International Journal of Future Generation Communication and Networking
Vol. 14, No. 1, (2021), pp. 2811–2823

Automating the Railway Track Inspection Process through Drone Technology using state-of-the-art Deep Learning Techniques

Lalitha R[1], Anto Arockia Rosaline [2], Kanimozhi Suguna S[3*], Dimitrios A. Karras[4*], Sagayasree Z[5], and Sushanth Arunachalam[6]

[1]Professor, [5,6]UG students,
Department of CSE, Rajalakshmi Institute of Technology,
[2]Asst.Professor (SG), Department of IT, Rajalakshmi Engineering College
Chennai, India
*[3]*Assistant Professor, Department of CSE, School of Computing, SASTRA Deemed University, Thanjavur, India*
*[4]*Professor, Department General, Faculty of Science at National and Kapodistrian University of Athens, Greece*
E-mail: lalitha.r@ritchennai.edu.in, [3]*kanimozhi.suguna@gmail.com, [4*]dakarras@uoa.gr

Abstract

Rail transport is said to be the second-largest transportation means in India. This transportation mode is said to be the fastest way within a large network of commercial nodes in a country to transport various goods, products and passengers every day. Hence, the quality and maintenance of railway tracks in good condition are highly important for safe and secure transportation. Cracks existing in the rail tracks may lead to train accidents. As the railway tracks pass through rural areas and non-residential places, it is practically difficult for human beings to check for any cracks in the tracks daily. Even if it is observed, the distance between two stations will be large and hence it takes a long time to repair the cracks in the track. Timely detection is therefore, critical for the warranty of uninterrupted continuous transportation. Hence, automating the railway track inspection process through Drone technology is proposed in this paper as an efficient methodology to manage such problems. A drone is designed and trained to inspect the railway tracks automatically and frequently in a periodical manner. The drone has a high-resolution camera fixed which captures the images of the track and checks and detects cracks in them. The drone is equipped with a Global Positioning System and a Wi-Fi module and interface with the base station drone unit located in the nearby railway station. It intimates or sends an alert message to the station master when a crack is detected. The exact location with latitude and longitude parameters are captured and sent to the station master. Thus, it saves manpower and minimize the time in the inspecting process. Above all, it assures a safe journey through the rail tracks.

Keywords- Drone, Drone technology, Global Positioning System, railway cracks segmentation and detection, deep learning

INTRODUCTION

The world today is looking forward to adapting to automation and many fields have changed their work lifestyle in an automated manner. In this era, many technologies have been evolved to change the tasks which are manual and to provide an automated implementation of tasks for the society and to satisfy their daily needs as well as to earn income in a spontaneously manner. Various technologies are being evolved based on the improvements added to the previously existing technologies. Some of the emerging technologies in the current era are Drone technology, Unmanned Aerial Vehicle (UAV),

ISSN: 223-7857 IJFGCN

Augmented Reality (AR), Virtual Reality (VR), Deep Learning (DL), Machine Learning (ML), Internet of Things (IoT), Computer Vision (CV) and various other technologies. Drone technology plays a vital role in easily automating things and helps in efficiently solving real-world problems. Drones are used in all fields of engineering, science, and technology to solve real-world problems. Drone technology is also applied in various fields such as Agriculture, Disaster relief, Disease control, Health care, weather forecast, etc.

It can also be used by railways for various purposes like scanning the crowd in the station, recording important events in stations, spraying sanitizers in railway coaches, etc. Drones can also be to avoid train accidents by taking precautionary measures in advance by the railway authorities. Generally, rail accidents occur due to negligence by driver, defective tracks, stalled vehicles on the track, over speed, fault in traffic signal, derailments due to faults in tracks. Hence, to avoid derailments or accidents due to cracks in the tracks, an inspection team will carry our randomized checking of the railway tracks to find out the cracks. This checking may be done periodically once or twice a week or a month. As human beings are doing a manual inspection, it is a more time-consuming and tedious process. Because even after identifying the cracks, the engineers and laborers must reach the place in time and rectify the problem soon.

To avoid these situations, the drone can be trained and automated to inspect the tracks. The proposed automated drone would inspect the tracks to detect cracks, holes, or any other defects in the track. When a crack is detected, the drone stops at that specific position and captures the image of the track, and sends it to the drone unit.

The drone is attached with a camera that would perform the capturing of images as well as video streaming. It also sends the location of the crack through Global Positioning System (GPS) module with latitude and longitude parameters. The specific altitude and distance to be covered by the drone are fixed by the inspection team. Through image processing techniques and deep learning algorithms, the defects are detected and captured. The drone with the help of a Wi-Fi module sends the live video to the drone unit at the nearby railway station. This video can be seen by the station master and engineers on their mobile phones. Thus, immediate action can be taken to fix the defect in the track. The track monitoring can be done automatically at any number of periodic frequent intervals. Thus, it optimizes the resources, time, cost, and energy in inspecting the tracks frequently and also ensures safe transportation.

RELATED WORK

In this section, the ideas proposed by many researchers in drone technology are discussed. Many authors have proposed different solutions to solve real-world problems. The concept of the problem is generalized but the way to solve the problems is different which is based on the ideas proposed by the authors.

Hayre (1974) have proposed a system that is used to automate the inspection of the railroad. The author proposed a method called *in-situ* excitation which is related to the railway communication system. The proposed system by the author focuses on tracks and the rails and checks for any fissures, misalignment, or any other variations in the track. The main feature of this system is it uses a real-time segmentation system and helps in detecting the spatial arrangement of tracks. Cabrera (2002) has designed a system that is used to make the inspection process automated by considering certain factors such as guard rails, and they use devices to report the condition of tracks and helps in prioritizing the tracks' condition. The authors have focused more on improving the structure of the

ISSN: 223-7857 IJFGCN

track they use and helps in detecting the track for any wear of tracks, alignment of the trackbed. This system helps in maintaining the system by inspecting the tracks and reporting to the respective authorities.

M.Singh (2006) has proposed a system that inspects the rail tracks. The authors have implemented a video analysis system which would take videos of tracks and performs analysis of the recorded video. This system overcomes the method of visual inspection. The authors have designed a system that would inspect the track automatically using certain methods such as image processing techniques and analysis methods to provide accurate results. The system mostly focuses on the image clips. It detects the missing clips in the track and helps in replacing the damaged clips. The proposed system shows an accurate result by providing the video as a large dataset that is taken in real-time. Pavel Babenko (2009) proposed a system that would inspect the tracks for the misalignment of the trackbed. It uses computer vision methods to solve the problem of inspection. It uses two methods to solve this problem. The first method will consist of a set of pairs of unaligned video cameras and the second method uses deep learning algorithms. It applies Mach filters and correlation filters to inspect the position of clips, track beds and detect any errors in the track. The authors have developed a library called MinGPU, which consists of both computer vision methods and correlation filters embedded within the library. The library has received an accuracy result of 0.98 for detecting the fastener by using the MACH filter present in the Graphics Processing Unit GPU. The MinGPU library is being designed in the ‘C’ language and the execution time is expected to be minimum and the system has achieved it with accurate results.

Trinh (2012) has proposed a system that would automatically inspect the track using vision-based methods. The system mainly focuses on the important component of the track which is called Anchor. The system mostly detects anchor-based rail defects and other errors. The system also detects other important components such as ties, anchors, plates with accurate results. The detected components by the camera are processed as video frames and combine the video frames with Global Positioning System GPS and speed measured using Distance Measuring Instrument DMI. The system performs two kinds of analysis. One is data integration analysis which detects the rail defects sequentially and the other is quantitative analysis is applied on the real-time online fielding test over the tracks. The system has achieved accurate results for the prediction of rail track components in the real-time field test.

Zheng (2012) has designed a system that automatically inspects the tracks. The proposed system mainly focuses on the inspection of the track gauge and the irregularity of the gauge. The system dynamically inspects the track by using computer vision methods. The system used a Charge-Coupled Device CCD cameras and two red laser lights. Then the inspection process, as well as the calibration method, is being analyzed. This system uses image component extraction, differential iteration threshold processing techniques. The system provides accurate results of predicting the rail gauge points in a faster manner.

Resendiz (2013) has proposed a design system that is used to make the inspection process automated. They use computer vision methods which will consist of the video processing facility with analysis methods embedded within the system. The system performs various detection tasks such as segmentation, and defect analysis of the track components. The methods which would predict the track components called Spectral estimation and signal processing are used. The authors conclude that the proposed system provides better results based on the field-acquired images as well as videos.

ISSN: 223-7857 IJFGCN

Li (2014) proposed a system that performs a real-time automated vision-based system of inspection at 16km per hour and frame rate of 20 fps and helps in detecting all the rail components such as ties, clips, anchors, with high accuracy and yields efficient results. The system has image and video analytics with multiple cameras, GPS, and Distance Measuring Instrument DMI. The proposed system focuses on analyzing the anchor patterns and performs quantitative analysis on a large dataset consisting of videos as well as images. Then the real-time field test is conducted to predict the efficiency results of the proposed system. The proposed system has a 94.67 % precision value and 93% of recall rate by detecting the rail components and 100% efficiency of detecting the rail components.

Ramesh (2014) has designed a system that would automate the process of inspection of rail tracks. The proposed system tells about the global standards which have not been achieved by rail transport in terms of reliability and safety measures. They have addressed this problem and proposed their idea which solves the problem of inspection and helps in automating the tasks. The system uses Controller Area Network CAN Controller, Global Positioning System (GPS), Global System for Mobile communications GSM, and ATMEL Processor. Using Radio Frequency RF module which consists of both transmitter and receiver with encoder and decoder. The proposed system with the help of the above components fixes in track at every node and in the train as well, when the light passes to the next node then there it means there is no crack in the track.

Gibert (2015) has proposed an idea which mainly focuses on the fastener component. They mentioned that it is the most important component of a track which has to be monitored frequently. The proposed system uses a method to detect fasten using computer vision. They first align the training data and reduce intra-class variation and improve the classification margin. With the help of histogram-oriented gradient features and Support Vector Machines SVM, the proposed system inspects the tracks for ties and errors that occurred in the track. The system achieved a detection value of 98%.

Arivazhagan (2015) has designed a system that focuses on derailments of tracks. They have proposed a system that is used to perform automated rail track inspection for derailments in tracks. They have implemented this idea by using a machine vision algorithm to detect cracks in tracks. They use an analysis method called Segmentation based fractal Texture Analysis SFTA and the input image is decomposed by Gabor filter and extracts texture features by applying above the methods. The features are being classified as an image with a defect or no defect. The system was tested for real-time samples and the accuracy results were quite satisfactory.

Gibert (2017) has proposed an idea that would enhance the prediction of defects in the track and helps in detecting other errors. They have addressed the automation of the inspection of rail tracks. They have mentioned that the automation process is still challenging and the prediction accuracy is also varying for other proposed systems. The computer vision methods and pattern recognition methods helped in solving these problems. They have used a multi-learning network in combination with multiple detectors to enhance the detection accuracy and to produce accurate results. The proposed system helps in detecting the rail components such as ties, anchors, rail fasteners in an improved accurate manner. Min (2018) has proposed a system that helps in detecting rail surface defects by using machine vision methods. They use image processing techniques for detecting surface defects. The proposed system consists of an image acquisition device with a led light source and the system is tested in real-time. The system uses a morphological process to optimize the surface defects on the track. The maximum positioning time for the system is 4.65 *ms* and the system for maximum

ISSN: 223-7857 IJFGCN

positioning failure is 5%. The system has experimented and then measured these values. The speed of the system is 2 *m*/*s* and the speed of processing the picture is 245.61 *ms*.

Kaewunruen, (2013) has proposed an idea that would help in monitoring the rail tracks and safety inspection for critical structures. It mainly focuses on a system-based information framework on board as well as on-site inspection of data. During the inspection, the extreme climate changes are also being considered by the proposed system. The system helps in improving the agility, adaptiveness, and readiness of the framework. It mainly helps in maintaining the total track inspection activities and infrastructure integrity. The new challenges for the proposed system are being addressed and highlighted as pieces of evidence.

Although developments in this field have a long research record, for the automated visual inspections of railway track components, there are still several open problems to solve. Reviewing previous research efforts, the two main challenges are still

1- Dust, surface erosion, rusting, snow, stones, and heavy rain are considered a tough challenge in all published methods, including the neural networks, for successful cracks segmentation.

2- Need for optimum illumination conditions to obtain excellent detection results. Some researchers are trying to overcome these issues by heading towards nondestructive methods such as eddy current techniques, which seems a promising solution. However, the visual detection methods are considered the closest to the human performance attitude, and this area is improving unceasingly.

Another identified drawback in this research is the lack of a benchmark database for railway cracks visual inspection. With the goal to more efficiently classify railway cracks several Machine Learning methods have been introduced including traditional neural networks techniques as well as deep learning approaches.

The latest relevant such published papers include Faghih-Roohi, et al. (2016), Gibert, X. et al.(2017) and Wei, X., et al. (2019), that had used the Convolutional Neural Networks methodology. These research papers have shown positive results to an extent. However, none of these papers has considered more advanced deep learning models having a single model that can classify all track components simultaneously. In the herein presented study it is attempted, in addition to the novel drone based framework for enhanced railway crack visual inspection, to apply state of the art deep learning techniques based on the successful deep learning object detection approach of YOLOv3 algorithm, illustrating its promising high performance potential.

PROPOSED MODEL

The proposed system is used to detect the cracks in tracks through an automated drone. The drone is trained to automatically detect the tracks for cracks, errors, defects. To make the system automated, it uses technologies such as Artificial Intelligence, Deep learning (DL), Computer Vision, Drone Unmanned Aerial Vehicle (UAV) technologies to automate the process of rail track inspection.

ISSN: 223-7857 IJFGCN

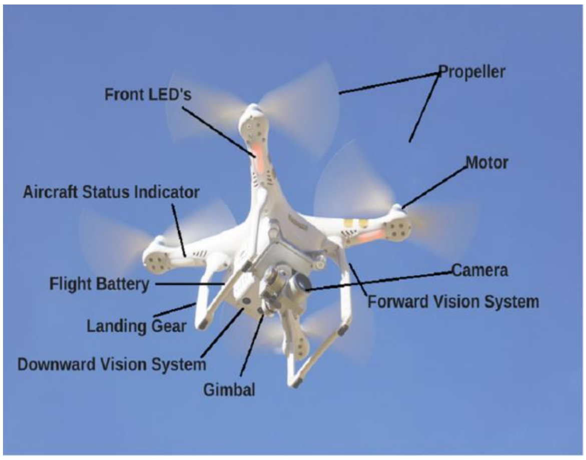

Fig. 1 Components of Drone (Courtesy: droneu.com)

The automated drone technology has various features and functions embedded in it. The system has a drone unit set up at the railway station. The drone unit is used to send the drone for inspection as well as appoints station workers who can address the tracks whenever the drone detects cracks or other defects in the track.

Fig. 1 shows the components of a drone. Some of the mandatory components are

a) Battery
b) Propellers
c) Brushless Motors
d) Frame
e) ESC
f) Battery charger
g) PCB
h) Flight Controller
i) Transmitter
j) Receiver

These are some components of the drone which will be used in the proposed system. The Battery which is used to power up the drone is called a LIPO (Lithium-ion Polymer) battery and the frame used in the system is said to be carbon frame and the propellers are also based on carbon fibre. The Electronic Speed Controller (ESC) is the component that controls the speed of rotation of the brushless motor. Printed Circuit Board PCB is the one in which the entire drone is being constructed. The Flight controller is said to be the brain of a drone. It is the component that gives instructions to all other components such as ESC's, Motors, Receiver, etc. The proposed system uses Pixhawk flight controller. The receiver is the component that receives information from the transmitter and then sends the input to the flight controller. The camera is being attached at the bottom of the drone and has a Global Positioning System GPS module fixed with the drone. The camera is used to take images and videos and the GPS module is used to send the drone's location dynamically to the drone unit.

To make the drone detect the crack present in a track, it needs certain image processing techniques and some intelligence to be fed so that it can able to recognize through the camera. The proposed system uses a computer vision methodology along with a deep learning algorithm to make drone recognize cracks. The system uses the You Only Look Once YOLOv3 algorithm that is a deep

ISSN: 223-7857 IJFGCN

learning algorithm as given in Fig. 2 and it works in combination with the computer vision-based methods. The Yolov3 algorithm is an object detection algorithm which is used to detect objects in an accurate manner accurately with a high rate of accuracy. The YOLO-v3 version has an advanced version of the deeper architecture of the feature extractor which is termed Darknet-53. There are 53 convolutional layers each followed by a batch normalization layer and the Leaky Rectified Linear Unit (ReLU) activation function.

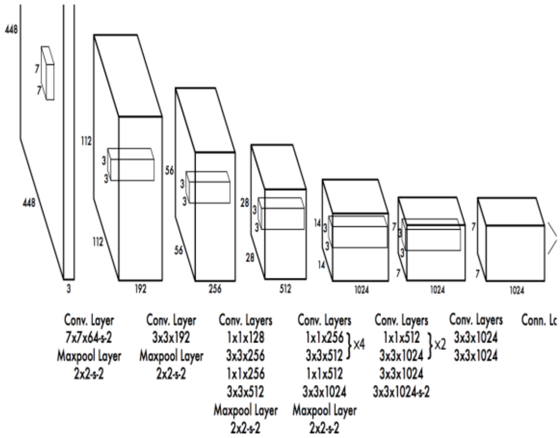

Fig. 2 Yolov3 Algorithm Architecture

Courtesy: medium.com

The output is said to be the list of bounding boxes along with the recognized classes. YOLO-v3 has three anchors which result in three bounding boxes per cell. The predictions are based on the height and width of the input image. It also calculates the object's score and class confidence. The algorithm follows the principle of looking only once at the image that requires forward propagation through a neural network to make predictions. There are three versions of the Yolo framework, they are Yolov1, Yolov2, and Yolov3. In this system, we use the Yolov3 algorithm. The proposed system is designed in four modules. The modules are:

A. Building Custom Dataset
B. Training Yolov3 Algorithm with Custom dataset
C. Testing Yolov3 Algorithm
D. Drone unit Initialization and Drone Inspection process

A. **Building Custom Dataset**

The automatic detection of cracks in tracks should be accurate. The proposed system first collects the dataset of tracks with cracks in it. When the dataset is said to be enough for training the algorithm, then it has to be labelled. Before labelling the images, the dataset is being split into two datasets such as Training dataset, testing dataset. The Training dataset should consist of 75 % of the images collected to train the algorithm efficiently and for prediction accuracy also. The Testing dataset should consist of 25% of images for testing the algorithm's prediction accuracy.

ISSN: 223-7857 IJFGCN

Fig. 3 Image of Track with crack

The images are being labelled by a software tool called as Microsoft VoTT tool. This tool is used to label the images and have the parameters of labels stored in either .csv, .json, or some other formats. During project creation in the VoTT tool, the name crack track has to be provided in the tag name. Then the process of labelling starts when the images are labelled. The tag name is presented over the frame drawn on the image. Then the images have to be exported in the form of .csv format. A sample image of a track with a crack is shown in Fig 3. When the images are exported it has an excel file which is a .csv file containing the frame parameters as in Fig. 4

The labelled images are stored in a separate file. Then the images have to be annotated to train the Yolo algorithm. So, the custom dataset is annotated and converted into yolov3 format. Then the custom dataset for the Yolov3 algorithm is made.

B. Training Yolov3 Algorithm with Custom Dataset

Once the custom dataset is being made, now the custom dataset is used to train the yolov3 algorithm as shown in Fig. 5. The custom dataset is provided for training the algorithm, but the algorithm needs another set for training which is the pre-trained model of Darknet weights which is efficiently built to detect objects accurately. After downloading the weights, the weights have to be converted to Yolov3 format. The darknet weights are then converted to Yolov3 format by running a detector. After converting both the custom dataset as well as the darknet weights, they are being fed to the Yolov3 algorithm and trained. The algorithm takes time for being trained. After some time, the algorithm will be trained with a custom dataset as well as darknet weights.

It would have learned the features, anchors, etc from the custom dataset and is now ready to apply its learning features over the test images.

ISSN: 223-7857 IJFGCN

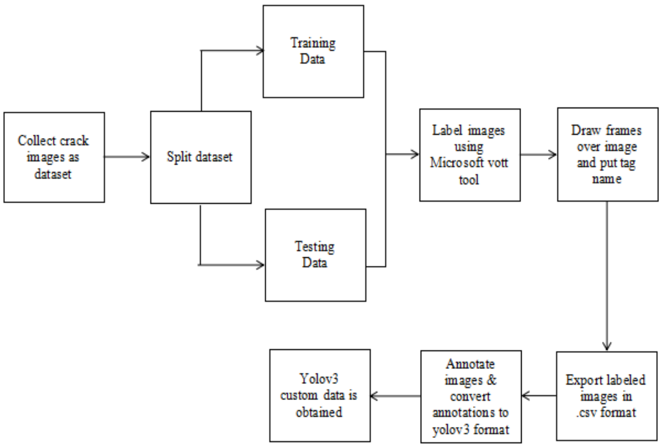

Fig. 4 Building Custom Dataset

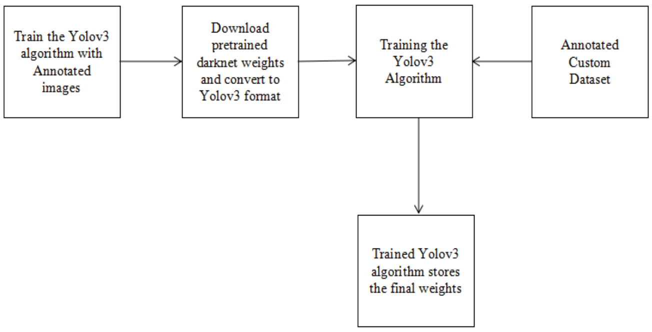

Fig. 5 Training Yolov3 algorithm with custom dataset

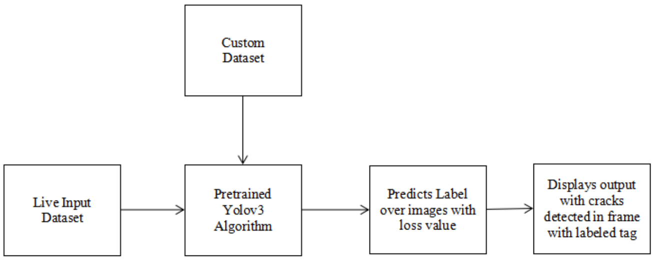

Fig. 6 Testing the Algorithm

C. **Testing the Algorithm**

Fig. 6 represents the testing of the algorithm by providing test images to the algorithm. The live input dataset is being fed to the pre-trained yolov3 algorithm. The algorithm applies its learning features to the test images and calculates the confidence loss values for the predicted images. The predicted images are drawn with a label and the name of the label with a confidence score value. The confidence score value lies between 0 and 1. The algorithm provides the prediction accuracy value along with the confidence score value for the predicted images.

D. Drone Unit Initialization and Drone Inspection

The proposed system has designed an automated drone that would perform an automatic inspection of the rail track. The drone is constructed by calculating the payload, battery power, and then the flight time, stability of the drone is considered during the construction of the drone. The

ISSN: 223-7857 IJFGCN

trained yolov3 algorithm is fed into the drone through the flight controller and embedding it in the camera present in the drone. The drone's camera will always be in inspection mode that is the algorithm would be running in the background which uses computer vision techniques. In Fig. 7, the figure has a unit called a drone unit. The drone unit consists of various parts.The drone unit consists of a database, drone, drone unit controller, live video display interface, and drone operator. Each part has its functionalities to perform. In Fig. 7, the database is used to store when the drone was used for inspection, its location details, specifications, services, its recordings, images, etc are being stored in the database for easy access of data, and the inspection team can view it whenever they want. It records the current inspection date and stores video and image formats so that any time data can be analyzed.The drone control unit is used to set the drone in an automated manner or manual. It is used to set the height of flight and the distance it has to go and return. All operations are made automatic by setting these constraints before the inspection process begins. The Drone operator operates the drone, fixes the height, distance and then sets it to the field. The live video interface is the part in which both the railway officials as well as drone operators can view it through this unit available in the drone unit. It lively telecasts the video to the drone unit.The drone is now being set by the drone control unit as well as the drone operator. The height of flight and distance to be travelled are set. After setting these parameters, the drone connects with the drone unit and control unit as well as the live video interface unit. It initializes its receiver and camera and video streaming is now real-time and telecasted to the drone unit. It also initializes the camera with the code embedded in it and the GPS module.The drone hovers over the track at the same speed and same height of altitude. When a crack is being detected by the drone, then it stops at that place and it takes the image of the crack and the location parameters such as latitude and longitude details with the image as well as the video format is being sent to the drone unit and it gets stored in the database. The drone starts moving when the details are sent, if not sent it waits until the information is sent. It checks for the distance to be travelled if the distance is more, it continues its inspection process. If the distance is less, then the drone turns back and goes to the drone unit automatically. When the train comes during the inspection process, the drone will sense it using an ultrasonic sensor and it moves sideways and waits until the train moves. Then it resumes its inspection process.

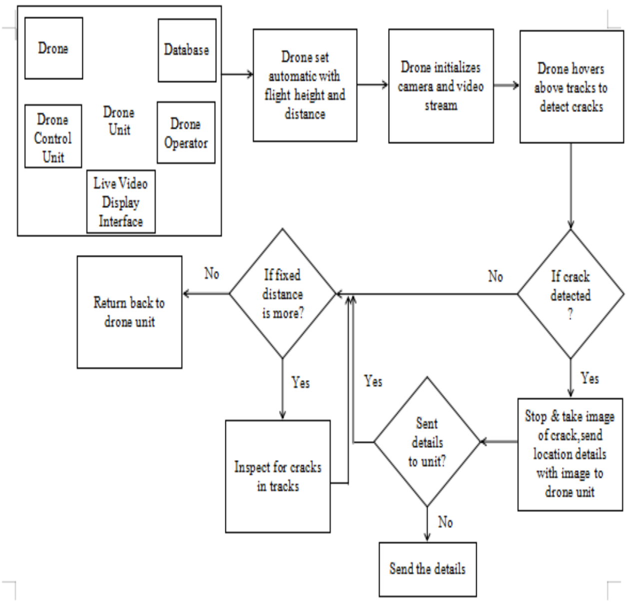

Fig. 7 Drone Unit Initialization and Inspection process

ISSN: 223-7857 IJFGCN

RESULTS AND DISCUSSIONS

The algorithm is embedded in the drone camera which would help in detecting the crack present in the track by using the algorithm. The prediction of the crack in the track is said to be accurate due to the algorithm's efficiency and the frame's processing speed. The drone is automated by the drone unit and it is controlled by the drone control unit. The level of flight from the track surface is set and the distance to be travelled by the drone is set. The initializing values and other details are being recorded in the database up to date. If the crack is detected then it automatically sends the image, video files with location details to the drone unit.

The proposed system can be implemented by using python 3.7 language along with deep learning with computer vision algorithm Yolov3 algorithm. This algorithm uses computer vision's package for an image as well as video detection called OpenCV package. The algorithm is purely implemented using python code. The drone's flight controller is optimized using software called PX4 software.

The proposed system has experimented with this algorithm by collecting the images of crack images and manually labelling them. Then the labelled images were given two tag names track, crack. Then each image was labelled with the tag names and then the image dataset where exported in .csv format. Then the folder consists of the annotated images with .csv file.

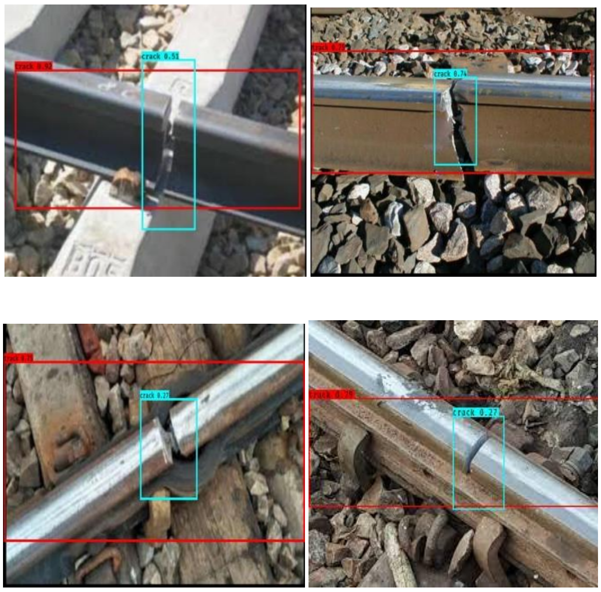

Fig. 8 Experimental Results

Then the code for training the algorithm is done in Jupyter notebook which is used for training bigger algorithms like Convolutional Neural Network CNN. The annotated images are provided to the detector and then it converts it into yolov3 format. Then, the system downloads pre-trained Darknet weights and converts them into Yolo weights. The algorithm was trained and then the test images were uploaded to the directory and were tested for the algorithm's prediction accuracy. The test images were detected with the track and crack labelled by frames with confidence scores being displayed as in Fig. 8

The proposed system works in an automated manner and helps in reducing human errors while inspection. The system is used to predict the crack accurately with the prediction results of 95%. The

ISSN: 223-7857 IJFGCN

system involves a drone and makes all the transactions that have to be stored manually in an automated way by using a database and linking it with the drone as well as the drone unit. The proposed system is said to work in all environmental conditions and give its best results to make the inspection process in an automated manner. The system finally ensures the rail track safety as well as to the railway department and to safeguard the people.

V CONCLUSION

This suggested methodology of automating the inspecting process of railway tracks through drones involving deep learning techniques will minimize the time to detect the cracks in railway tracks. Any number of drones can be used in-between stations and they can be used to monitor the tracks efficiently at frequent regular intervals. In this study we have outlined an effective architecture for implementing such a methodology and discussed preliminary promising results.

REFERENCES

[1] Hayre, H. S. (1974). Automatic railroad track inspection. *IEEE Transactions on Industry Applications*, (3), 380-384.

[2] Cabrera, A., Marshal, A., Morehead, B., Panuska, A.,Rachandran, B., and Mark Rudnicki, (Sept. 2002). Rail Transit Track Inspection and Maintenance. *American Public Transportation Association APTA,* Tech. Rep.

[3] Singh, M., Singh, S., Jaiswal, J., & Hempshall, J. (2006, October). Autonomous rail track inspection using vision based system. In *2006 IEEE International Conference on Computational Intelligence for Homeland Security and Personal Safety* (pp. 56-59). IEEE.

[4] Babenko, P., (2009). Visual Inspection of Railroad Tracks. *Univ. of Central Florida, M.S., purl.fcla.edu*,Tech. Rep.

[5] Trinh, H., Haas, N., Li, Y., Otto, C., & Pankanti, S., (2012, Jan). Enhanced rail component detection and consolidation for rail track inspection". *2012 IEEE Workshop on the Applications of Computer Vision (WACV),* (pp. 289 - 295).

[6] Zheng, S., Chai, X., An, X., & Li, L. (2012, Aug). Railway track gauge inspection method based on computer vision. *IEEE International Conference on Mechatronics and Automation (*pp. 1292 - 1296).

[7] Resendiz, E., Hart, M.J., & Ahuja, N. (2013, Jun). Automated Visual Inspection of Railroad Tracks. *IEEE Transactions on Intelligent Transportation Systems,* 14(2), (pp. 751-760).

[8] Li, Y., Trinh, H., Haas, N., Otto, C., & Pankanti S., (2014, Apr). Rail Component Detection, Optimization, and Assessment for Automatic Rail Track Inspection. *IEEE Transactions on Intelligent Transportation Systems,* 15 (2), (pp. 760 - 770).

[9] Ramesh, S., Arvind, S., Rituraj, Roy, M.K., (2014, Apr). Automatic Track Inspection in Railway Network. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE),* 9(2), (pp. 41-46).

ISSN: 223-7857 IJFGCN

[10] Gibert, X., Patel, V. M., & Chellappa, R., (2015, Jan). Robust Fastener Detection for Autonomous Visual Railway Track Inspection. *2015 IEEE Winter Conference on Applications of Computer Vision,(* pp. 694- 701).

[11] Arivazhagan, S., Shebiah, R.N., Magdalene, J. S., & Sushmith, G., (2015). Railway Track Derailment Inspection System Using Segmentation Based Fractal Texture Analysis. *ICTACT Journal on Image and Video Processing*, 6(1), (pp. 1060-1065).

[12] Gibert, X., Patel, V. M., & Chellappa, R., (2017, Jan). Deep Multitask Learning for Railway Track Inspection. *IEEE Winter Conference on Applications of Computer Vision,* 18 (1), (pp. 153-164).

[13] Min, Y., Xiao, B., Dang, J., Yue, B., & Cheng ,T., (2018, Jan). Real time detection system for rail surface defects based on machine vision. *European Association for Signal Processing EURASIP Journal on Image and Video Processing*, (3).

[14] Kaewunruen, S., Osman, M.H.B., & Rungskunroch, P., The Total Track Inspection. *Front. Built Environ.*,[Online]. Available doi: 10.3389/fbuil.2018.00084.

[15] Faghih-Roohi, S., Hajizadeh, S., Nunez, A., Babuska, R., De Schutter, B.: Deep convolutional neural networks for detection of rail surface defects. Proc. Int. Jt. Conf. Neural Networks. 2016–Octob, 2584–2589 (2016). doi:10.1109/IJCNN.2016.7727522

[16] Wei, X., Yang, Z., Liu, Y., Wei, D., Jia, L., & Li, Y. (2019). Railway track fastener defect detection based on image processing and deep learning techniques: A comparative study. Engineering Applications of Artificial Intelligence, 80, 66-81.

ISSN: 223-7857 IJFGCN