small sample size (or portion) of intrusive video frames is available; b) highinter-scene dissimilarity c)high intra-scene similarity:	The trained meta-model can quickly adapt to an unseen railway scene with only a few new video frame samples (with a few numbers of gradient descent steps).	FCN-32 FCN-16s FCN-8s	Produces 95.51% training accuracy and 61.13% maximum validation accuracy on the samples of meta-training scenes and meta-validation scenes, respectively
Railway Traffic Object Detection Using Differential Feature Fusion Convolution Neural Network	This involves identifying and locating objects within images or videos of railway environments, such as trains, pedestrians, and obstacles.	DFF-Net achieved 95.6% accuracy, outperforming existing methods. It is robust to varying conditions, has better feature representation, and is suitable for real-time applications.	DFF-CNN Model: A deep learning model that leverages the fused features for object detection.	The results showed that the DFF-Net achieved an mAP(mean Average Precision) of 90.12% with 54 frames per second (FPS)
Autonomous Railway Traffic Object Detection Using Feature-Enhanced Single-Shot Detector	object detection in railway traffic	Improved accuracy, efficiency, and robustness using feature-enhanced SSD	Feature enhanced single-shot detector (FE-SSD).	It achieved a mean average precision of 0.895 and a frame rate of 38 frames per second, demonstrating its real-time capability.
Railway Clearance Intrusion	The rail track region is confirmed in an aerial image using a linear	VGG19 achieves a 90.48% detection rate and 2.56% false	Keras 2.2.0 and other libraries,	The accuracy and false alarm rate of the proposed

Detection in Aerial Video Based on Convolutional Neural Network	segmentation detection algorithm, followed by line segment merging and screening.	alarm rate. The improved model performs better with a 97.62% detection rate and a 2.38% false alarm rate.	build the improved VGG-Net	method on this dataset are 97.62% and 2.38% respectively
Research on data processing method of railway safety information based on NLP technology	Develop a data processing method using NLP to analyze and interpret railway safety information.	Improved efficiency and accuracy in processing unstructured safety data, leading to better safety management and decision-making.	NLP techniques	Improved efficiency and accuracy in processing unstructured safety data, leading to better safety management and decision-making.
A Remote Surveillance System Based on Artificial Intelligence for Animal Tracking Near Railway Track	The paper suggests a system to use a Pi camera to detect animals crossing railway tracks and alert relevant groups. This is crucial for protecting wildlife in areas with extensive train networks.	Accurate detection and tracking of animals near railway track Effective classification of animals into species Reliable risk assessment and alert generation for potential collisions	YOLO (You Only Look Once) for object detection + DeepSORT (Simple Online and Realtime Tracking) for object tracking.	model achieves an accuracy of 99.53% on the Rail Sem 19 dataset, The system uses a Raspberry Pi 400 for real-time monitoring and alerts the user if animal motion is detected.
Research on the Application of YOLO v3 in Railway Intruding Objects Recognition	Investigation of Detection Algorithms Proposal of Enhanced YOLOv3 Network: Improvement in Detection Ability	The network improves the detection accuracy of targets at different scales, with a slight reduction in detection speed.	YOLO v3	accuracy reaches 79.2% with slightly reduced detection speed, which is 4.4% higher than the original network.
Suspicious Object tracking with YoloV3 with python Using Open-CV	Object Tracking: Object Detection: Multi-Object Tracking: Dataset Preparation: Analysis and Comparison:	The system is capable of detecting and tracking vehicles and pedestrians in real-time video streams.	YOLO SORT(Simple Online and Realtime Tracking)	It does not provide direct information on the accuracy of the object tracking and detection methods discussed.
A comparative study of machine vision-based rail foreign object intrusion detection models	Edge Detection: Canny edge detection combined with Hough transform was used to extract track features.YOLOv5 and Faster R-CNN models were trained and tested on dataset	YOLOv5 demonstrated better comprehensive performance in terms of detection accuracy and speed compared to Faster R-CNN.	YOLOv5 Faster R-CNN: for identifying candidate regions	Achieved a high precision of 0.998 and recall of 0.994,

III. Identified Gaps

- Overall use on complex environments: YOLO has a applied it to a variety of rail safety projects, yet there's also been an "intensity hole" in its application including environments that are more difficult-to-reach such as mountainous areas or locales with very heavy vegetation.
  Existing research often devotes to vehicle-mounted sensor or traditional computer vision technique, very limited have been proved on AI-based methods that dedicatedly serve for the challenging railway scene. Almost all of these studies are about detection and classification.

- Integration Challenges: Though YOLO is fine for object Although PCM is suitable for railway area detection, it faces a coupling problem with other systems such as LiDAR or thermal imaging techniques in the field of railways. While part such integrated systems show great promise, they are also fraught with cost problems real-time processing and computational complexity.
- Real-Time Performance and Accuracy: Even with the progress in exploiting YOLO for railway safety, high real-time Boosted Reversible Watermarking-For Railway Station Safety means doing so is still. learning outdated procedures, precision (mostly in small object detection), are the bottleneck. It also refers to efforts in enhancing detection speed and accuracy, but improving that balance continues to be an ongoing challenge.

IV. METHODOLOGY

The project was built entirely in Python, with a focus on real-time object tracking in movies using a combination of YOLO (You Only Look Once) and OpenCV. The goal was to develop a system capable of identifying and tracking objects continuously across video sequences, which is essential for film and video processing applications.

To begin, a custom dataset of 800 images was created, with each image tagged in the YOLO format. The dataset covered six object categories: people, cars, trucks, buses, bicycles, and motorcycles. Keras was chosen for model development due to its ease of use and strong support for deep learning tasks. To speed up the process, transfer learning was applied using YOLOv3's pre-trained weights, and Google Colab was utilized to efficiently manage the necessary computational resources during model training.

Once the model was trained, it was integrated with OpenCV's dnn module to enable object detection within video streams. This allowed the system to identify objects in real time by drawing bounding boxes around them and displaying confidence scores.

To improve detection accuracy, a Canny edge detector was incorporated into the pipeline. The edge detector helped to better define object boundaries in images, which was particularly useful for reducing false detections in complex backgrounds. This step made the object detection process more reliable.

Lastly, the DeepSORT algorithm was added to handle object tracking. DeepSORT improves upon the original SORT algorithm by incorporating a deep learning-based appearance model, which enhances performance in difficult scenarios like crowded environments and occlusions. It also ensures stable tracking, even when objects temporarily disappear from view.

In summary, this project successfully developed a pipeline that achieves real-time object detection and tracking, meeting the needs of dynamic video processing. Appearance features integration: To help the tracker to better match objects between frames and decrease identity switches. This is especially useful in film production, where tracking object identities across frames or shots could be extremely important for any post-processing analyses and the scenes themselves. continuity. Putting these tools together with thoughtful data preparation model training and evaluation, the system is poised to scale modern film production needs for detection of objects over complex video sequences in a accurate consistent manner

A. YOLO Applications

- RailSafe Vision Project: YOLO (You Only Look Once) for real-time detection of on-track hazards and accurate railway signals recognition in addition to providing immediate alerts to train operators. Strikingly Safety Vision initiative with the "RailSafe" project is only a piece.
- Remote Surveillance System: The combination of YOLO with DeepSORT (a tracking algorithm) for real-time detection and tracking of animals near the railway tracks, which is very necessary to protect wildlife in large train networks. An enhanced version of YOLOv4 for Railway Signal and Pedestrian Detection: This application is designed to detect locomotive signal lights in real-time and pedestrians on the railway track by applying an enhanced version of YOLOv4. The idea is to improve precision and speed in different lights). Yolo-v5 Vs Other Models: YOLOv5 has been compared to other models like Faster R-CNN, which proved to have higher detection accuracy and speed while detecting obstacles for railway emissions

B. Architecture Diagram

It shows a fully integrated solution that offers real time information to train drivers about track signals and obstacles. It uses computer vision methodologies, especially the Yolo (Model Architecture) algorithm to identify signals well as obstacles accurately and thereby ensuring safety in rail transportation. A camera mounted on the train captures input to start this process. The camera live feeds images of the tracks and surroundings to the system. Camera feed is the significant input data to be analysed by our system for relevant information. Now comes to the part where these images are loaded onto their system for deeper inspection. After the images are loaded, they have to undergo a series of preprocessing which helps in bettering their quality and makes them evolve for digital feature extraction. This step is really important since it will increase clarity of images and eliminate noise that could be cause inaccurate detections. The pre-processing phase is done using the Canny edge detector and image sharpening specifically. Edge detection techniques are used to find the edges and boundaries of objects within an image, one such technique that we use very frequently is called a Canny edge detector. Whereas, sharpening helps to improve the image details making more clear/crisp edges and texture which makes it even easier for an object identification. The next step within within the system, which is kept inside feature extraction stage.

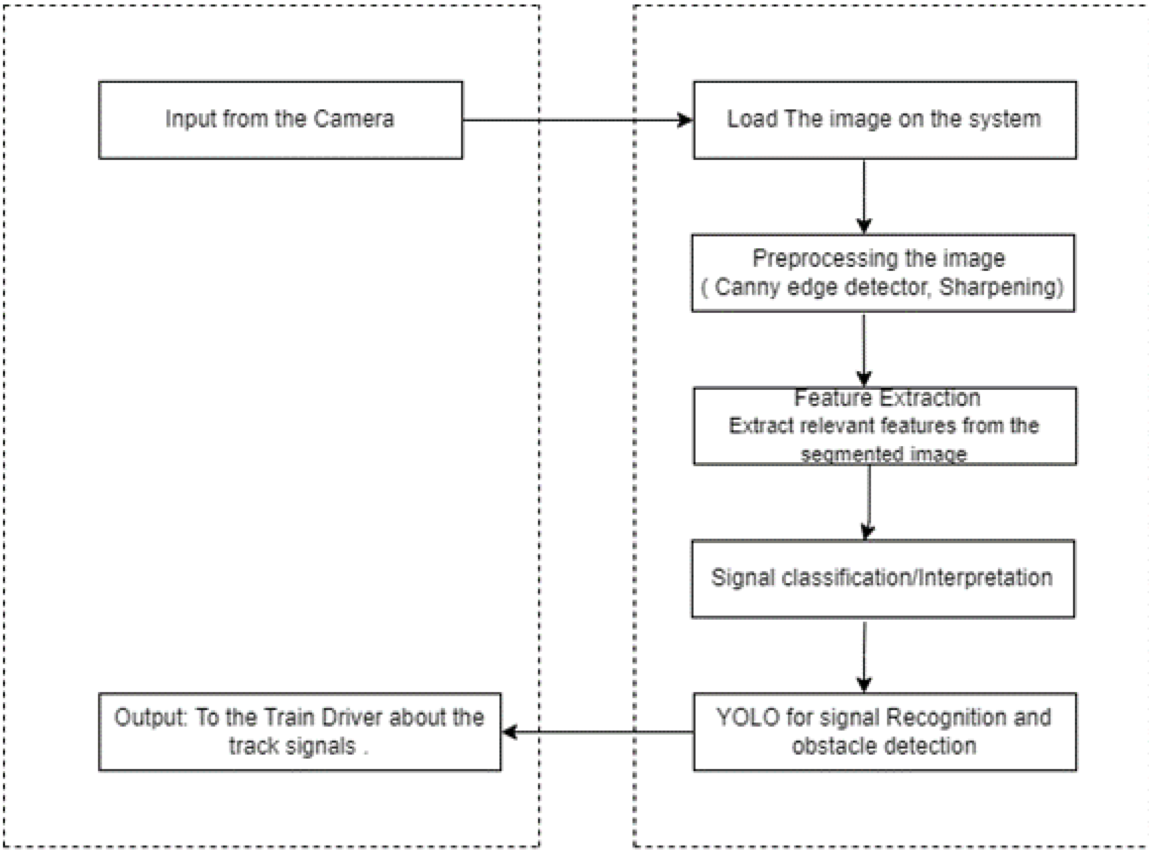

Figure 1

The system extracts important features from the image after segmentation. You need to extract important elements from images, i.e. Shapes Colours Patterns corresponding to track signals and possibly obstacles. K, and all these features get fed into the subsequent stages of the system where they are analysed to make a decision on whether any object or signal is available in that image. The set of extracted features are thereon given to a Signalling Classification & Interpretation Module. This module processes the signals that were captured by our camera, and groups them into categories like stop sign or go/ caution (like yellow lights in traffic signs). This classification is very crucial because the safety of train operation depends on it. Incorrect interpretation of the signals could result in catastrophic situations so this module needs to be highly dependable. Finally, the signal is recognized and detected using YOLO algorithm. The state-of-the-art object detection algorithm for detecting images in the YOLO image. In this stream, we apply YOLO to real-time detect track signals and obstacles on the tracks. The solution is to use YOLO, which allows the system to process an incoming video feed quickly enough such that it provides real-time feedback back to the train driver. When a signal is detected, the system decodes that message and provides an informative update to the driver. Similarly, if an obstacle is observed lying on the tracks ahead of it so notifies, he driver and asks him or her to take necessary action. This system produces a real time data feed to be shown on the screen in front of the train driver. The output is warning messages, or feedback that then allows the driver to make sense of lethargic signals and barriers.

V. Conclusion

"RailSafe Vision," a cutting-edge applied research project utilizing state-of-the-art computer vision and machine learning. Combining real-time hazard, recognition of the signal that is alerting you in head-up display makes this project a smarter and effective way to avoid future accidents merely based on human error or unexpected obstructions such as animals running towards your car etc. The use of such models, and something similar to the YOLO family discussed earlier deployed through OpenCV enables a leapfrog over traditional railway safety approaches by integrating AI with far-reaching legacy systems- which in many parts of world would be running bare-bones.The research covers a range from the detection of objects in complex environments to signal processing, demonstrating how they could enhance railway safety. But, there is still plenty of scope for improvement in the level of precision that this technology brings to complex environments—either making corrections or working faster

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