1.1 Introduction

Railways in India carry more passengers than any other country in the world. In 2014, Indian railways carried around 1,158,742 million passengers – KM that accounts for 38% of the worlds railway passengers carried. An estimated 3,049,392 million passengers are carried by world railway networks [1].

Most of the rail networks have adopted latest technologies in signalling, locomotives, coach design, accident avoidance systems, track maintenance and high-speed trains [2] - [6]. However, the most important and vital role is played by maintenance systems that monitor running trains in real time to avoid accidents.

In Indian subcontinent, this is performed by a large team of engineers under the branch named Rolling Stock Examination (RSE) [7] - [8]. Rolling stock examination involves human visual and auditory sensor identification of anomalies in the moving train. The challenges faced by rolling stock engineers and the common problems are discussed in [9] and new models with sensors along the track and on train is proposed to automate the process is proposed in [10].

Three trained humans on either side of a railway station monitor the moving train at >30KMPH when the train moves into and exits the station. These six personnel are deployed for every major train station for every train that passes the station. Fig.1.1 shows the personnel during a rolling stock examination process.

When trains enter the station, rolling examining staff take up positions on both sides of the train for inspection of the following components

(i) Any hanging parts

(ii) Lose fitting of vehicle parts

(iii) Break binging of any vehicle
(iv) Any broken or loose broken components

(v) Whistling sound of hot axel boxes

If all the above factors like no hanging parts or loose fittings, breaks are fine-tuned, no broken parts and axle box temperatures are within the range, then train is safe to run command is issued. This procedure is carried out at both ends of the station when train arrives into and leaves the station.

RSE performed during train moving in is called rolling In and departure RSE is called rolling out by the Indian Railways. At present the RSE system is human monitoring and is influenced by many factors such as environment, nature and the human self.

Most of the train accidents happen due to two major causes: faulty tracks and faulty train bogie. Train bogie is the under carriage of the train upper coach. Fig.1.2 shows two most commonly used bogies on Indian rails [11].
The automation in RSE is a complex and financially not viable with many sensors placed along the tracks or in each bogie part as proposed in [10]. We introduce a procedure for cost effective monitoring of RSE with computer vision and image processing [12]. The model uses a high-speed camera that captures frames at 240 fps to avoid blurring and aliasing effect due to moving train. The recording created a set of 10 videos of 5 trains at 4 different lighting conditions. This work focuses on ICF bogies only.

1.2 Train Rolling Stock Examination

The main area of this thesis is rolling stock Maintenance (RSM) and especially the area of Rolling Stock Examination (RSE). Rolling stock examination refers to all planning of rolling stock conducted during operation i.e. in real time.

Rolling stock examination is used for the coaching stock, goods stock & Locomotive. Coaching Stock (Vehicle) comes under several categories such as Passenger Coaching Vehicle & Other Coaching Vehicle’s. PCV’s are used for carrying passengers and OCV’s are Pantry cars & inspection cars. PCV’s are of distinct types like ICF & FIAT bogie made from India & Germany.

The under part of the train is called bogie. Bogie of a train is displayed in figure 1.3 It shows a model of bogie called Fabrica Italiana de Automobil Torino (FIAT). There are around six models.
operational in Indian railways. Figure 1.4 shows another model called ICF model which is a part of 70% of Indian trains. The idea behind rolling stock examination is to identify how these parts are behaving under movement of train.

The field of computer vision and its applications is of interest to many researcher’s around the world. The moving and rolling portions of a train are called rolling stock. Rolling examination is vital for passenger trains to identify defects that can possibly generated during movement of trains at high speeds. This process will ensure the safe movement of trains.

**FIAT (FABRICA ITALINA De AUTOMOBILE TORINO) bogie:**

The FIAT Bogie frame is Y shape fabricated structure. There two suspension primary and secondary suspensions, disk brake mounted with axel brake with hydraulic shock absorbers. The Bolster beam supports the vehicle body and bogie frame rest on primary suspension spring unit. Bogie frame linked with two vertical dampers and lateral damper.

![Figure:1.3 FIAT Bogie](image)
Components of FIAT bogie

i. Bolster beam
ii. Anti-roll bar
iii. Internal & External Springs
iv. Lateral & Vertical Dampers
v. Safety rods
vi. Hot axel
vii. Bogie Frame
viii. Primary & Secondary Suspensions

It contains Control arm, connected with axle bearing to a bogie for transmitting vertical forces, Rubber elements are used to reduce noise

Secondary suspension:

It provides vertical and horizontal displacements of bogie rotation w.r.t to human body when running through curves. It’s Operating speed is 160kmph. It has very little maintenance.

ICF (Integral Coach Factory) Bogie:

Figure 1.4: ICF Bogie

ICF Bogie is designed for Indian Track’s and providing suspension in primary & secondary it called AC (All Coil) Bogie
with a Wheel Base of 2896mm & Diameter 915mm. The Centre Pivot pin is located at the bolster. Axle rod is Straight and Solid with a capacity for A/c and Non-A/c coach are 16Ton’s and 13Ton’s respectively. Two shock absorbers are provided at in b/w Bolster and lower plank and another two are provided in modified ICF bogie (Hybrid Coach). Anchor link with bushes are used to braking force from body to coach and coach to body vice versa with Air Brake system 90±10mm. Finally, it can run at max of 110 kmph. (Ref: Rly. Board’s Letter No. G2/ M(c)/151/2 vol.- V dated 25/01/2011).

**Components of ICF Bogie:**

i) Primary Suspension  
ii) Axel Box Spring  
iii) Vertical Shock absorber  
iv) Lower spring beam  
v) Secondary suspension  
vii) Safety Strip  
vi) Bolster suspension hanger

Rolling stock is an essential item within the railway and transport systems, but it is one of the most complex. From running gear through strength and durability, drives, brakes, regulation and control systems and up to fire protection and occupational health and safety, all safety-relevant functionalities must be in full working order at all times. The entire system comprising the “rolling stock” must fulfil safety requirements according to both national and international standards and directives.
**Rolling Stock as a whole**

i) Testing and reports on the technical safety of rolling stock

ii) Evaluation of operators’ regulations and residual risks for passengers

iii) Responding to system-related questions and questions regarding standards and regulations

**Comparison between ICF and FIAT Bogies:**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>I.C.F.</th>
<th>FIAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Max operating speed=130 kmph</td>
<td>Max operating speed=160 kmph</td>
</tr>
<tr>
<td></td>
<td>tested speed=140 kmph</td>
<td>tested speed=180 kmph</td>
</tr>
<tr>
<td>2</td>
<td>Bogie Frame I Type</td>
<td>H Type Construction</td>
</tr>
<tr>
<td>3</td>
<td>Wheel Base =2896 Mm</td>
<td>Wheel base = 2560 mm</td>
</tr>
<tr>
<td>4</td>
<td>Wheel Dia =915 Mm</td>
<td>915 mm(new) 845 mm (worn)</td>
</tr>
<tr>
<td>5</td>
<td>Clasp Type Brake</td>
<td>Axle Mounted Disc Brake</td>
</tr>
<tr>
<td>6</td>
<td>Spherical Roller Bearing</td>
<td>Tapered Roller Bearing</td>
</tr>
<tr>
<td>7</td>
<td>Primary Single Spring</td>
<td>Primary nested spring =2No’s</td>
</tr>
<tr>
<td>8</td>
<td>Limited Noise Control Features</td>
<td>Noise Controlled By Using Thick Rubber Pad</td>
</tr>
<tr>
<td>9</td>
<td>Secondary spring on L.S. Beam</td>
<td>Secondary spring directly mounted on side frame</td>
</tr>
<tr>
<td>10</td>
<td>Coach Load Is Transferred Through Side Bearer (100%)</td>
<td>Through bogie body connection to side frame via sec. Springs.</td>
</tr>
<tr>
<td>11</td>
<td>Center Pivot Transfer Traction And Shock Load</td>
<td>Pivot assembly on transverse beam and bracket on dome take traction/ braking, shock load.</td>
</tr>
</tbody>
</table>
12. Anti-roll bar has not been provided.

13. Anti-roll bar has been provided to curb the tendency of roll.


15. Very little maintenance

15. Weight Of Bogie=6.2 T

15. Weight Of Bogie=6.3 T

1.3 **Manual Rolling Stock Examination:**

It is a manual system to identify defects visually and auditory of a moving train. The personal are placed at either side of the track nearer to the railway station. The process followed by Indian railways can be best understood using figure 1.5.

Two personal for monitoring and a third person for noticing the defects on either ends of the station make up a total team of SIX personal per train for examination. The following are the drawbacks identified:

- Human indulgence – error prone detection.
- Personal work load increases at peak hours – bound to make mistakes.
- Defects attended by maintenance staff in next
station.

- Weather dependent system.

According to India Risk Survey 2012, around 15% of the accidents happen in India and 90% of them are due to human errors and lack of proper maintenance of rolling stock. Here Rolling Stock is defined as industrial machinery mechanical movements that are designed for specific purposes.

Accidents are costly for the industry in terms of loss of revenue as the machine and person operating requires repairs. The reason for accidents in 90% of the cases is due to human errors or poor maintenance of the moving machinery in the industry. The cost of accident prevention is again costly for the small and medium scale industries in India.

To our surprise Indian railways also face from the same problems. We have approached Indian railways as it is easy to obtain video data of moving parts compared to other industries.

The following are the common defects arising Rolling Stock such as visual defects are falling objects, hanging suspension, missing parts, break functioning and axle box condition. Auditory defects include sounds produced during movement that can identify mostly flat tyres. Any unwanted object attached to the wheel base is termed flat tyre in trains.

Wheel alignment defects, axel defects, Spring gear defects, Broken gear defects, body and other defects like breaks & Hot Axle temperature. The unnoticed Hot Axle Condition will be leads to wheel derailment.

Over the decades, the rail companies have formulated procedures and invested hugely in making the rail travel safer. In
case of Indian Railways, rolling stock examination has brought down the accidents significantly but this incurs a huge financial burden on the rail company [13].

1.4 Computer Vision for ROLLING STOCK Examination

Video capture of moving objects introduces blur due to mismatching between shutter speed and object speed. This caused a problem for capturing moving train. During rolling examination, the train is moving at 30KMPH.

By using a 30fps video camera a significant amount of blur was induced into the frames and loss of object boundaries and regions. That made segmentation process complicated. At this point the algorithm required preprocessing in the form on de-blur model. After this preprocessing the image frame quality decreased considerably and proposed models failed to detect true edges. Another problem faced while capturing rolling stock is related to bogie fitting. Bogie fitting is capturing the entire bogie in a single frame. With a 30fps video camera it became impossible to capture a bogie in a single frame. To avoid blurring the frame rate should be at least twice the speed of objects in the image.

This experimentation requires full HD wide angle lens camera is required for capturing rolling stock. Hence, we use ISAW extreme sports action camera shown in figure1.6. It can capture full HD at 30fps, 60fps, 120fps and 240fps with wireless transmissions up to 10 meters. To record an entire bogie, the camera is set in 240fps, with 16:9 unscaled aspect ratio and $152^\circ$ field of view giving $853 \times 480$ sized video frames.
Figure 1.7 shows our team members collecting video database of rolling stock alongside rolling examination team of Indian railways.

Figure 1.8 shows a video frame of a train bogie during rolling stock examination. The frame resolution is $1080 \times 1920$ for the captured video frames showing detailed view of the parts for segmentation. A sample database of rolling stock consisting of 10 videos under different lighting conditions is created for testing. Figure 1.8 shows video frames at different time straps of a day.
1.5 The Problem Definition and Literature review

To build a robust real time intelligent monitoring system, it needs at least 3 cameras, 2 on either side of the track and one under the track with proper lighting as shown in figure 1.9.

Experimentation of the rolling stock video segmentation is carried on an intel core i7 processor with 8GB Ram and MATLAB 15 software. A high-speed camera captures the transit bogies at 240fps to evade motion blur. The camera is additionally
equipped with a wide-angle capture lens to record the whole bogie in one frame.

These trains in Asian Country (India) are stacked with 15 to 20 compartments. Every compartment has 2 bogies per compartment, making it 30 to 40 bogies per train. Every bogie video records for around 80 frames. This research proposes to replace the maned rolling examination with a high-speed camera based computer vision automated rolling examination.

Computer vision research is currently driving most of the software industry giants such as Google and Facebook. Research shows face recognition; image search; video compression and playback; deep learning algorithms are revenue generators for the tech sector companies. Vision research has deeply made inroads into automobile with autonomous driving cars [14], transportation monitoring [15], structural quality assessment [16], agricultural [17] and manufacturing [18] industry from last decade onwards. Specialized cameras such as high speed, laser
and hyperspectral cameras are being used for video capture for monitoring and testing applications.

Narayana swami, et al [19] provides a vision for future of transportation in urban environments. The ideas discussed in this work help understand the link between technology and automation required to save on time and finances with focus on avoiding accidents. In [20], Sabato, et al uses 3D digital image correlation (DIC) algorithms to inspect railroad ties and ballast. Two cameras at a specific displacement are mounted on a rail car moving at 60Kmph to produce a 3D image. Deformation of railway tracks is identified with 3D DIC and pattern projection algorithms. US Federal Railroad Administration data between the years 2005 and 2015 show 16000 derailment due to track, ballast and rolling stock failure. Automation of Rolling stock is important for railways around the world for cutting costs and saving trains from derailment. Computer vision processing can be used for monitoring rolling stock to identify defects in bogies. Hart, et al [21] used multispectral imaging to extract bogie segments for inspection. They recorded both RGB videos and thermal videos of a moving train with processed the frames using panoramic representation and correlation. The focus was on detecting high temperature regions on the undercarriage parts such as brake shoes, axel box, air conditioning blowers and wheel joints. However, the work is of great use to rail companies with a shortcoming in frame rate as the cameras induce blurring which makes it difficult to identify non-heating parts on the moving train.

Kim, et al [22] transforms the rolling stock brake inspection problem into image curve fitting problem. The methods developed use a database setting of the undercarriage of the train bogies
and use cure fitting tools to identify brake alignments during train movement. The cost of the setup poses a big drawback for such a system to be implemented in real time. The patent from Sanchez-Revuelta, et al [23], shows the use of computer vision for rolling stock examination two decades prior to our work. This patent says, artificial vision will be used to monitor rolling stock by mounting cameras on the train. The captured videos on a moving train call for many fold misalignments and more computation power is required to again process the same for a closer inspection. Kazanskiy, et al [24], proposed a vision based computer technology for rolling stock monitoring system. The work integrates glare free lighting system, video compression models and structured lighting module to detect the presence of train on tracks to monitor rolling stock. This work reaches close to making rolling stock a reality, however there is little mention on evaluating each bogie part for inspection. Freid, et al [25] provides an undercarriage arrangement with lighting and a camera for rolling stock evaluation and processing. They used simple edge detection models for extracting axle rod and measuring its temperature using thermal camera. The model provides a good insight into the importance of the problem in automating rolling stock examination. In [26] and [27], the authors proposed a 3D reconstruction for monitoring contact strips and rolling stock wheel surfaces. These methods are effective as the 3D models perfectly reconstruct the surface defects in moving parts. These methods use lot of computation time and energy for processing as it is difficult to model all defective surfaces.

Few researchers in literature have attempted work related to railway computer vision and processing. Machine vision is
assisting automobile [28], transportation [29], structural [30], agricultural [31] and manufacturing [32] industry for around two decades now. Specialized cameras such as high speed, hyperspectral and laser cameras are used for video capture in industries. Bottling plants around the world use high-speed action cameras that record at 5000 frames per second to separate defective bottles from good ones when they are travelling on a conveyer at 85KMPH.

Rail industries around the world are relatively slow in adapting computer vision for maintenance tasks. Rolling examination is prevalent for every passenger train in Indian subcontinent to prevent accidents due bogie parts failure in transit. The idea is to replace humans for this task with high-speed cameras and an algorithm to identify defects. The real challenge in designing solutions that achieve good performance with respect to imposing constraints by the complexity of the problem gives research motivation.

Fuzzy weighted logarithmic least squares method is studied for train rolling stock examination with machine vision. Video acquired with normal camera at 30fps of the rolling stock is thresholded and a fuzzy model based on the triangular fuzzy number (TFN) is built. Weighted logarithmic least square method classifies the segmented rolling parts. The model evaluation process described in [33] does not comment on the accuracy of detection and performance of the algorithm under various natural circumstances.

Embedded system based intelligent monitoring of rolling stock for safety enhancement in rail transit is a constrained solution proposed in [34]. This work reviews models for rolling stock failure with observable parameters for failure during movement
of trains in real time. Artificial immune algorithm makes a detection and prediction of health of rolling stock on the data collected from a set of sensors attached to the rolling stock. But signal noise from the sensors in transit is a major issue.

Most of the industrial safety in the current scenario is based on cost cutting maintenance. In this regard, the motive of the authors in [35] deals with preventive maintenance (PM) forecasting to decrease the budget distribution for rolling stock examination. The authors use heuristic search algorithms such as genetic algorithm and simulated annealing to discover optimal maintenance breaks for rolling stock life span maximization. Extensions is added to calculate optimum number of spares required during maintenance cycles and their market availability in the long run. Automation of the entire process is a void that could have changed the course of rolling stock maintenance.

Developers in [36] worked on wireless monitoring of rolling stock with extensive reviews and analysis which leads towards potentially equivalent advantages of the prior model. The authors propose a standardized framework for rolling examination with a multi-hop mesh network. The network provides temporary and semi-permanent observable functions of rolling stock by localized network processing along with energy harvesting power management through wireless capability. Accordingly, the methods complement each other well for the job, except that they could not capture the entire essence of rolling stock examination.

In the recent past researchers focused on thickness measurement of lining-type brake with computer vision for automatic rolling stock monitoring. To spot the round outline of the disk lining brake, interest points are detected with Hough transform and the brake edge is explored for anomalies in the
region of interest. The paper also gives a mechanism to test the algorithm in real time by setting up cameras on tracks under the moving bogies. Experimental testing of the proposed system measures the thickness of lining-type brake with a precision of 1.15mm, at the distance of 1.0m from the camera [37]. Similar methods and systems are being executed for break and wheel systems of bogies [38-39] using computer vision and pattern classification for extracting and clustering brake shoe defects with a real time on track installed high speed camera.

Experimental module Technicatome has been developed as a demonstrator for RATP (the Paris subway company) based on interconnected digital systems is reported in [40]. This demonstrator is currently in operation on an MF 88 train set to the long existing and still operated with conventional relay-based systems.

With all these gaps in rolling stock automation using computer vision, we propose a high-speed sensor to capture moving trains and advanced state of the art level sets formulations to identify bogie parts and defective bogie parts. The bogie parts segmentation is formulated as a convex curve fitting problem with pre-information regarding the shape of the bogie part. From the Indian railways manual in [13] there are around 10 important and crucial things to be checked during rolling examination. This thesis reports the simulations for extracting and identifying bogie parts as defective and non-defective based on the quality of the algorithms used.

Literature work

Active Contour models first introduced by Terzopoulos [41] to modelling shape by using segmented images. Evolution of equation in the active contour is labelled snake principally was
familiarized by Kass [42]. The Chan Vese level set algorithm uses image gradients to detect object regions. Image gradients are prone to rapid brightness variations as can be found in the rolling stock video frames. Due to brightness inconsistency, the contour spread takes in large iterations as pointed out in [43]. The Chan Vese Level Sets is expressed by minimizing energy function. The energy function of the Chan Vese Level Sets is minimized by using Mumford-shah [44] piece wise linear function. By using the level set models in to solve the minimizing problems and the modified equation of the level set function is expressed by Jiang [45]. The challenging task for rolling stock frame segmentation is in decreasing the computation time with optimal bogie segmentations for quick maintenance.

To improve the speed and segmentation accuracy of ultrasound medical images [46] is being tested for rolling stock segmentation. The Chan Vese technique is a capable model for many segmentation problems but it is impossible to segment a complex image where objects are tightly bound together. However, level sets [47] handle topological changes in the objects of the image exceptionally well. Still all active contours depend solely on the gradient of the image for terminating the evolution of the curve. We proposed to replace the Chan Vese model’s image gradient with a morphological Differential Gradient (MDG) term [48].

To improve the segmentation in high density environments like the video frames appearing in rolling stock, shape prior models in active contours is being proposed next [49]. Shape priors have a distinct advantage of driving the contour towards the object boundaries [50].

Several versions of level sets with shape [51] and texture
priors [52] were very popular with the image processing research community. A combination of color, texture and shape features are used exclusively by computer vision researchers for complex image segmentation [53]- [55].

Literature shows a variety of shape representations in the form of single shape prior term [56], Multiple shape priors [57], mean shape priors [58] and statistical shape priors [59] for active contour models. The curve evolution is dictated by a fraction of energy contributed by the shape prior term [60].

Another model that is extensively popular with image processing researchers is active contours based image segmentation. First introduced in [61] as Geodesic Active contours which used image gradients to drive the contour on the image boundaries. However, the curve evolution is controlled soon after by shape priors in [62], where a statistical model of shape prior influences the contour movement.

Image gradients are inclined towards changes in pixels making contour sensitivity to such variations. Chan Vese active contour model solved the problem by defining the level set model insensitive to edges and is based on image regions [63]. They proposed a global energy minimization problem based on convex optimization EM algorithm. However, the model is popular for classic medical image segmentation applications [64] with shape priors.

Prior knowledge about the segmented portions in the image makes the algorithms supervised. Shape priors are the widely-used models for image segmentation with both graph cuts and active contours. Apart from shape, which must be hand segmented or through any other model makes the process again supervised. A supervised model with unsupervised pre-
information is proposed in the form of color or texture information in [65]. Knowledge base for the active contour is also supervised with graph cuts in [66].

Color and texture information supervised unsupervised image segmentation models using active contours are making their way into complex natural image segmentation process [67]. In recent times machine learning is activating the field of segmentation with classification models such as support vector machines [68] and neural networks [69]. Deep learning convolutional neural networks are proposed to segment tumors in medical images through powerful learning algorithms [70].

Machine learning algorithms are combined effectively with active contour models where a learning environment is created for the contour for segmenting unknown regions with precision [71]. All the above algorithms are iterative but accurate in most of the cases. Clustering is slowly becoming a part of image segmentation for natural images as they are simple though iterative. K-Means is a simple yet powerful iterative algorithm for image segmentation which depends on l2 norm of computation of distances between centroids of regions [72]. Fuzzy C-Means is another model brings fuzziness into segmentation making it adaptable for human like visual system [73].

Variational methods use fuzzy rule base for contour propagation and extracting local segments. However, all the models are image specific and small bias corrections are to be added for near perfect segmentations. In this work, we propose a train rolling stock video segmentation with multiple unsupervised without shape, with shape and shape invariance models to supervise active contours. The rest of the thesis is organized as follows.
1.6 Thesis Framework

Fig._ shows thesis overview. Chapter 1 discusses problem statement and introduction to train rolling stock monitoring with computer vision models. It also contains the sensor used and capturing modes of rolling stock.

Chapter 2 gives a brief overview of variational methods and introduces Chan Vese (CV) level sets. Details of energy minimization framework is provided. A new morphological differential gradient term is introduced into CV level set framework and its implicative results are presented on segmentation of train rolling stock.

Chapter 3 provides an overview of shape prior model with single shape term per bogie part as an input to CV level set model. Results are encouraging as it becomes simple with minimum number of interactions to segment a bogie part.
However, the model develops complications during the shape deformations of the parts on a moving train.

The problem in chapter 3 is addressed and a shape invariance level set model is proposed in chapter 4 to handle deformable models. The shape prior is modeled to eliminate the problems of scaling, translations and rotations parts undergo during train movement.

In chapter 5, all 4 rolling stock segmentation algorithms used the thesis are compared with respect to structural similarity index (SSIM), Image Quality Index (IQI) and Peak Signal to Noise Ratio (PSNR). This is done to improve upon the gaps left by these algorithms and the corrections to initiated to improve the algorithms for real time implementations.

Finally, chapter 6, concludes with a reference to future scope of this work. This work shows a promising scope in using computer vision as a monitoring tools for visual maintenance systems.