aribot

TEAM ARIBOT

DEFENCE AND INDUSTRIAL TECHNOLOGY

AUTONOMOUS RAILWAY INSPECTION ROBOT

Team Members:

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1. Project Abstract:

Regular maintenance and inspection is very crucial for the effective and safe usage of railways as a mode of transportation. Presence of any sort of cracks or defects in railway tracks can cause track failure which will lead to undue disasters.India, having the fourth largest rail network in the world with total track length of over 67368 km, traditional inspection of railroads is practically difficult, time consuming, labor intensive, and prone to errors. In India, most railway track inspections are conducted manually by railroad track inspectors. It is practically very difficult to manually look for defects along long stretches of tracks, making it inaccurate due to human errors. Thus, an autonomous system for railway inspection is critical to maintain the trust and safety of rail transport. Our project, Aribot – **A**utonomous **R**ailway **I**nspection Ro**BOT** aims to streamline the inspection process to ensure high safety standards of railways.

We propose a prototype, a fully autonomous flexible 4-wheeled robot capable of detecting railway defects by performing various testing techniques such as ultrasonic test for internal crack detection and 3D-laser profiling system for surface cracks. It is also equipped with a machine vision system (camera) for anomaly detection. Our proposed system will inspect the track for missing bolts, ballast area and anchors using a vision based approach and simultaneously detect surface and internal defects by the above mentioned methods. All the captured data will be broadcasted to a nearby base station. The bot is equipped with modules like GPS to locate the position of the robot at any given time, using which, if a defect such as metal crack or fastener failure is detected , the spatio-temporal coordinate is reported to nearby stations for immediate action to be taken. Data acquired by the robot during its travelling time along the tracks along with the camera feed can be used for predictive analysis of tracks.

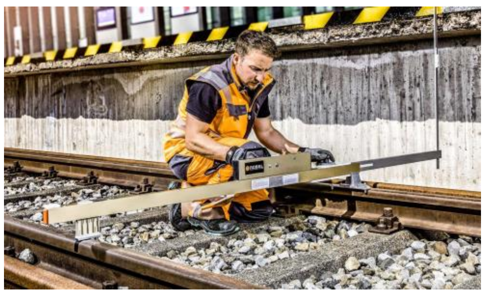
Keywords — laser profiling, NDT, machine vision, railway maintenance, ultrasonic testing.

2. Background Research :

Some of the many existing testing methods:

- **Turnout gauge – to verify gauge length**
- **Ultrasonic NDT kit with intensity monitor**
- **Track geometry assessment trolley to check track parameters**
  Electric trolley for crack detection by performing NDT

3.



Proposed Design:

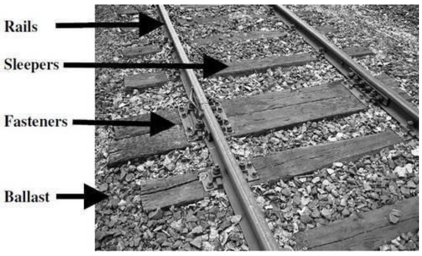
A. Objective:

The objective is to design and develop a fully autonomous 4-wheeled adjustable bot capable of active inspection using visual inspection, laser profiling, and NDT methods like ultrasonic inspection; predictive inspection of railway track using computer vision and Machine Learning Algorithms. Our objective serves to detect:

Internal as well as surface metal cracks in rail

Defective Ballast profile and gauge lengths

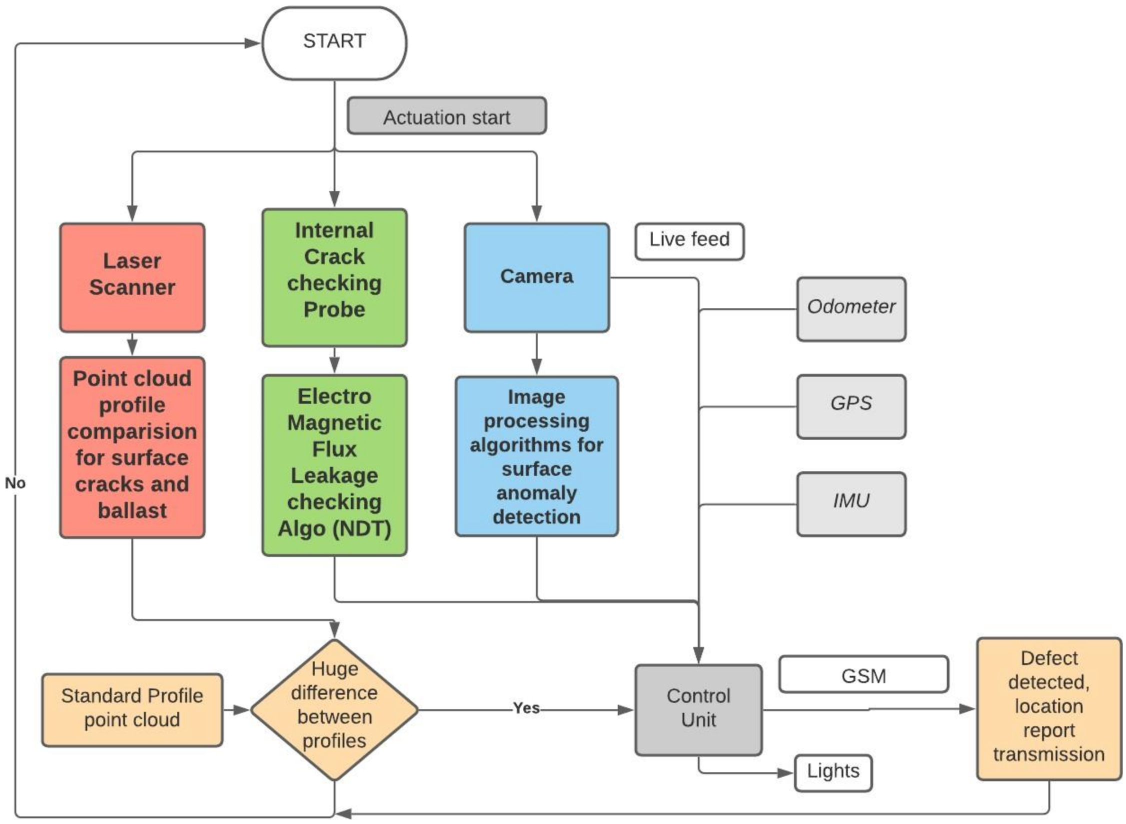
Anomaly detection in Sleepers and fasteners



Once a defect is identified the bot will notify the nearest railway station with the spatio-temporal coordinates allowing quick maintenance of the rails and also captures the images of the rails which can be used for predictive maintenance and verifying false alarms. This way, the robot reduces human labour and performs the same task of railway track inspection in a faster and economical way.

B. Proposed Solution:

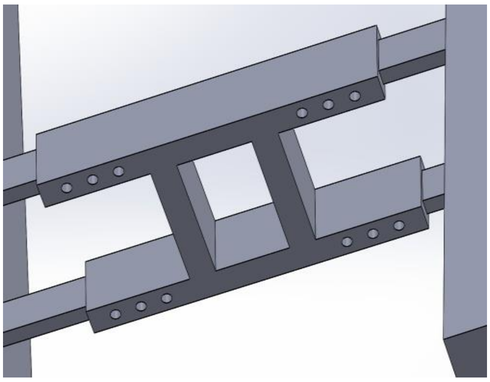
Block Diagram:



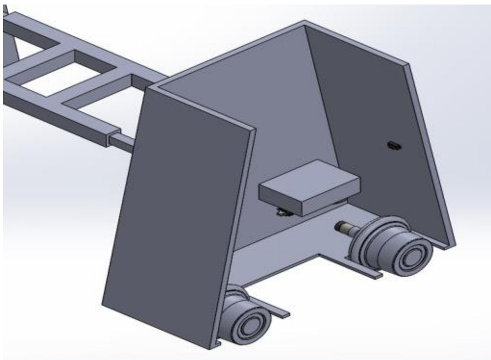
4. Modules :

1. Chassis Unit
Design:

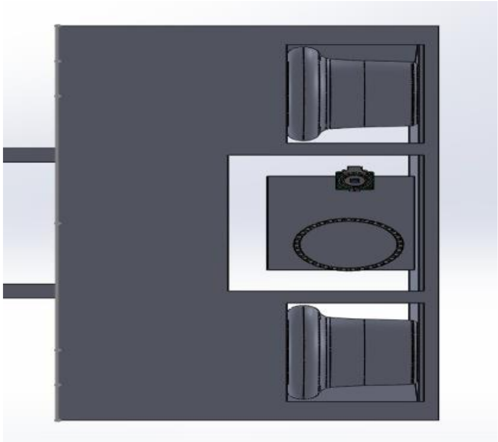
- **The bot consists of two trapezoidal boxes, one on each side of the central unit, connected by movable rods.**
- **The side unit contains all the components of the testing unit, sensors, and wheels.**
- **The base of the side unit has sectioned holes to support the wheels and probe unit for the NDT testing.**
- **The angular dimension of the unit supports the field of view of the laser scanners used.**
- **The sensors are placed on the inner walls of the unit.**
- **The top of the side unit carries a light source and a shading box to provide a uniform illumination environment for the camera attached.**



CENTRAL UNIT



SECTIONED ISOMETRIC VIEW



BOTTOM VIEW
OF THE SIDE UNIT

LINK TO SIMULATION: **CHASSIS ASSEMBLY**
CHASSIS SIMULATION: Robotic **O**perating **S**ystem

- ROS (Robotic Operating System) is a robotic framework that helps us integrate different systems together.
- Gazebo is a simulation software that is easy to integrate with ROS.
- The entire Robotic system, primarily camera and laser unit, is simulated in gazebo and ROS.
- The sensor feedbacks are published to a particular topic which then can be subscribed for processing.
- Rviz and Rqt helps us visualise sensor feedbacks

- **REASON FOR USING ROS FRAMEWORK:**

The codebase and ROS nodes developed here to process and integrate all these testing units can be **directly moved to hardware** with slight tweaks.

```
world_pkg/
├── CMakeLists.txt
├── images
│   └── rail_section.png
├── include
│   └── world_pkg
├── meshes
│   ├── track.blend
│   ├── track.blend1
│   └── track.dae
├── models
│   └── track
│       ├── meshes
│       │   ├── track.blend
│       │   ├── track.dae
│       │   ├── track_single_.blend
│       │   ├── track_single.blend
│       │   ├── track_single_.blend1
│       │   └── track_single.blend1
│       ├── model.config
│       └── model.sdf
├── package.xml
├── src
└── world
    └── track_world.world
```

```
aribot/
├── CMakeLists.txt
├── config
│   ├── joint_names_Aribot.yaml
│   ├── rviz_config.rviz
│   └── velocity_controller.yaml
├── include
│   └── aribot
├── launch
│   ├── display.launch
│   ├── gazebo.launch
│   └── spawn_urdf.launch
├── meshes
│   ├── BLW.STL
│   ├── BRW.STL
│   ├── FLW.STL
│   ├── FRW.STL
│   └── Main_Frame.STL
├── package.xml
├── src
└── urdf
    ├── Aribot.csv
    └── Aribot.urdf
```

LINK TO SIMULATION: SIMULATION

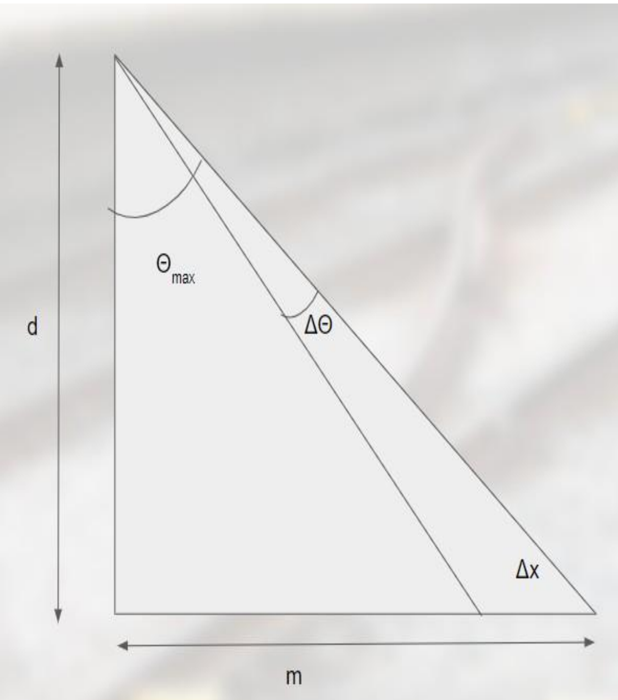
2. Laser Scanner Profiling

- **3D-laser profiling system** for surface cracks and ballast:

1. Laser scanner is mounted on either side of the robot to generate point cloud data of the surface of rail tracks.
2. The surface point cloud collected is compared with standard point cloud data using various algorithms to identify the type of crack.
3. This point cloud data can also be used to check gauge length of track

- Laser scanner is a time of flight sensor which outputs distance of obstacle and intensity of reflected signal along radially outward directions. Values are uniformly scaled across theta where $\Delta\Theta$ is the sample width. Laser scan values are combined across time using transforms to obtain the point cloud data of rail and sleeper which is further processed in MATLAB. Methods such as
    a. Statistical outlier removal
    b. Extraction of primitive
    c. Clustering of data

  are performed to find the location of crack on both sleeper and rail.



- d : Height of laser scanner above ground
- m : Gauge length
- Δx : Least count (Usually smaller than crack)
- $\Delta\Theta$: Sample size of laser scanner (Uniformly sampled along theta)
- Θ_{max} : arctan(d/m)
- Δt : Sampling rate = $\Delta x / v_{max}$

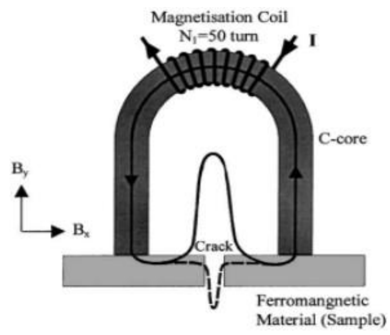
Where v_{max} is the maximum velocity of Inspection bot

LINK for LASER_SCAN Module: LASER_SCAN

3. NON-DESTRUCTIVE-TEST(NDT) for internal Crack Detection

Design and working :

- EMFL NDT probe consists of a linear hall effect sensor and Magnetization coil.
- On passing current through the coil, magnetic flux linkage core and rail material occurs.
- In the presence of cracks (horizontal), the normal component of flux will increase which is detected by the sensor.



METHODS:

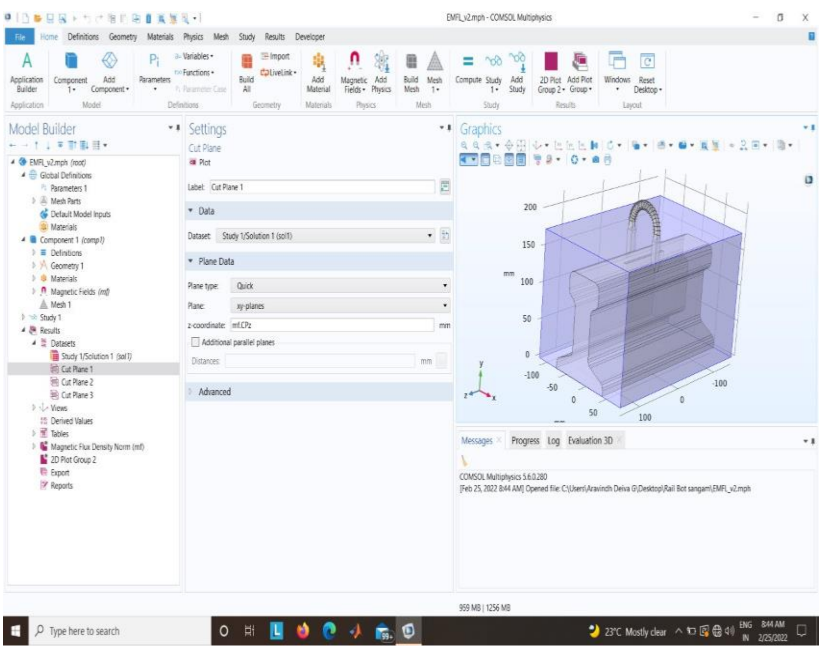
Electro-Magnetic-Flux-Leakage (EMFL):

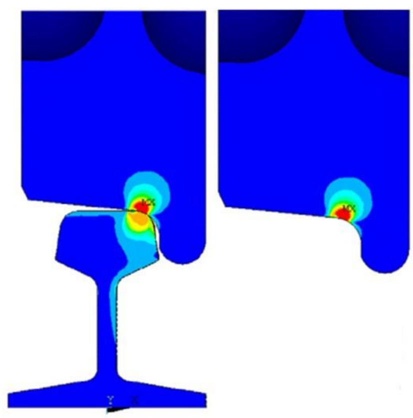
- Implementation of EMFL probe in COMSOL.
- probe consists of a linear hall effect sensor and Magnetization coil.
- Can detect surface cracks and sub-surface cracks.

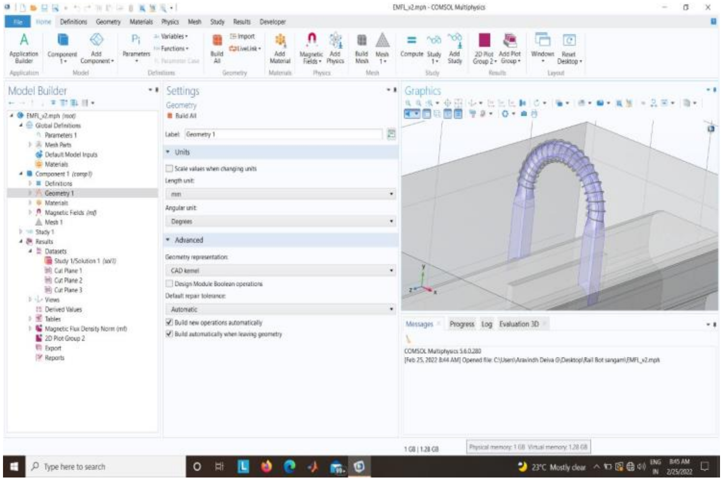
ULTRASONIC Test (Phased Array method):

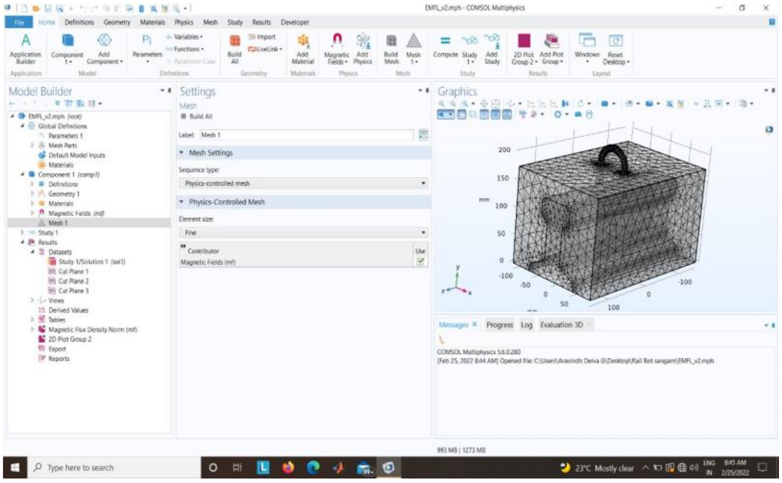
- Detection of Internal cracks using feedback of Ultrasonic sound
- Transient analysis of reflected wave Intensity is plotted to spot crack.
- Uses Phased Array Methodology to change direction of Ultrasonic Beam to spot cracks with variable orientation

COMSOL SIMULATION:









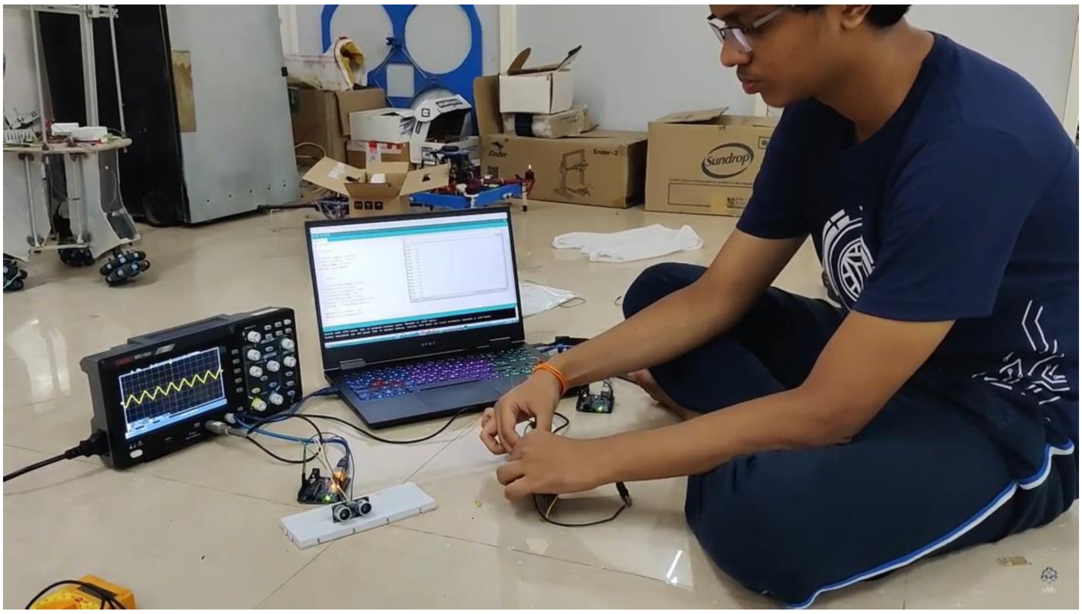
Phased Array NDT

THEORY:

- Detection of internal and external cracks using reflected beam intensity variation.
- By changing the phase of sound emitted by each probe (time delays) which results in interference of waves in space results in change of effective beam direction.
- This direction change tech is exploited to look for cracks with any orientation**.**

TEST:

- Transmitter is made to send Ultrasonic sound (40 Khz), PWM signal of pulse width 16 us with 50% duty cycle is sent through a microcontroller.
- The reflected beam is sensed through the Receiver, whose signal is amplified and plotted continuously.



4. Machine Vision System

Machine Vision enables the robot to provide us with insights about the railway track based on features identifiable from images of various regions of interest. A single image provides us huge amounts of information in less time and low computational power requirements.

The Dataset:

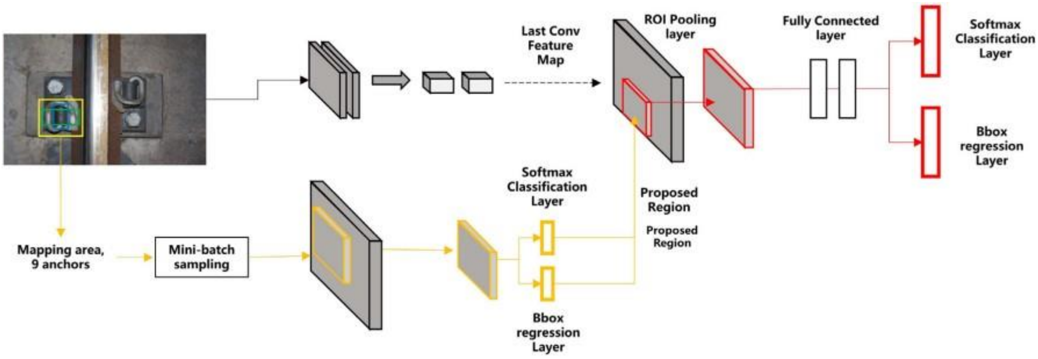
Custom video footage of rail-tracks were collected for datasets due to the lack of dataset specific to the Indian railway system.

Video Link : [Dataset]

Some of the images from this dataset is presented below:

Architectures Tried:

1. Faster R-CNN Network
2. SSD (SIngle Shot Detector)



OUTPUT snippets:

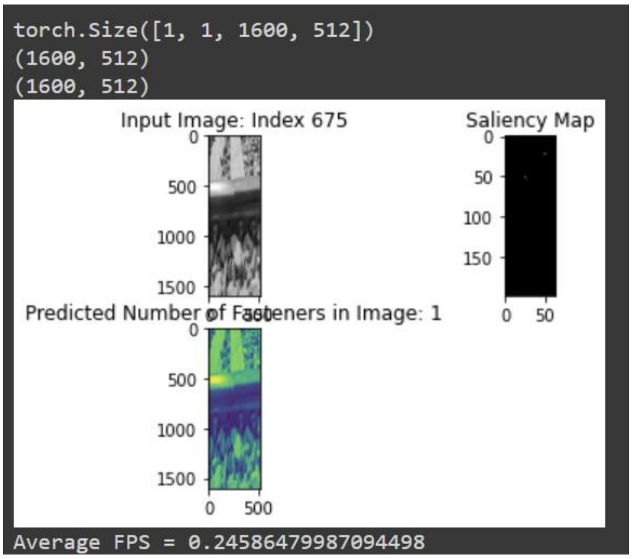


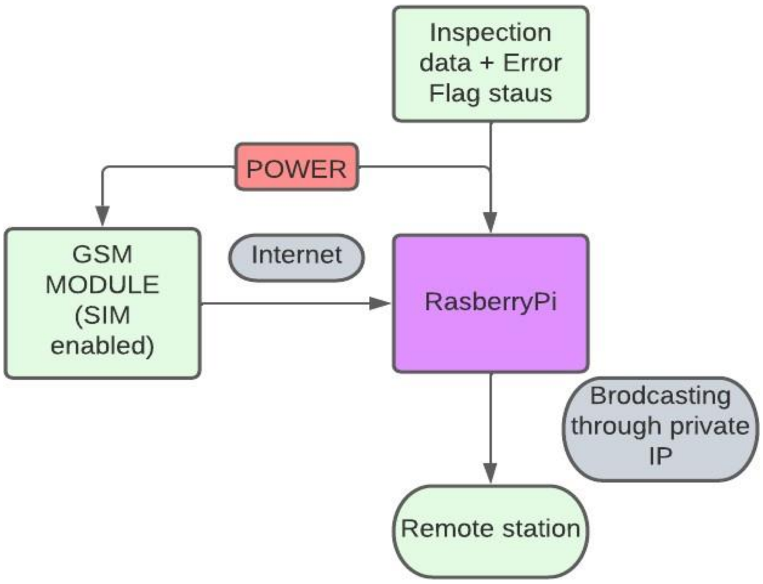
Image Processing Methods:

Pure image processing methods using contouring and thresholding were attempted to detect cracks on railway lines.

All the Codes are available in our github page: [ARIBOT]

5. Integration of all Sensors

FLow Chart of the Communication System



Working:

- **NGINX** server is hosted for private communication
- **RP** is connected to the internet and broadcasts the video footage using the NGINX server.

B. Components Required:

COMPONENTS / PARTS	How is it being used in the proposed solution? Explain its role/functionality.
Microcontrollers and Microprocessors (Arduino Mega /Raspberry pi4)	For processing data and decision making
Ultrasonic Probe	To perform NDT (Non Destructive Test)
Laser Scanner	Surface metal crack checking

Camera (Pi cam)	For vision and image acquisition
Motors	To drive the wheels
Wheels	Locomotion
Chassis	Base frame of bot
Battery (Li-Ion)	Power supply
Odometer	To measure distance travelled
GPS	Positioning of bot
GSM (SIM900A)	Communication interface
IMU (MPU-6050)	To measure inertial properties (orientation, position)
Lights	To aid camera unit/visibility

Innovativeness of the Proposed Solution

The rail bot is designed in such a way that it is compatible with different gauge lengths and performs automated testing for various defects such as internal cracks, fastener dislocation, and other anomalies. It broadcasts live feed of rail track along with continuous testing results to a remote location for predictive analysis.

Compared to existing railway maintenance and testing methods which are complex, labour intensive, and time consuming, this bot provides a novel solution by integrating various testing techniques along with predictive inspection and remote vision, significantly reducing the amount of work in the existing railway maintenance system.

Impact of the proposed solution (Application):

For the effective usage of railways as a mode of transportation, it becomes very essential to have accurate railway track maintenance with minimum error rate in defect detection. Incorrect detection of defects by manual inspection (human error) might lead to track failure and derailment. It is estimated that 50-60 percent of railway accidents are due to railway staff failure and asset failures like track defects such as rail fracture and inadequate maintenance remain the biggest cause of accidents which can be avoided by aiding human labourers with an autonomous system capable of detecting rail defects in a far more robust manner.

The proposed solution will significantly reduce the amount of manual inspection and hence human error associated with manual inspection. Complete automation will reduce the time required for inspection and hence enables performing frequent inspections. Further, the inspection data can serve as a training data to develop a model for predictive analysis.

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