ANALYSIS & STUDY OF AI TECHNIQUES FOR AUTOMATIC CONDITION MONITORING OF RAILWAY TRACK INFRASTRUCTURE

TANMAY PODDER

Master Thesis in
Computer Engineering’2010
Reg. No: E3845D
**DEGREE PROJECT**  
Computer Engineering

<table>
<thead>
<tr>
<th>Program:</th>
<th>Reg. number:</th>
<th>Extent:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Artificial Intelligence</td>
<td><strong>E3845D</strong></td>
<td>15 ECTS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name of student:</th>
<th>Year-Month-Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanmay Podder</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supervisor:</th>
<th>Examiner:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Siril Yella</td>
<td>Prof. Mark Dougherty</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Company/Department:</th>
<th>Supervisor at the Company/Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Computer Engineering, Dalarna University</td>
<td>Dr. Siril Yella</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANALYSIS &amp; STUDY OF AI TECHNIQUES FOR AUTOMATIC CONDITION MONITORING OF RAILWAY TRACK INFRASTRUCTURE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Keywords:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial intelligence; Non-destructive testing; Condition Monitoring; Machine Vision; Neural Network; Genetic Algorithm; Fuzzy Logic; Expert System.</td>
</tr>
</tbody>
</table>
Abstract

Since the last decade the problem of surface inspection has been receiving great attention from the scientific community, the quality control and the maintenance of products are key points in several industrial applications. The railway associations spent much money to check the railway infrastructure. The railway infrastructure is a particular field in which the periodical surface inspection can help the operator to prevent critical situations. The maintenance and monitoring of this infrastructure is an important aspect for railway association. That is why the surface inspection of railway also makes importance to the railroad authority to investigate track components, identify problems and finding out the way that how to solve these problems. In railway industry, usually the problems find in railway sleepers, overhead, fastener, rail head, switching and crossing and in ballast section as well. In this thesis work, I have reviewed some research papers based on AI techniques together with NDT techniques which are able to collect data from the test object without making any damage. The research works which I have reviewed and demonstrated that by adopting the AI based system, it is almost possible to solve all the problems and this system is very much reliable and efficient for diagnose problems of this transportation domain. I have reviewed solutions provided by different companies based on AI techniques, their products and reviewed some white papers provided by some of those companies. AI based techniques like machine vision, stereo vision, laser based techniques and neural network are used in most cases to solve the problems which are performed by the railway engineers.

The problems in railway handled by the AI based techniques performed by NDT approach which is a very broad, interdisciplinary field that plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. The NDT approach ensures the uniformity, quality and serviceability of materials without causing any damage of that materials is being tested. This testing methods use some way to test product like, Visual and Optical testing, Radiography, Magnetic particle testing, Ultrasonic testing, Penetrate testing, electro mechanic testing and acoustic emission testing etc. The inspection procedure has done periodically because of better maintenance. This inspection procedure done by the railway engineers manually with the aid of AI based techniques.

The main idea of thesis work is to demonstrate how the problems can be reduced of this transportation area based on the works done by different researchers and companies. And I have also provided some ideas and comments according to those works and trying to provide some proposal to use better inspection method where it is needed.

The scope of this thesis work is automatic interpretation of data from NDT, with the goal of detecting flaws accurately and efficiently. AI techniques such as neural networks, machine vision, knowledge-based systems and fuzzy logic were applied to a wide spectrum of problems in this area. Another scope is to provide an insight into possible research methods concerning railway sleeper, fastener, ballast and overhead inspection by automatic interpretation of data.

In this thesis work, I have discussed about problems which are arise in railway sleepers, fastener, and overhead and ballasted track. For this reason I have reviewed some research papers related with these areas and demonstrated how their systems works and the results of
those systems. After all the demonstrations were taking place of the advantages of using AI techniques in contrast with those manual systems exist previously.

This work aims to summarize the findings of a large number of research papers deploying artificial intelligence (AI) techniques for the automatic interpretation of data from non-destructive testing (NDT). Problems in rail transport domain are mainly discussed in this work. The overall work of this paper goes to the inspection of railway sleepers, fastener, ballast and overhead.
I would like to start by thanking Dr. Siril Yella, my thesis supervisor for the last five months. I am grateful to him for his wonderful guidance, rapid support, encouragement, and as an endless sources of ideas. His breadth of knowledge and enthusiasm inspired me to carry out the thesis project successfully. I thank him for his valuable hours for discussing the thesis work with me, reading, verifying my work, and editing my writings. The research experience that I have had with him during this period, has given me confidence and encouragement for doing further research work in the future.

Finally, I would like to express my deep love to my parents for their blessing, encouragement and wishes for me so that I can complete my thesis and masters programme very successfully.
Table of Contents

Abstract .................................................................................................................................. i
Acknowledgement .............................................................................................................. iii
Table of Contents ........................................................................................................ iv
List of Figures ................................................................................................................ vi

Chapter 1: Introduction ........................................................................................................ 1
  1.1 Purpose .................................................................................................................. 2
  1.2 Problem Formulation ......................................................................................... 2
  1.3 Proposed Solution ............................................................................................. 3
  1.4 Previous work .................................................................................................. 3

Chapter 2: Background ...................................................................................................... 4
  2.1 NDT for automating interpretation of data ....................................................... 4
  2.2 Artificial Intelligence ....................................................................................... 5
  2.3 Artificial Intelligence Techniques ..................................................................... 5
    2.3.1 Neural Network ....................................................................................... 5
    2.3.2 Machine Vision ..................................................................................... 6
    2.3.3 Case Based Reasoning .......................................................................... 6
    2.3.4 Fuzzy logic ........................................................................................... 6
    2.3.5 Genetic algorithm .................................................................................. 6

Chapter 3: Automatic Condition Monitoring of Railway Track Surface ........... 8
  3.1 Railway Sleeper ................................................................................................ 9
    3.1.1 Monitoring of railway sleeper ............................................................... 9
    3.1.2 Reason of monitoring railway sleeper ................................................. 10
    3.1.3 Previous techniques of monitoring for railway sleeper ..................... 11
    3.1.4 Different techniques based on AI for sleeper .................................... 11
    3.1.5 Failure analysis of Concrete sleeper .................................................... 11
    3.1.6 A stereo Vision system for concrete railway sleeper measurements .... 14
    3.1.7 NDT for system assurance in railway construction ............................ 16
    3.1.8 Railroad Track Inspection Systems ..................................................... 17
    3.1.9 Design of a system to measure track modulus .................................... 19
    3.1.10 Railway Maintenance and Safety: Artificial Intelligence Links ........ 20
    3.1.11 Comparison of Multivariate Linear Regression and Neural Network Algorithms for Ground Penetrating Radar (GPR) Estimation of Track Modulus. .................................. 20
  3.2 Railway Fastener ............................................................................................... 21
    3.2.1 The reason of monitoring railway fastener .......................................... 21
    3.2.2 Previous techniques of monitoring railway fastener ......................... 21
3.2.3 Monitoring of the fastening bolt based on AI techniques ..................22
3.2.4 Visual recognition of fastening bolts ..............................................22
3.2.5 Dynamic behaviour of rail fastener .................................................24
3.3 Railway Ballast ..................................................................................26
3.3.1 The reason of monitoring railway ballast ........................................26
3.3.2 Previous techniques of monitoring railway ballast ..........................26
3.3.3 Different techniques of monitoring based on AI ..............................26
3.3.4 Mechanical Behaviour of railway ballast .......................................27
3.3.5 Measuring the stiffness and density of railway ballast ....................28
3.3.6 Defect detection of ballast by considering its anomalous behaviour ....29
3.4 Railway overhead ..............................................................................31
3.4.1 The reason of condition monitoring of the overhead lines ................31
3.4.2 Previous techniques for railway overhead .......................................32
3.4.3 AI techniques of monitoring railway overhead ...............................32
3.4.4 Condition monitoring of pantograph contact strip ...........................32
3.4.5 Study on expert system of overhead lines ..........................................33

Chapter 4: Solutions Provided by Different Companies .........................39

4.1 Rail sleepers and its surface ...............................................................39
4.1.1 BvSys ..............................................................................................39
4.1.2 Railway inspection systems by bvSys ................................................39
4.1.3 Mermec Group ..............................................................................41
4.1.4 Track Surface Measurement System by Mermec Group ..................41
4.1.5 Beena Vision ..................................................................................42
4.1.6 Innovation in non-contact train and track inspection systems by Beena Vision 42
4.1.7 ENSCO ..........................................................................................42
4.1.8 Evaluate Geometry Conditions of Track at Normal Operating Speed (24) 43
4.1.9 ENSCO security services, provided by ENSCO ...............................44
4.1.10 Different types of sleeper provided by P-TEC .................................44
4.2 Rail Fastener ......................................................................................45
4.2.1 PANDROL .....................................................................................45
4.2.2 Rail Fastening System ...................................................................45
4.2.3 Vossloh ..........................................................................................46
4.2.4 Track Fastening System .................................................................46
4.3 Rail Overhead ....................................................................................47
4.3.1 DTK ...............................................................................................47
4.3.2 Rail Infrastructure measuring and monitoring ...............................47
Benifits ........................................................................................................47
4.3.3 Wire and catenary check by bvSys ...................................................47
4.3.4 Mermec Group .............................................................................48
4.4 Railway Ballast ..................................................................................48
4.4.1 Rail.One ........................................................................................48
4.4.2 Ballasted Track System .................................................................48
4.5 AI based Analysis in context of companies ........................................49

Chapter 5: White papers provided by different companies .......................50
List of Figures

Figure 2-1: Different Steps of NDT technique ..............................................................4
Figure 3-1: Wooden Railway Sleeper with Good(1st one up) and Bad condition(2nd one down).(2) .................................................................................................................9
Figure 3-2: Fastener with rail .......................................................................................21
Figure 3-3: The experimental Setup ............................................................................23
Figure 3-4: Balled Strip Track with Sleepers ................................................................26
Figure 3-5: Setup of 3D reconstruction model ............................................................30
Figure 3-6: Typical Railway Overhead Configuration ................................................31
Figure 3-7: Schematic diagram of the data acquisition equipment..............................35
Figure 3-8: The software structure .............................................................................35
Figure 3-9: Logic chart of the software Consequence and discussion of the system ..36
Figure 3-10: Traction power system .........................................................................37
Figure 4-1: Cracks on concrete railway sleeper ............................................................40
Figure 5-1: Forces of wheel rail contacts ....................................................................53
Figure 5-2: Gage Widening .......................................................................................53
Figure 5-3: Rail roolover ............................................................................................53
Figure 5-4: Hollow worn wheel .................................................................................54
Chapter 1: **Introduction**

Railroad engineering practices regulations require track to be inspected for physical defects at specified intervals, which may be as often as twice per week. Currently, most of these inspections are manual and are conducted visually by railroad track inspectors. Inspections include detecting defects relating to the sleepers, fasteners, rail, and special track work and ballast section. Enhancements to the current manual inspection process are possible using advanced technologies such as machine vision in most cases which consists of recording digital images of track elements of interest and analyzing those using custom algorithms to identify defects or their symptoms.

The science of non-destructive testing (NDT) is concerned with all aspects of uniformity, quality and serviceability of materials and structures to assure that structural components and systems perform their function in a reliable manner. NDT tests are performed in a manner that does not affect the future usefulness of the object or material, as a result of which it provides a good compromise between quality control and cost-effectiveness. During the past several years, NDT methods and procedures have been employed for the inspection of various materials and civil engineering structures with a goal of assessing embedded flaws as quickly and accurately as possible in a cost-effective fashion (36).

This inspection process performed in the regular intervals of time because the product which is needed to inspect not a matter of inspection only for one or twice. So, it is very much needed to inspect this in the entire existence of the tested object. In the area of railway it is more important to inspect each area in a regular basis. Because it is not only make a harm of this product when a problem occur but sometimes also take valuable human life as well. So, by concerning this important factor of NDT technique it has been introduced for automatic interpretation of data together with AI techniques to make the inspection process more reliable and cost effective fashion.

I have reviewed a large number of papers in this work and gathered information from other sources. The research papers which I have reviewed based on almost AI techniques with NDT and related to the inspection of railway products. For every research work I have tried to analyze their methods they are used, objectives of their work and results. For each research I have mentioned some concluding remarks from my point of view and propose new methods or techniques if necessary. I have tried to mention the advantages and disadvantages of each system.

I have analyzed articles based on four different areas of railway. Their activities in this area, which type of problem occurs in each area and previous works which have been done namely manual based inspection also mentioned. Areas are mentioned in following which have analyzed in this particular work.

- Railway Sleepers
- Fastener
- Overhead
- Ballast
1.1 Purpose

Now a day, railway industries are very much concerned about the inspection and failure of different railway objects and the prevention techniques of those. Because the failure of different areas of railway like derailment, cracks on sleeper, missing fastener may cause a significant harm in this area so that a lot of properties including human life can damage in a moment.

In case of railway sleeper the main problem is that the cracks and defects on it may cause a vital sleeper failure. The sleeper failure is assumed to be one of the causes of track failures as the structural integrity of rail sleeper is a function of many factors such as age, fatigue stress, manufacturing defect and so on. These factors will always be present, and their effects become more pronounced as time goes on. At some point in time, rail conditions such as those mentioned go unnoticed.

Problems in railway fastener is the stiffness and damping of rail fasteners, and in particular the elastomeric pads inserted between the rail and sleeper, are important parameters determining the dynamic behaviour of railway track and the absence of the fastening bolts that secure the rails to the sleepers.

Problems in railway ballast are the compaction of them. The ballast's shear wave velocity hence the ratio of its shear modulus and density increased with depth. An accurate prediction of the behaviour of ballast under static and dynamic loading conditions is important for the stability of railway tracks.

The railway overhead problems consists classification of railway accidents caused by electrification problems, the estimation of failure rate in power equipments and failure analysis using fault trees. The effect of cable slackening on stiffness computation of railway overheads is another problem to consider. Icing is another problem on overhead lines of railway.

So, the main purpose of this paper is to review researches based on different AI techniques which are able to solve these problems. Another purpose is to demonstrate the merits and demerits of those approaches and different companies which provide their products and solutions to avoid these problems.

1.2 Problem Formulation

As railway is a big and growing industrial sector, there are some typical problems occur regularly though some initiatives take before occurring these problems. But this initiative or precautions is not efficient for this big industry because always there are some possibilities to occurring problems in any area. For this reason it is essential to go forward some experts to identify these problems by using some effective methods like AI based techniques with the help of NDT (Non Destructive Technique) of automatic interpretation of data. A few different manual techniques were exists before the invention of these AI based techniques in this area. Railway objects were inspected by human operator by walking along the track and examining the sleeper or other objects by the sound analysis and visual examination. The sound analysis is done manually by hitting the sleeper with an axe and then classifying by the quality of sound produced. In both ways of manual inspection methods the classification of sleepers is based on the intuitive skills of the human operator. Manual inspection on each single sleeper is time consuming and tiresome which also effects the classification of sleeper by operator. These methods of identification of problems have taken more time to identify problems. The serious problem is that the necessary manual inspection is error prone. Every human operator has their own experience in
detecting problems but sometime it may not be possible for humans to discriminate between the good and bad classes of rail sleeper. Other areas like ballast, fastening bolt and overhead also inspected by hand held device or other non AI based techniques manually in the past. As a result the impact of those techniques is not the same like AI techniques by considering the reliability and accuracy manner.

This is the reason for I have reviewed some research paper which results can clearly distinguish the performance and accuracy of these techniques with comparison to previous hand held based manual inspection system of flaw detection.

1.3 Proposed Solution

As the previous inspection techniques were carried out by manually with hand held devices, there are some possibilities to inaccurate data with some vital error. Because the human operator who are responsible for this inspection, his inspection cannot assuring that informations from the inspection are without error. That is why it is most essential to take initiative for the adoption of advance technology to reduce the error and maximise their implementation.

In this thesis work it has been observed that the inspection method and solutions founded by implementing AI techniques are more effective than the previous manual techniques. Data acquire by the NDT method using AI techniques are actually make a big deal in this area.AI based techniques like Neural Network, Machine Vision, Case based reasoning makes a big difference and wonderful solutions for condition monitoring and detecting problems of the rail track surface.

1.4 Previous work

Before the implementation of AI techniques, other techniques were existed for the inspection of track surface and other components. In most cases operator use hand held devices for inspection process and visual analysis has performed which use digital cameras and image processing software. This manual and visual inspection method is able to monitor the surface but not be able to provide accurate data to the railroad engineer to make decision based on these. As the manual inspection requires much effort and is expected to be error prone sometimes and also appears difficult to discriminate even for a human operator by the frequent changes in inspected material. Both these method of determining defect was slow indeed. As a result at present the transportation industry is not really interested to continue this manual approach because of the issue of speed and accuracy of modern railway. Different problems like derailment, rail head crash, sleeper crack, switching and crossing problem in this area require to be reduce and the monitoring system have to be more reliable and effective for the well manner of railway industry. So, the railway staffs now a day wishes to adopt more advance approach like AI techniques which can ensure more security and reliability.
Chapter 2: Background

Railway has become an important sector now a day in transportation area. But for the important and heavy duty of rail transportation, there are a lot of uncertainties and accident occurs in all over the world and this cause a serious damage of properties and human life. The cause of these accidents is failure of railway components like sleeper failure, rail deterioration, due to lack of ballast compaction, fastener bolts failures, overhead problem and the problem of switching and crossing and so on. That's why the adoption of AI based techniques has taken an important place due to its perfection, real time response and reliability. It takes a lot of approach for proving support to the consumer and I have studied in this work few of these approaches based on the area of railway sleeper, fastener bolts, and ballast and railway overheads. So, by considering AI based techniques I have analyzed different approaches like machine vision technique, neural network, genetic algorithm and expert system which playing an important role in this sector by providing excellent result based on the nature of the problem. In this work, different areas of railway like rail sleepers, fastener bolts, and railway ballast and overhead has studied. Details of these areas has discussed in the context of their nature, cracks on the surface of sleepers, problems in other areas and the process of condition monitoring, defect detection procedure.

2.1 NDT for automating interpretation of data

Non-destructive testing (NDT) is a name for a range of methods and procedures used to determine fitness of industrial products for further use. The use of NDT testing techniques results in data in the form of signals, images, or sequences of these, which have to be analysed in order to determine if they contain any indications of defects in the inspected objects. In the past, systems have been built which used neural networks (and other statistical classifiers) as well as expert systems to interpret NDT data.

The inspection is performed using a non-destructive testing (NDT) technique. NDT techniques normally do not present the direct information about unsuitability of the inspected object for further use, but provide data in the form of signals, images or sequences of these, which have to be interpreted in order to determine if they contain any indications of dangerous defects in the inspected object. (1)

Figure 2-1: Different Steps of NDT technique
2.2 Artificial Intelligence

Artificial Intelligence is a technique which means that the ability to perform different types of actions, and to performs this activities where needs intelligence. To accomplish these activities needs the ability of a machine to perform this action. Those actions which need to perform AI are logical deduction and inference, creativity and ability to make effective decisions based on some previous experience information's and also has to the ability to understand the spoken language. In the field of AI, the intelligent machine has to be more flexible than a computer and this machine understand the thinking that exactly what a people think. In general AI is the branch of computer science which is concerned with the development of a machine which has already these intelligent abilities.

Artificial Intelligence is concerned with different area of its own like neural network, machine vision, case based reasoning, fuzzy logic, genetic algorithm and expert systems. These techniques have different implementation based on the nature of the problem domain.

2.3 Artificial Intelligence Techniques

Artificial Intelligence is a very great innovation in the field of information technology. And this idea has taken part very much importantly in different fields now a day. These techniques use human intelligence in most cases. In many areas these techniques have more contribution than human intelligence. That’s why; the AI techniques have taken part as most important field of information technology. The area of railway industry we can see the great impact of these technologies. In different areas of railway like sleepers, rails, switching and crossing, railway ballast and overhead these AI techniques has provided systems so that this sector identify those as a most reliable and important part in this transportation domain.

Different techniques of AI discussed briefly in the following

2.3.1 Neural Network

An Artificial Neural Network (ANN) is an information processing system that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this structure is the information processing system which is formed with a large number of highly interconnected processing elements named neurones working to solve specific problems. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurones.

The basic processing elements of neural networks are called artificial neurons. In a simplified mathematical model of the neuron, the effects of the synapses are represented by connection weights that modulate the effect of the associated input signals, and the nonlinear characteristic exhibited by neurons is represented by a transfer function. The neuron impulse is then computed as the weighted sum of the input signals, transformed by the transfer function. The learning capability of an artificial neuron is achieved by adjusting the weights in accordance to the chosen learning algorithm.
2.3.2 Machine Vision

In many areas like industry and manufacturing, machine vision is known as an application of computer vision. But in case of computer vision is the general discipline of making computers but in machine vision, it is being as engineering discipline, is interested in digital input and output devices and computer networks to control manufacturing equipment.

Machine vision is the subtitle of engineering that is related to computer science, mechanical engineering and industrial automation. Some machine vision algorithms have been developed to mimic human visual perception, a number of unique processing methods have been developed to process images and identify relevant image features in an effective and consistent manner. Machine vision and computer vision systems are capable of processing images consistently, but computer-based image processing systems are typically designed to perform single, repetitive tasks, and despite significant improvements in the field, no machine vision or computer vision system can yet match some capabilities of human vision in terms of image comprehension, tolerance to lighting variations and image degradation, parts variability. The prime task of machine vision application is surface monitoring of a subjected area.

2.3.3 Case Based Reasoning

Case based reasoning is a technique of Artificial Intelligence that attempts to solve new problems by using past experience. The main task involves matching problem details against records of previous cases. The cases are stored together with solutions so that when the nearest case is located the corresponding solution can be adjusted to suit the current problem. There are many different approaches to the design of the matching process, the storage of the cases, and methods for modifying the retrieved solution to fit the current problem.

2.3.4 Fuzzy logic

A mathematical technique for dealing with imprecise data and problems that have many solutions rather than one. Although it is implemented in digital computers which ultimately make only yes-no decisions, fuzzy logic works with ranges of values, solving problems in a way that more resembles human logic. Fuzzy logic is used for solving problems with expert systems and real-time systems that must react to an imperfect environment of highly variable, volatile or unpredictable conditions.

2.3.5 Genetic algorithm

Genetic algorithms are a part of evolutionary computing, which is a rapidly growing area of artificial intelligence. As you can guess, genetic algorithms are inspired by Darwin's theory about evolution. Simply said, solution to a problem solved by genetic algorithms is evolved. A genetic algorithm is a search technique used in computer science to find approximate solutions to optimization and search problems. Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, natural selection, and recombination.
2.1.6. Expert Systems

Expert Systems is an Artificial intelligence based system that converts the knowledge of an expert in a specific subject into a software code. This code can be merged with other such codes (based on the knowledge of other experts) and used for answering questions submitted through a computer. Expert systems typically consist of three parts: first one is a knowledge base which contains the information acquired by interviewing experts, and logic rules that govern how that information is applied. Second one is an inference engine that interprets the submitted problem against the rules and logic of information stored in the knowledge base. After all the third one is the Interface that allows the user to express the problem in a human language such as English. Despite the high outcome of it, expert systems technology has found application only in areas where information can be reduced to a set of computational rules, such as insurance underwriting or some aspects of securities trading. Also called rule based system.

AI techniques which has discussed above has the specific applications by considering their implementation and impact on the proposed system and based on the category of the problems which are going to be solved by these techniques. The problems which occur in railway industry usually use these techniques like machine vision for monitoring the condition, neural network for classify the problem in different categories based on pattern recognition, case based reasoning and fuzzy logic as well.

The implementation of these techniques in the different area of railroad sections has been discussed in the following sections.
Chapter 3: Automatic Condition Monitoring of Railway Track Surface

Condition monitoring has taken a unique part in the transportation area because of the importance of it and assuring the safety and security of this transportation domain. In all cases of transportation this condition monitoring techniques has applied like rail, air, marine, cargo and so on. The transportation area now a day is too much competitive and always tries to provide their best services to the customer. As a result they are always upgrading their existing system to ensure this issue. For the better service they update their serviceability by adopting new technologies which can assure the reliability, efficiency of service and cost effectiveness. As a result the different industries always make a monitoring plan based on the newly developed systems. These systems are developed by the AI techniques. By studying these techniques and the systems developed by these techniques, it can be mention that these systems provide enormous performance in the transportation domain. In this work, the research topics which I have reviewed and analysed, demonstrate that AI techniques basically the machine vision make this thing easy and effective.

Since the previous technique of inspection based performs almost manually and done by hand held devices that’s why the problems in the railway was increasing day by day because of this inefficient inspection technique. By the evolution of automated technique of condition monitoring of the railroad component and devices, it has been introduce a great chapter in this area. The AI techniques make these issues easy and effective, produce a good analytical data. For these automated techniques of monitoring, NDT (non destructive technique) has provided a great contribution to inspect the object in an effective way so that it is done without destroying the object. After implementing these techniques by some railway organisation in different countries observe that the techniques provide the organisations a reliable and real time information periodically in most cases so that those organisations can make decision to operate their business in a safe way by concerning to secure their vehicle and save the important human life. The monitoring activity has performed by taking these sorts of inspection techniques in a regular interval of time. Because in the railway it is necessary to inspect the component of track surface and other areas in regular time interval and real time inspection has taken an important role because of the importance of this transportation domain.

The study an analysis of railway sleeper, fastener, ballast and overhead are demonstrate in following which are based on the AI techniques with the aid of NDT techniques.
3.1 Railway Sleeper

There are a number of component exists in the basic railway track structure. These basic components are the ballast, sleepers, fasteners and rail. Sleepers are support members that are part of the railway track structure. Sleepers are embedded into the ballast and support the rails above. Sleepers tie the rails together maintaining track gauge (distance between the right and left hand rails) and the rail position. Sleepers also resist lateral and longitudinal movement of the rail systems.

![Image of railway sleeper](image)

Figure 3-1: Wooden Railway Sleeper with Good(1st one up) and Bad condition(2nd one down). (2)

3.1.1 Monitoring of railway sleeper

Railway sleepers monitor is done manually by human operator moving along the rail sleeper and gathering information by visual and sound analysis for examining the presence of cracks by hand. Human inspectors working on lines visually inspect wooden rails to judge the quality of rail sleeper. And for deeper inspection of the railway sleepers is carried out by using and axe to judge how hard a railway sleeper is. This process is slow and expensive and maintains the quality of railway sleepers is difficult. For this reason there is also requires skilled staff to operate this function of inspection. But due to the possibility of error in this sort of condition monitoring and inspection procedure there are a few AI techniques has taken into account including effective machine vision technique to reduce these sorts of errors from the data which has been achieved by the effective inspection process.

To classify good and bad sleepers there are some properties to specify these characteristics of sleepers. And these properties are carried out by the skilled personnel that this sleepers are good and these are bed one. (4)

Based on the figure (2) it can be observed that the above one is called good because of the following properties

- The sleeper doesn’t hold any long cracks from the outer edge into the fastening.
- On the surface, this sleeper doesn’t hold any wide cracks.
When hit by an axe, this sleeper produces a crisp sound.
- The metal plate which is never sunken into the sleeper.
- Still grip the nails hammered into them tightly.

And the sleepers which are on bad condition in the figure (2) is classify based on the following properties as well.
- The sleeper holds a long cracks running from the outer edge into the fastening.
- The sleeper bear wide cracks on the surface.
- When the sleeper will be hit by the axe, it will produce a dull sound as well.
- Have a metal plate which is sunken into the sleeper.
- The sleeper has one or more nails which are loose when the sleeper is struck.

Both properties of sleepers which are mentioned above, the impact of their inspection depend on the weather condition. In bad weather condition the sound will be different than the good weather condition. So, to classify which sleeper is good or which one is bad, it is not essential to consider all of the criteria mentioned above. In few cases it is possible to classify it by considering few of them important criteria by considering the property like cracks on sleeper.

3.1.2 Reason of monitoring railway sleeper

The main reason of monitoring of railway sleeper to identify and detect different types of problems exists. Problem like serious cracks on the railway sleepers may cause a vital damage in this transportation domain.

One Study by Bogdoniak et al (2003) demonstrate that the condition monitoring of the different failure of railway the railway sleepers are a main and major factor in the railway transportation.

Sleepers are one of the most important parts of railway track. If the sleeper failed, a number of undesirable consequences may happen. In order to keep the railway track run safely, sleepers are inspected periodically to identify the number and position of defective sleepers. In terms of the inspect results, sleeper replacement will be carried out.

The condition monitoring has different aspects such depends on some structures of railway sleepers which is in position or the functionality of these components are in the right track or not. Such considerable functions concern with railway sleepers are studied by Bonnett (3) are the following

- Spread Wheel Loads to ballast.
- Hold rails to gauge and inclination.
- Transmit lateral and longitudinal forces.
- Insulate rails electrically.
- Provide a base for rail seats and fastenings.

These functions are the main concern of the investigation of the railway sleepers because these might cause a vital problem in this area. These functions demonstrate that the railway sleepers are one of the most important elements of
Chapter 3. Automatic Condition Monitoring of Track Surface

the railway which can cause derailment by sleeper’s failure. And such type of risk can reduce by replacing the sleepers which are infected but the main scope of these research work is that to identify which sleepers should be replace based on some experimental data and how the data is achieved is the main concern of this work by monitoring the condition of sleepers by different AI approach.

3.1.3 Previous techniques of monitoring for railway sleeper

Different techniques which are taken into account to monitor the condition of sleeper performed manually by a human operator; such inspections are to large extent based on visual analysis. Inspections are done by hand held devices. The human operator walks along the track to visually examining each sleeper in turn. Where necessary some deeper inspection may be carried out on site, for example using an axe to judge how hard a sleeper is. This is slow and expensive and maintaining an even quality standard is difficult. But by this type of condition monitoring technique, it is very difficult to identify cracks and on railway sleepers. Because of the inability of human operator to monitor the surface of the track and sleepers in correct way and it is not possible to expect from human operator that every sleeper will be monitor perfectly by him. There are a lot of important factors related to the inspection of rail sleepers. Like rail fastener, metal plate rail head. So, when monitor the rail sleepers all of these things needs to taken into account importantly. When all of these considerations are taken into account, it is not possible to inspect sleepers for free of errors by human operator and this sort of process is not cost effective and there are always chances to exist some errors which may cause a vital consequence in this transportation area. But the data achieved by the skilled personnel is more effective to analyse and take decision by using some effective AI with the aid of NDT.

3.1.4 Different techniques based on AI for sleeper

Condition monitoring has the ability to perform this monitoring activity in efficiently and effectively so that this process can easily monitor the condition of test object. Now a day this activity has performed by the AI techniques with NDT which target to collect data from that object without making any damage of it. Then the data are processed which are retrieved by the NDT and AI techniques.

In railway transportation, it is a common issue to inspect the railway track surface. This issue is done by AI techniques at present. In most cases AI technique like machine vision, case based reasoning and neural network etc has done this job by providing more acceptable monitoring approaches and solutions to the railway authority so that they can take a quick initiative to overcome this unexpected incidents and can make the thing easy.

Now, in this case of condition monitoring, I have reviewed some relevant and important research in the area of railway sleepers based on AI techniques with NDT.

3.1.5 Failure analysis of Concrete sleeper

Work on failure analysis of railway track (5) based on the analysis of concrete sleepers in a heavy haul railway tracks demonstrate a method with which type of failure should be analysed and developed in a specific case. Due to this load on the transportation vehicle may cause some substantial settlement of the track foundations
that’s why in this study they stated that, it is required suitable sleeper and ballast design that allows these elements to uniformly transmit axle loads to the ground.

**Basic Idea**

In this study the main aim is to demonstrate a method with which this type of failure should be analyzed and they developed a specific case, establishing the causes of failure and offering guidelines for improving the design and upkeep the sleepers and ballast on which the tracks are laid.

This work has focused on the loads which are being making pressure on the railway track. All these loads are ultimately transmitted to the ground through the system formed by the rail, sleepers and ballast. In appropriate design of the railway track may thus be best appreciated in this case. On the other hand, it is precisely in these structural elements that failure first appears when the track has not been correctly designed.

This research work reports on the methods which analyze the causes of damage resulting from track settlement. They start out from the characteristics of a heavy haul railway track in which traditional wooden sleepers have been substituted by new, pre-stressed concrete sleepers. After a short period of activity, the sleepers on this track presented a high degree of damage, with numerous fissures and cracks. They study the effects of the ballast and the concrete sleeper with different ground characteristics. The resulting values are not intended to be absolute indicators of damage but can be used in a comparative way to assess the effects of different concrete sleeper and ballast designs.

They study the effects of the ballast and the concrete sleeper with different ground characteristics. The resulting values are not intended to be absolute indicators of damage but can be used in a comparative way to assess the effects of different concrete sleeper and ballast designs.

They focused on the failure analysis of the concrete sleepers forming part of railway track foundations. They first study the materials that make up each element of the track foundations to then describe the detected failure. Finally, they determine the causes that have triggered this failure.

**Method & implementation**

The sleeper failure was observed to be directly related to wagon traffic. These wagons are supported by two assemblies of six wheels with a separation of 7200 mm. Each assembly is made up of two bogies with a centre separation of 1350 mm. Each bogie has three wheels with a centre separation of 1200 mm. The locomotive has two bogies with a centre separation of 9880 mm made up of three wheels with a centre separation of 2118 mm.

Torpedo wagon traffic was initially carried out on track consisting of wooden sleepers that were periodically removed in accordance with track maintenance cycles. When these sleepers were substituted by concrete ones, fracture failure of the sleepers was detected.

In order to monitor this failure, visual examination of the state of the sleepers was carried out on two different occasions (October 2003 and February 2004). The track was divided into seven sections, obtaining the percentages of cracked sleepers. As can be seen, the increase number of sleepers affected by cracking over a short period of
time is quite considerable, thus substantially conditioning the feasibility and safety of this railway line. In this case it should be noted that the broken sleepers continue to work despite being cracked and must only be replaced when the cracks grow until becoming a clear fracture.

Apart from the fractured sleepers, extrusion of the base plates was observed at some points, these being forced out of their position little by little. In this initial visual inspection of the track, it was observed that there is no direct relation between the characteristics of the sub grade and the presence of cracked sleepers. Failure appears both in areas whose sub grade is made up of bedrock, as well as in areas of the sub grade formed by repeated refilling with material.

They demonstrate mainly two reasons of failure of railway sleeper.

- The ballast does not uniformly transmit the load to the ground, resulting in failure of the sleepers.
- If the ballast performs correctly, the sleepers are not designed to support such heavy loads, either due to defects in the concrete or as a result of their deficient pre stressing.

To fulfil the goal, a visual inspection and identification test on the materials has been carried out.

- Analysis of the subgrade and of the ballast via in situ and laboratory testing.
- Analysis of the sleepers, studying the concrete and prestressing steel of which they are made.
- Instrumentation and measurement of the displacements suffered by the sleepers and of the pressures transmitted to the ballast during the passing of the torpedo wagons.

Due to identify more precisely the cause of truck failure here at first the finite difference numerical modelling employed. And then for the complexity of the numerical model another simplified model is carried out named 3D model for serving this purpose.

**Results and Discussion**

The main fact to be drawn from this study is that no single cause can be found for the cracking of the sleepers, but rather that a series of factors exist that would not be decisive in isolation but which are so when acting in conjunction. More precisely, we may conclude that:

- Analysis of the sleepers allows us to rule out anomalies in their manufacture or in their technical characteristics. However, it is clear that these sleepers were not designed for the axle loads transmitted by the wagons and thus work at their strength limit and do not suffer mass failure.
- Seeing that the sleepers must work under limited conditions, which are imposed by the heavy freight loads, the status of the ballast–sub grade system is determinant in the appearance of cracks. Thus, any deficiency in one of
these two elements may bring about failure of the sleepers. Throughout this study, faults and anomalies were detected in both the ballast and the sub grade.

- The ballast presents a lower grain size than recommended. A high content in particles which was produced by degradation of the ballast originally laid on the track.
- The sub grade presents deficiencies at some points on the track. The penetration tests carried out show considerable heterogeneity in the bearing capacity of the sub grade.
- The problems of the ballast in conjunction with those of the sub grade condition the existence of a great variety of properties in the ballast–sub grade system, as shown by the load plate tests. In these tests, it was observed that the ballast coefficients at the sides under one and the same sleeper may vary.
- The results obtained via instrumentation of the track enabled them to observe the evolution of the displacements of the sleepers and the pressures on the ballast as the train passes.

**Remarks on the analysis of railway sleeper and propose further development**

- Increase the CBR of the sub grade and standardize this at least transversally.
- Improve the strength of the fragility of the ballast in order to reduce its degradation, which would be achieved by using another type of quartzite that is stronger, or even granite.
- Improve the design of the concrete sleepers, increasing their cross-section and their pre stressing, as a result of which they would take longer to fracture.
- The strength characteristics of the base plates should be improved owing to the fact that they laminate as a result of heavy freight loads.
- The frequency of ballast maintenance on the track should be increased so as to increase, as far as possible, the life of each one of the strength elements that depend on the ballast, especially the sleepers.

As this work is based on the monitoring of the crack on the concrete railway sleeper, it is very easy to implement automated machine vision based technique for easily monitoring the condition than manual vision based technique. So, in this case it has been observed that, the company named BvSys provide the machine vision technique to crack detection of the sleeper can be taken into account to monitor the condition of the concrete sleeper. Because, the system use heavy line scan cameras with high resolution and also provide the real time monitoring. It is essential to implement for better monitoring activity to explore the system like the BvSys provide.

### 3.1.6 A stereo Vision system for concrete railway sleeper measurements

Another work, J.J. Aguilar, M. Lope, F. Torres, A. Blesa has developed a stereo vision system for non contact concrete sleeper measurement (6). This work has developed a fast stereo metric system to measure free-form surfaces of railway concrete sleepers and calculate track and rail seat dimensional tolerances. This system allows non-contact measurement to make possible efficient inspection of post-stressed
production before curing of the concrete, and speed up the digitizing process reducing some difficulties associated with stereo vision.

Method use

For the measurements of rail seats and position of fastening a move to digital measurement using digital verniers and data loggers which store data onto computers. This allows the data to be analysed with statistical process control to ensure both moulds are set accurately, giving total process control. The result is outstanding track geometry and the greatest possible operating reliability.

The main problem of this method is the manual operating of the system that limit accuracy and it is not possible to measure soft parts (concrete before curing) because it is a contact measuring instrument.

Optical systems for capturing the geometry of free-form surfaces from 3D objects or design models and for quality inspection in prototype or series production have proven to be very important in this area.

A stereo metric system has been developed for measuring concrete sleepers. This instrument allows non-contact measurement of soft parts to make possible efficient inspection of post-stressed production before curing of the concrete. This fully automated method reduces also errors produced by manual operation of traditional contact systems. The digitizing process consists on capturing two images of both sides of the sleeper, processing this information by means of stereo vision.

To speed up this process a holographic optical element has been designed and manufactured to generate a bundle of light planes. The aim is to reduce the time required for capturing the 3D information from the scene with only a couple of images. The active stereo system is based on two CCD-cameras and a static structured light projector. The operation of the system has two stages: camera calibration and static measurement of the sleeper.

Data Collection

For the data collection, an image captured with one of the cameras can be used. The image processing and feature extraction process by this way is more robust and less time consuming.

Results and Discussion

A test set-up has been mounted to measure the concrete sleeper shows how the cameras and the lasers are located to obtain two images of each side of the object. A travelling platform has been designed and manufactured to move the calibration object and the concrete sleeper.

Here are some optimum diffraction grating systems have been developed for the surface stereo metric measurement. By changing the intensity of the outer side has resulted in a fast and easy resolution for the problem of the correspondence. Measuring strategy, illumination, surface structure, and geometry of the object determine the errors. Therefore accuracy cannot be characterized only by measuring error limits. It is necessary to use a more complex way, obtaining their error limits under specified conditions of operation. Consequently, the accuracy of the stereo vision system has been successfully checked with different tests, under controlled conditions and with several pattern objects.
Remarks on this system and proposal to accept alternate system

It has been clearly seen that the digital measurement of sleeper surface is very much effective which provide a better track geometry and good reliability of measuring the quality and accuracy of the sleeper. In spite of this, it can be proposed that as the machine vision based system used in this work to carry on the inspection process, so this technique has to the ability to extract a more accurate and exact image and process it by analysing a number of effective criteria so that the system can produce a better impact. With a high quality image capturing method, the machine vision can manage this image processing and extractions process effectively. The normal procedure of applying the machine vision because in this case the work is basically is to measurement rail seat and position of the fastener. Since, these criteria based on the tolerance ability of the sleeper that is why the machine vision technique provide by the company BVSYS also can be useful to measure the sleeper stability and the condition of sleeper.

3.1.7 NDT for system assurance in railway construction

Combined NDT methods for system assurance in railway construction (7) have identified a strategy on how to proceed in the testing in order to get the best outcome from the combined use of various techniques so that the information regarding the presence of defects could be refined. The main objectives of this work is to monitor the injection process at given points and to document that the injection material was correctly placed and locate voids and to measure the bonding between the concrete plate and the solidified injection materials detecting the possible presence of defects.

Method used

In this work a new radar application has been implemented to monitor the progress of injection of bitumen mix under concrete, the antennae were kept stationary. For the first time Impact Echo was employed to produce 2D sections of the concrete elements. Ultrasound technique could clearly differentiate between good and bad bonding below concrete. The impact of this test is long term durability, uninterrupted service, improved safety of passengers and reduced maintenance costs.

This is the experimental system which is for railway line construction measurements were aimed at testing whether NDT techniques were capable of monitoring the correct on site assembly and laying of new concrete sleeper. The advantage of the various techniques is that not only the results from one could be confirmed by other techniques, where possible, but that they could complement each other in carrying out a thorough investigation and in refining the information regarding the presence of defects, their location, depth and possible size.

Data collection

As the investigation carried out testing a number of sleepers. The data collection results reported here refer to the testing of the underneath of two of these heavily reinforced concrete plates. There are two different purposes: in the first phase the monitoring of the injection between the concrete and the asphalt layer below; subsequently the localisation of an artificial void.
For radar the data acquisition rate was fast enough to keep up with the rapid changes due to the progress of the fluid fill front and the raising of the fill level. Furthermore, radar also offers the advantage that collected data can be seen on the screen in real time.

To locate the position of the voids it was thought that the best approach would be to use first the technique which more rapidly could cover an extended area to be tested by the radar, so to identify the voids or the areas of possible interest.

Then to use the techniques which could refine the information by sizing the voids, then it takes the use of impact echo and ultrasonic methods.

The above mention data is collected by these combined NDT techniques and then to be analyse for the specific purpose.

**Results and Discussion**

In case of radar, from the reference measurements performed with different polarisation of the antenna, reinforcement was located. This allows calculation of the plate thickness. Data presented here were collected with 900-MHz antennae. In impact echo output data from the reference plate highlight the concrete thickness. Data are shown in frequency plots where the peaks at 10.5 kHz correspond to the reflection from the bottom of the concrete. In case of ultrasound the value of the thickness is slightly smaller than the true thickness of the plate because of the ultrasound velocity chosen for the calculation.

The investigation of the bonding between concrete and set bitumen mix gave initial encouraging results in discriminating between good and bad areas.

**Remarks on the system developed by combined NDT methods**

It is essential in the area of condition monitoring that the important functionality of NDT techniques and the effectiveness, efficiency of these techniques is quite clear in case of investigation of railway sleeper. But in some cases it is less practical the higher attenuation characteristics and hence lower frequency signals are required to obtain a reasonable penetration. To overcome these drawbacks it is essential that the good coupling of the transducer to the surface. It is difficult to understand the variability both in the construction materials and geometry of the structure that the NDT specialist can and cannot quantify. NDT is slow to relate their measurements and interpretations to geotechnical and engineering parameters. Finally, this system developed by combined NDT technique makes a good impact to differentiate the good and bad area of railway sleepers.

**3.1.8 Railroad Track Inspection Systems**

The machine vision system has developed for the inspection of railway tracks and its surface. It has been mentioned that now a day inspections are manual and are conducted visually by railroad track inspectors. Inspections include detecting defects relating to the ties, fasteners, rail, special trackwork and ballast section. Advancement to the current manual inspection process are possible using advanced technologies such as machine vision, which consists of recording digital images of track elements of interest and analyzing them using custom algorithms to identify defects or their symptoms. Based on some previous accidental data, this research focuses on using
machine vision to detect irregularities and defects in cut spikes, rail anchors, turnout components and the crib ballast.

Machine vision inspection

The first element is the data acquisition system, in which digital cameras are used to obtain images or video in the visible or infrared spectrum. The next component is the image analysis system, where the images or videos are processed using machine-vision algorithms that identify specific items of interest and assess the condition of the detected items. The final component is the data analysis system, which compares and verifies whether or not the condition of track features. The data analysis component may also involve a combination of IT and data mining techniques to provide a holistic approach to infrastructure management through improved planned maintenance procedures.

The advantages of machine vision in this case include greater objectivity and consistency compared to manual, visual inspection, and the ability to record and organize large quantities of visual data in a quantitative format.

Data Collection

For the development of machine-vision algorithm, a synthetic images from the VTM (virtual track model) and used handheld cameras to capture images at selected camera locations. These images provided insight into challenges such as lighting and the degree of variation in component design and allowed to test the initial algorithm’s ability to identify specific track components.

Results and Discussion

The inspection of most railroad track components is currently conducted using manual, visual inspections. Machine vision inspection of track, there are interim approaches to automated track inspection that will potentially lead to greater inspection effectiveness and efficiency prior to full system development and implementation. These interim solutions include digital video capture using vehicle-mounted cameras, digital image enhancement using image processing software and assisted automation using machine-vision algorithms.

The goal of this machine-vision system for track inspection is to supplement current visual inspection methods, allowing consistent, objective inspection of a large number of track components.

Their algorithms use edge detection and texture information to provide a robust means of detecting rail, ties and tie plates, which narrows the search area.

Future work involves refinement of the algorithms to improve the reliability of spike and anchor detection.

The training on an initial set of videos will be done using labelled texture data and labelled components provided by a user through a process known as supervised learning. In the field, without the benefit of user-labeled data and user interaction, they will experiment with updating their model based on the appearance of the components that they detect.

In addition, they will conduct lighting experiments to achieve better results from the algorithms in adverse lighting conditions. Once the algorithms and lighting for
inspection of spikes and anchors have been refined using the video track cart, they intend to begin working on adapting the system for testing on a high-rail vehicle.

**Remarks on machine vision based track inspection system**

It is already known that machine vision technique is well defined for any surface inspection especially in the railway transportation domain. The system developed by this approach is more accurate and less time consuming to identify of the present condition of the track surface and their different components. Image processing and captured technique is also well defined. But in this case they use hand held camera to capture images. My concern is to use a test vehicle with a high resolution camera which can make sure to capture the image from the both side of the track including ballast, fastener rail and ties is to be more precise. Because it is too important to maintain this sort of inspection process of track so that this transportation domain can provide a secure and reliable service to the customer.

Some disadvantages of machine vision include difficulties to adjust with unusual circumstances (e.g. unique track components) and the need to control of the conditions typical of the railroad environment.

Following three research work has been studied from one of the documentation of an international conference which was held on 2003 named “Railway engineering”.

### 3.1.9 Design of a system to measure track modulus

Another work, design of a system to measure track modulus from a moving railcar (9) has developed a system to measure the track from a moving railcar. Track failure is a major factor in many railroad accidents. Track modulus, or stiffness, is an important parameter in track quality. This work describes the preliminary design of a system for on-board, real time, non-contact measurement of track modulus. Measurement of modulus from a moving railcar is non-trivial because of the lack of a stable reference for the measurements. The proposed system is based on measurements of the relative displacement between the track and the wheel/rail contact point. Low modulus track will have a higher deflection under the weight of a passing railcar when compared to stiff track.

**Method used**

A laser-based vision system is used to make the measurements. A mathematical model is then used to estimate the track modulus from this data. A mathematical analysis has been performed to determine the best location and minimum amount of data required to determine the track modulus. The full system has been tested in a dynamic simulation and in a laboratory setting. Field tests have also been performed on a stationary railcar under various loading conditions.

**Remarks on the vision based track inspection system**

The track of railway consists of different components like rail, sleeper, ballast and fastener with the rail and railhead etc. So it is eventually important to monitoring the condition of the overall track in a real time manner. The system which is developed for this measurement of the overall track it has been found an enormous performance to do this operation. It has used a laser vision based system and other mathematical
model to fix this measurement in different condition. But for this test they used a stationary rail car. In this case they can use the railcar mounted higher speed tests in various track conditions with high power and resolutions visual cameras which can capture the image when the car will run on the track in different condition on the both sides of the track.

3.1.10 Railway Maintenance and Safety: Artificial Intelligence Links
This work, James F Findlay W. L. Gore Simpson Parkway, Kirkton Capus on railway maintenance and safety system (9) there are numerous variables interacting in a complex manner which due to the large amount of data available, cannot be explicitly described by an algorithm, a set of equations or a set of rules in the railway assessment. In any situation, there may be both a shortage of key information and an excess of other information. Neural network and approximate logic techniques have demonstrated its usefulness and accuracy in predicting accidents that would occur under different combinations of conditions in some fields in parallel and aviation industries.

This paper presents the recent research result of the development of fuzzy linguistic risk levels using approximate logic approach to deal with uncertainty with their industrial partners. Expert and engineering judgements are then mapped and transferred to neural network models of an intelligent safety prediction system for railway infrastructure safety analysis. It will be evaluating the accuracy of risk predictions made by conventional (statistical) and AI techniques.

3.1.11 Comparison of Multivariate Linear Regression and Neural Network Algorithms for Ground Penetrating Radar (GPR) Estimation of Track Modulus.
Ground Penetrating Radar (GPR) Estimation of Track Modulus (9) is a non-destructive and non-invasive technology that has recently been applied to assess the integrity of track substructure, including estimation of track modulus. A single electromagnetic pulse of energy at an appropriate frequency is launched into the ground, and reflections from various subsurface layers are recorded. The timing of the reflected pulses provides information on the depth of the layers, while the pulse amplitude yields information on the type of anomalies and subsurface characteristics causing the reflections. In order to perform subsurface imaging, a sequence of such pulses is launched as the system is towed over the surface. There exists a definite relationship between the composition of the track substructure and the GPR image. The track substructure composition also impacts the strength and thus the track modulus. Thus, GPR image characteristics are related to track modulus, and this relationship can be established based upon coincident GPR and modulus measurements.

Using GPR reflectivity values at specific depths, they have developed two models to predict the track modulus within a value of 3.4 MPa. The first is a multivariate linear regression analysis model and the second is a neural network model. A comparison between the two methods reveals that the neural network technique performs better than the linear regression technique for predicting actual track modulus. However, the former is computationally more intensive than the latter. Both models can be used to predict the track modulus from the GPR measurements and would considerably reduce the time and expense of operational track maintenance strategies.
3.2 Railway Fastener

Due to the construction of the railroad track, rail fastener is a component which fixes the rails to the railway sleepers. To fastening the rail to a wooden railway sleeper a few procedure have been followed like flat bottomed rail, this rail has a flat base and this rail can stand upright without any support. And another one is a flat bottom rail which has a cross section and this usually held to the sleeper with a sleeper plate. And a metal plate attached to the sleeper.

Due to the sliding movement of the rail over the sleeper plate, this may cause misaligned spaced ties. And to prevent this, fastener may be placed transversely under the rail at each side of the sleeper to prevent the slippage of the rail and the sleeper to each other. The sleeper fastener is usually a spring loaded clip placed with a wrench.

![Figure 3-2: Fastener with rail](image)

3.2.1 The reason of monitoring railway fastener

The main reason of monitoring the railway fastener is to detect the absence of the fastening bolts that secure the rails to the sleeper. On the other hand due to the reliability and robustness is another concern to monitor the fastening system. Detecting the presence/absence of the fastening bolts is important to prevent dangerous situations. This kind of problems is very serious because it can modify the rail structure generating consequences for safety issues. Another reason of monitoring this is to ensure the rail is correctly joined with the base plate of the sleeper.

3.2.2 Previous techniques of monitoring railway fastener

In the last decade the problem of surface inspection has been receiving great attention from the scientific community since the quality control and the maintenance of products are key points in several industrial applications. Different sensors have been used to solve this kind of problems, but there are many contexts in which visual inspection could be suitable to detect critical situations.

The railway infrastructure is a particular application context in which the periodical surface inspection of the rolling plane is required, in order to prevent any dangerous situation. Usually, the maintenance of the railway plane is done by trained personnel who periodically observe the images recorded by a TV camera installed on a moving train. Actually, this manual inspection is lengthy, laborious and potentially hazardous
Chapter 3. Automatic Condition Monitoring of Track Surface

and the results are strictly dependent on the capability of the observer to catch possible anomalies and recognize critical situations like the missing fastening bolts.

The railway companies over the world are interested in developing automatic inspection systems which could increase the defect detection ability and decrease the inspection time, risk in order to guarantee of more frequently maintenance of the entire railway network.

3.2.3 Monitoring of the fastening bolt based on AI techniques

Because of monitoring the condition of rail fastening systems, the artificial intelligence techniques like machine vision play an important role in this sort of important area. The inspection is possible to inspect accurately and efficiently by the AI techniques to detect the missing bolts which are connected to the rail and the sleeper. So, the AI techniques are able to make this process easier and more reasonable to continue this inspection process.

3.2.4 Visual recognition of fastening bolts

The visual recognition of fastening bolt (11) has developed a vision-based technique to automatically detect the absence of the fastening bolts that secure the rails to the sleepers. The images are pre-processed by using several combinations of WT and PCA methods and The final detecting system has been applied on a long sequence of real images showing a high reliability and robustness.

The automatic visual system that detects missing fastening elements by inspecting the images acquired by a TV camera installed under a train. Usually two kinds of fastening elements are used to secure the rail to the sleepers: hexagonal-headed bolts and hook bolts.

Method use

In this work they have developed a visual inspection system that recognizes fastening elements on the sleepers by using neural classifiers. A neural classifier has been trained to recognize the hexagonal-headed bolts. Hexagonal-headed bolts, with different orientations have been selected in the images in order to create the training set. Other two different classifiers have been trained to recognize the right and left hook bolts, respectively. The image patterns are firstly, pre-processed and then they become the input to the classifiers. Wavelet transform (WT) and principal component analysis (PCA) have been applied to the patterns, in order to represent significantly them in a reduced number of coefficients. During the detection phase the classifiers analyse only areas of interest of the image to detect the absence or presence of the bolts, i.e. image areas which contain the sleepers. Different pre-processing techniques based on the combination of WT and PCA, have been compared in order to choose the best one for this application domain.

The techniques producing the highest detection rates for the recognition of the three types of bolt have been used in the final recognition system. The final tests have been carried out on a long sequence of images which covers about 4 km of rail.

The proposed system is based on the sleepers identification by using cross-correlation techniques and data classification by using a supervised learning scheme. In particular, three different types of neural classifiers have been developed: one has been trained to recognize hexagonal-headed bolts and the others to recognize the right
hook bolts and left hook bolts, respectively. In this approach they compare WT and PCA to pre-process the image patterns extracted from the original image. After the pre-processing step resulting features are fed into the neural classifiers for the recognition step.

In this detecting system two different types of neural architecture have been used: (1) the Multilayer Perceptron trained by the back-propagation algorithm; (2) the Radial Basis Function (RBF). Both network architectures have three layers of neurons. The input layer has a number of neurons equal to the number of image features extracted in the pre-processing step. The output layer has only one unit which generates an output ranging from 0 to 1 signifying the detection of the considered bolt or not.

In the case of left hook bolts the training set contains 61 positive examples and 54 negative examples. Finally, the training set relative to the right hook bolts contains 50 positive examples and 56 negative examples.

The neural classifiers have been trained on those training sets for both types of training algorithm like back-propagation and RBF.

Result

In this section they showed the following outcome by implementing the system:

- The images of the rail have been obtained by a line scan camera.
- A pixel resolution of 2 · 2 mm² can be obtained choosing a TV camera with a focal length of 6 mm.
- The integration time of the TV camera has been properly set in order to acquire images at a maximum speed of 200 km/h.
- A long video sequence of a rail network of about 50 km has been acquired in order to experiment the proposed visual-based inspection system.
- The training set for the classifier trained to recognize the hexagonal headed bolt contains 99 positive examples and 74 negative examples.
Finally from the result it can be said that the detection of fastening bolt is too high than the absent bolt where the percentage of these is very low.

**Remarks on visual inspection system**

The system which has been developed for the detection of the fastening bolt has produced a very good result.

The inspection system uses images acquired by a digital line scan camera installed under the train. Neural classifiers have been trained to recognize hexagonal-headed and hook bolts. Firstly, the images are pre-processed by using WT and PCA based methods. Then, the obtained detecting system has been tested on a validation set to establish the best pre-processing techniques for each type of bolt. After that, a long sequence of tests on real images has been examined. The system correctly detects the presence as well as the absence of the bolts on the sleepers. High percentages of detection rate have been obtained showing a high reliability and robustness of the system.

### 3.2.5 Dynamic behaviour of rail fastener.

The work of measuring the dynamic behaviour of rail fastener (12) has identified the different dynamic behaviour of the rail fastening bolt which plays an important role in the area of wheel and rail rolling noise.

The stiffness and damping of rail fasteners, and in particular the elastomeric pads inserted between the rail and sleeper, are important parameters determining the dynamic behaviour of railway track. Vibrations, generated at the contact zone, are transmitted through the track and wheel structures, and these vibrations are then responsible for radiating airborne noise.

**Method used**

In this work, the models which have been developed are enable predictions to be made of wheel-rail rolling noise for a given combination of wheel and rail designs and the models usually incorporated with the computer package named TWINS. And the models require data on the high-frequency dynamic stiffness and damping of the ballast and the rail fasteners, in particular the elastomeric pads inserted between the rail and sleeper.

A measurement method has been chosen in which the rail fasteners can be measured in their entirety, so that not only the material properties but also the geometrical factors can be measured. The effects of the rest of the fastening system can thereby also be taken into account.

The measurement method is designed to measure the transfer stiffness of resilient elements that is the blocked force transmitted per unit displacement input at the free side of the element. The lower side of the resilient element experiences high impedance, and is effectively blocked, so the deflection in the element is approximately equal to the displacement of the upper side. The force transmitted through the element is measured indirectly from the small acceleration of the lower block, multiplied by its mass.
Result

In this work, actually the fastener produced by different companies are analysed based on their different geometrical and physical structure. And after analysis the dynamic behaviour of different fasteners it is concluded that every fastener has the unique quality to fix the track with the railway sleeper and to provide flexibility to fixing them up freely without any corruption. As a result after analysis the dynamism of fasteners by the measurement methods, it is easy to take decision so that what type of fastener can be used for different types of track bed based on the sleepers also with that track. So, the measurement result provide a well defined specification of different fastener and help the track engineer to take quick decision about the fastener to fixing them up.

Remarks on the measurement of dynamic behaviour of fastening bolt

As the model requires high frequency, it is essential to analyze properly the exact frequencies while doing work and check it for proper implementation details in final assessment. The noise can be of any type so in frequency based systems there is a need of careful inspection of ballast and fastener at good weather conditions for better measurement process.
3.3 Railway Ballast
Railway track Ballast is one of the most commonly used construction materials in railway tracks. Under heavy train loads, ballast is subjected to a high stress level that is always associated with significant track deformation.

Railway sleepers are laid on a surface which surface is made up of ballast. It is packed between, below, and around the sleeper. It is used to facilitate drainage of water, to distribute the load from the railroad sleepers, and also to keep down vegetation that might interfere with the track structure. This also serves to hold the track in place as the trains roll by. It is typically made of crushed stone, although ballast has sometimes consisted of other, less suitable materials.(13)

![Figure 3-4: Balled Track with Sleepers](image)

3.3.1 The reason of monitoring railway ballast
An accurate prediction of the mechanical behaviour of ballast under static and dynamic loading conditions is important for the stability of railway tracks. And another reason is to monitor the ballasts compaction. The vibration of railway ballast is a key factor to cause track geometry change and increase of track maintenance costs. The ballast fouling problem is another problem to concern. The thickness of the ballast layer under the sleeper is another thing to be taken into account as another problem of ballast of the railway transportation.

3.3.2 Previous techniques of monitoring railway ballast
Every year the railway association spending much money to check the railway infrastructure. The use of vision-based techniques in railway infrastructure monitoring has assumed great importance. Currently, the procedures adopted by main railway companies consist in stopping train traffic over the route that is analysed by human operators that walk along the tracks looking for defects. This cannot be used for its inefficiency.

3.3.3 Different techniques of monitoring based on AI
By considering the previous techniques of inspection of railway ballast it can be seen that there are some flaw exist during the monitoring. And this flaw may cause the
severe damage in the static and dynamic loading condition and the compaction of railway ballast. But AI techniques like neural network and stereovision techniques make the difference than the conventional approach.

3.3.4 Mechanical Behaviour of railway ballast

The work, modelling the mechanical behaviour of railway ballast using artificial neural networks (14) the investigation of feasibility using Artificial Neural Network for modelling the mechanical behaviour of railway ballast under static loading condition is established. And the database used for development of the ANN model is demonstrated. Predictions from the ANN model are compared with the results of experimental tests and with those obtained from the hardening-soil constitutive model in PLAXIS finite-element code. The plastic dilation and contraction of ballast at various confining pressures and the strain-hardening and postpeak strain-softening behaviour of ballast are also well simulated. The ANN results indicate that the model is able to accurately predict the stress–strain and volume change behaviour of ballast.

Establishment of model

The railway track are often governed by the mechanical behaviour of ballast, necessitating an accurate prediction of stress–strain and volume change relationships for ballast under different loading conditions are concerned for the stability and performance of the railway track. These relationships for ballast are very complex and highly nonlinear, which implies that modelling ballast behaviour using conventional analytical solutions will require rigorous mathematical procedures. Consequently, it is difficult to simulate ballast behaviour using conventional analytical constitutive modelling, unless several ballast parameters are incorporated and various model simplifications are made. It can be observed that the development of an ANN model for ballast under static loading conditions, based on the general critical state framework, that performed well. To achieve accurate results, this model needs 11 parameters that have to be determined in the laboratory via triaxial tests, and the tests have to be interrupted at different stages of loading so that the required data can be measured.

Results and discussion

The model performed well in the training and validation sets. The nonlinear relationships of deviator stress versus axial strain and of volumetric strain versus axial strain for ballast were predicted accurately. The strain hardening and the gradual decrease of deviator stress beyond peak failure (post peak strain-softening) were very well simulated. The transition of ballast behaviour from initial compression to dilation at low confining pressures and the change from dilative behaviour at low confining pressure to overall compacting behaviour at high confining pressure were also well captured. In conventional constitutive modelling, the strain softening region will result in negative soil modulus, which tends to increase the mathematical modelling effort significantly. These results demonstrate that the ANN model has a strong capability to accurately simulate the complex nonlinear behaviour of ballast.

Comparison of ANN with PLAXIS

The PLAXIS constitutive model is able to simulate the strain-hardening behaviour of ballast in some tests. However, it generally failed to simulate the exact strain-softening behaviour. This is attributed to the fact that the constitutive model used in PLAXIS was developed to simulate the strain-hardening behaviour of granular soils
rather than strain softening, which the ANN was able to predict accurately. The results demonstrate show that PLAXIS could not simulate accurately the volumetric strain versus axial strain behaviour of ballast in some tests.

**Remarks on modelling the mechanical behaviour of railway ballast**

Since the research work is concerned with the mechanical behaviour of railway ballast. Thus this work is combined two approaches, a model to simulate the hardening behaviour of ballast but in this case the model is failed to simulate the softening behaviour of ballast. Thus the ANN is explored to simulate the softening behaviour of ballast. These two models together can accurately simulate the overall behaviour of ballast in different condition. In this case the model named PLAXIS, based on the computer model has been developed precisely so that it can simulate and support the ANN very perfectly.

### 3.3.5 Measuring the stiffness and density of railway ballast

Continuous Surface wave and impact methods of measuring the stiffness and density of railway ballast (15) has performed a test like continuous surface wave and transient impact execution on strip of the ballast to monitor its compaction.

**Different testing process to perform activity**

To study the dynamic response of a railway ballast material, three sets of field tests were performed. The first set of field tests involved impact excitation of hammer blow on a steel plate embedded in the ballast with the measurement being made by an accelerometer sited at various distances away in the ballast. The second set of tests involve impact excitation by instrumented drop hammer with response measurement by two accelerometers at varying distances from the input pulse. Thirdly a continuous surface wave technique was used with a vibrator setup alongside the ballast and the linear array of geophones recording the grounds response.

**Result and discussion**

Here the test demonstrate that, the change in bulk to find the density variation along the strip of ballast was measured both by sand replacement test and by measurement of the total mass of ballast placed per layer. After the first pass the final density achieved. But in this results it can be shown that the density was less stable after few more passes.

In the second test it has been seen that the natural frequency was observed in the frequency response function results with increasing compaction. But in this case there is no change occurs with different frequencies. In this case this results demonstrate that the increase in the ballast density could not be easily quantified by examining its natural frequency increase. And in this case it can be observed that the frequency and amplitude of the first peak in FRF records generally decreased with increasing distance between excitation and response points.

In the third test the ballasts dynamic response to drop hammer was recorded by two accelerometers some distance apart. For this reason there was a decrease in the amplitude with increasing distance. The reason of this because of high attenuation through the compacted ballast. There were no significant changes in the peak frequencies.
3.3.6 Defect detection of ballast by considering its anomalous behaviour

Ballast 3D Reconstruction by a Matching Pursuit Based Stereo Matcher (16) has produce a system which able to detect defect where the ballast bed has an anomalous behaviour. The system which has been produce is based on two high resolution line scanner TV cameras, installed under the train. To detect defect of the layer ballast we developed stereo vision techniques use Matching Pursuit method to extract features from images and the similarity function to execute the correspondence between left and right images. Visual inspection can help to increase the control quality and reduce costs to maintenance.

Stereo matching is active research areas in computer vision. The fundamental goal of this is recovering three-dimensional images of stereo techniques. The problem of recovering the missing dimension (depth) from a set of images is essentially a correspondence problem: given a point in the first image to find the corresponding one in the other images.

In this work, a fixed patch and methods of the matching pursuit had been applied. The result is a vector of coefficients used for stereo matching. The coefficients in correspondence of every fixed patch in the left image and shifting a fixed window in the second one has been compute. This second window moves in the right image by integer increments along the epipolar line and an array of coefficients is generated for each increment.

Equipment used for visual inspection

Some railway companies have introduced the use of diagnostic car equipped with sensors of different kind. At first, these cars had only data acquisition and recording functionalities. After, a human operator, offline, had to analyse recorded data and searching for anomalies. Now, these cars operate autonomously by mean an analysis system able to detect defects. They only require the human supervision task.

In this paper a visual system able to perform the 3D reconstruction of the ballast is described. This functionality is important in railway maintenance, because it permits to detect context where the ballast bed has an anomalous behaviour. This system is a stereo ring, based on two high resolution line scanner TV cameras (2048 pixel/line), installed under the car. The field of view can reach 1200 mm.
Activities taken by the proposed 3D reconstruction systems

The 3D reconstruction is based on a new area based stereo matching technique. For this technique they have developed a model like the following

![Diagram of 3D reconstruction model]

**Figure 3-5: Setup of 3D reconstruction model**

From the above mention model, it is quite clear the different steps which the model has taken into account.

In initial step, they acquire two images, left and right, from two line scanner TV cameras C1 and C2 namely.

Then in the next step, they compute the coefficients for every fixed patch in the left image shifting a fixed window in the right image. To compute the coefficients from the extracted patch we use the method of the matching pursuit.

**Results and discussion**

They have applied algorithm of stereo vision to artificial and real images. In this work the algorithm applied for to produce a dense depth map. The results are very good for both of the method and the error rate here is very low. Actually in this work the main and unique approach of stereo matching technique is described.

The significance of the coefficients is selected by the Matching Pursuit technique. The method, in spite of computational complexity, seems to perform better than well-known area based matching technique. Future work is devoted to speed-up the technique in order to address Railroad inspection requirements and reduce the time complexity of this approach. Unless the time complexity of this approach it is obvious to say that in the field of machine vision this approach like 3D reconstruction by stereo matcher has provide a very good approach in the field of image processing.
3.4 Railway overhead

The main objective of the design railway overhead line is based on the principal of one or more overhead wires situated over rail tracks, raised to a high electrical potential by connection to feeder stations at regular intervals. The feeder stations are usually fed from a high-voltage electrical grid.

![Figure 3-6: Typical Railway Overhead Configuration](image)

The centenary contains several physical conductors that can be grouped into three groups: positive, negative and ground or neutral wires. In case of multiple tracks, other conductor arrangements are possible. The positive wires are the positive phase feeder, the sustainers or messenger wire and the contact wire. There is usually only one negative wire called negative phase feeder. The neutral wires are the rails, the collector wire and the return or guard wire.(17)

3.4.1 The reason of condition monitoring of the overhead lines

- A common issue in electric railway operation is the wear of the pantograph contact strip. The ice or rime frost on the overhead line that causes arcing between the contact strip and the contact wire.
- Overhead line icing and melting may cause extensive damage to the electrical installations and railway contact wires. As a result, the transmission provider of overhead lines deployed substantial efforts to mitigate the effects of future ice storms.
- Cable slackening is the smoothing of stiffness distribution at the local vicinity of the slackening dropper and consequently reducing the average stiffness of the railway overhead. So, cable slackening and stiffness is another big issue in the area of condition monitoring.
- The electric railway consists of traction power systems, various vehicles, operating equipment, track, overhead line and electric equipment. It is a
fundamental function of traction power systems that they supply customers with acceptable reliability and high quality power. So, traction signal system is another concern for this sort of monitoring.

### 3.4.2 Previous techniques for railway overhead

Before the implementation of the modern AI techniques in all cases of the area of condition monitoring has taken place manually by human operator. This monitoring is accomplished by different hand held devices used by different railway organisation. In the area of overhead and pantograph contact strip, there were also manual monitoring method to detect the cable slackening, or any damage in overhead for the reason of icing and melting. As a result there are possibility of getting monitoring result with error due to the inefficiency and lack of monitoring knowledge of human operator. Not only the lack of knowledge of human operator but the less efficient monitoring device also makes the difference between the traditional and the AI techniques of monitoring systems. Due to this error and inefficient staff, it was essential to looking forward to introduce a new and efficient technique of monitoring. That is why the different AI techniques taking an important role in this area.

### 3.4.3 AI techniques of monitoring railway overhead

The electrification systems of railway supply electrical energy to the railway vehicle and the different units of the railway. Due to this service to the railway it is a great advantage to this sector but this is matter of better inspection system of this service. Because this system provides electricity to the vehicle without having onboard prime mover. So, this issue of monitoring overhead condition by the AI based techniques instead of previous traditional techque is essential. The technique like fuzzy logic, neural network and machine vision perform this function very well.

### 3.4.4 Condition monitoring of pantograph contact strip

The work, condition monitoring of pantograph contact strip (18) has established a method based on the maintenance of the contact strip. The wear of the contact strip is predicted by monitoring the running distance of the pantograph as well as the DC component of the locomotive current. To evaluate the method, measurements have been carried out on a Swedish Rc locomotive during winter conditions.

In winter season, in Europe especially in country like Sweden, the wear of the contact strip can be several times higher than during the summer, leading to more frequent need for replacement. The wear during winter is dramatically varying and not only a function of running distance. A worn out contact strip may lead to damages of the over head centenary system, thereby interrupting train operation and causing extensive costs. During winter the contact strip needs to be inspected up to three times. The maintenance plan for railway vehicles often consist of activities based on running distance where intervals for advanced activities are constructed from multipliers of intervals for less advanced activities. Therefore the most frequent inspection restrains the entire maintenance plan.

### Arcing in railway traction system

The arcing in railway traction systems divided into three different regions: cathode, positive column and anode. The cathode and anode represents two thin layers at each
electrode surface and the positive column represents an arc between these two. The voltage drop across the different layers depends on the direction of the current, whether the material function as an anode or a cathode. The basic idea of this study is to explore the possibility to monitor the contact strip wear by means of the DC component of the locomotive current. To evaluate the idea, measurements have been carried out on a Swedish Rc locomotive during winter conditions.

**System monitoring and measurement**

- Measuring the arcing in the DC component
  - Demonstrate the result of this measurements
  - Influence of rms current
  - Influence of train speed
  - Measure other causes for DC components in the locomotive current
- Monitoring the contact strip wear
  - Estimation of mechanical wear
  - Design of the current logger

**Remarks on the monitoring system**

In this research work, the condition monitoring of the pantograph contact strip showed an overall condition of the overhead contact strip and the strategy of monitoring the condition of this area is demonstrate the flaws and the real time condition after regular interval of time.

The overall field test

- A DC component in the locomotive current can be used as an indication of arcing.
- There is no correlation between train speed and the DC component due to arcing.
- There is a dependency between the RMS value of the locomotive current and the DC component.
- The DC component increases with increasing RMS current.

The implementation of this method ensures that the range of the wear of the contact strip is propagates by the intensity of the arcing and thus the level of DC component also demonstrates its range also shows the importance of this system. And in this work the depence of the contact wear strip and the DC component also provide accurately and without any error.

**3.4.5 Study on expert system of overhead lines**

The work based on expert system of overhead line icing and melting (19) developed to estimate the ice accretion type on wires of electrical transmission lines and the melting of this ice using the heat generated by the currents flowing in the wires, based on the meteorological parameters such as air temperature, relative humidity, wind speed, which obtained by corresponding sensors. Actually this system aims to reduce the icing damage in electrical transmission lines and railway contact wires.
This paper reports on efforts to develop an expert system to de-icing the iced overhead lines by electrical currents. The electrical de-icing calculations provide values of the current required to melt a given build up of ice in a given time interval or the time required to melt the ice build up for a given current. The icing types are estimated according to meteorological parameters such as air temperature, relative humidity, wind speed, wind direction, obtained by corresponding sensors, ice thickness is measured by video cameras.

**Different functions**

In order to melt iced cables safely and effectively, it should be known that what type of ice accretion occurred, how thickness of the ice covered the cables, ice density, and the current required to melt a given build up of ice in a given time interval or the time required to melt the ice build up for a given current. Then it is to decide when start or to stop the melting operation. In order to complete this activity the system has follow the following steps

- Data acquisition
- Icing type estimation
- Electrical de-icing estimation
- Start stop strategies
- Data management

The system configuration is the following

**Hardware configuration**

Data acquisition equipments

- Sensors (including temperature and humidity sensors, speed sensors, wind direction sensors, ice thickness sensors, and cameras).
- Signal conditioning system
- Data acquisition card
- A computer

Signals are acquired by various sensors or special equipment in this System, amplified, filtered and converted A/D processing in the signal conditioning system. The final signals are acquired from data acquisition card to a computer and then showed in the software for further analysis and Processing.
It can be shown by the following schematic diagram in a whole.

**Software system**

From the following schematic diagram the overall software function for the system can be demonstrate:
Figure 3-9: Logic chart of the software Concequence and discussion of the system

Remarks on this expert system

- The expert system for the icing and ice melting is depend on electrical current.
- This propose system can estimate ice type.
- It is possible to fixing the current required to melt a given thickness ice in a given interval of time.
- The system can stop the melting process in advance, with the help of video cameras.
- This expert system based ice melting system basically used in the electrical railway system and electric power transmission provider and it will be meaningful for reducing the impact caused by icing.

3.4.5 Failure analysis of traction power system

The failure analysis of traction power system (20) has presents a analysis of traction power system of electric power system. In this paper they mentioned that the most commonly used reliability assessment for railway systems has been the failure analysis of the traction signal system. This paper deals with the classification of railway accidents caused by electrification problems, the estimation of failure rate in power equipments and failure analysis using fault trees.

TPS (traction power systems)

The traction power system can be divided in to three parts; substation, contact wires, and distributions. The substation receives power from utility companies and converts power to traction energy. Contact wire delivers power to the vehicle. Distribution
supplies power to customer stations. These components are samples for traction power systems.

![Image of Traction Power System](image)

**Figure 3-10: Traction power system**

**Analysis of failure**

For the failure analysis, there are two types of processes taken into account for traction power system.

- Classify the equipment of traction power systems. This is time-consuming work. The data can be collected from surveyed data books, which contain installation date and area, the number of each equipment and operation time.
- Then the history data of faults is investigated and classified. It contains location, causes, duration time and effects. Each fault case belongs to the inspection items.
- Next, failure rate for power system equipments is estimated.

The failure analysis process is demonstrate by a flowchart in the following

![Flowchart of Fault Tree Evaluation](image)

**Figure 12: Flowchart of fault tree evaluation**
This is called a top-down analysis method for representing the logical combination of various states which lead to a particular outcome for system failure.

Remarks on analysis

Initially in this paper, a traction power system using a fault tree is suggested. The reliability assessment in traction power systems is an indispensable issue. The system deals with electrification of traction power system. The fault data and the amount of installed equipment for electrification are collected and analyzed. The failure history is investigated and classified in detail. The failure rate is estimated under the circumstances of real accidents. The fault tree method for failure analysis is applied to a railway substation. In order to consider secondary failures in fault analysis, a greater insight into the system is required. The results of this paper may greatly affect the design of railway substations.
Chapter 4: Solutions Provided by Different Companies

According to the problems of railway transportation area, there are different railway companies provide and propose some important and efficient solutions and products based on these problems and their customer demands. And the solutions and products which they provide and propose shown that their enormous contribution with the AI techniques.

In this section I have mentioned different solutions of different companies.

4.1 Rail sleepers and its surface

Based on the railway sleepers and surface there are few companies provide some systems and solutions as well as products which are together useful to solve the problem involve in this area as well. Companies like Bvsys, Beena Vision, Enisco, Mermec, P-tech and so on, provide solutions and products.

4.1.1 BvSys

Since 1990, the Bv.Sys-team has stood for the professional and high sophisticated development of hard- and software and comprehensive services provided from one team of experts. The company provide services in the field in rail, overhead, vegetation and track surface which are more effective and use the concept of AI and most of the ceases AI techniques directly.

4.1.2 Railway inspection systems by bvSys

Railway Inspection Systems has provided some magnificent solutions in the railway transportation domain. (22)

The solutions is based on the following area of railway

- Catenary Check
- Crack Check
- Head check
- Profile check
- Rail check
- Rail scan
- Vegetation Check
- Wire Check

The Railway Inspection System can identify the following defects in rail track

- Detection of surface faults and rail breaks
- Detection of missing fastening elements
- Sleepers damage
- Anomalies in the railroad bedding
- Crack structure in the rail edge
- Crack structure in the ballast less tracks
- Degree of vegetation
Chapter 4. Solutions Provided by Different Companies

- Measuring of the rail cross and rail longitudinal profile
- Measuring of the gauge
- Measuring of the contact wire and contact wire position
- Inspection of the catenary system.

**Crack check of concrete railway sleeper**

In the automatic inspection systems of railway, the crack check is one of them which checks concrete sleepers and the “slab track” for cracks at high speeds of more than 100 km/h and produces a rail condition protocol as a result, which generates an objective status of the inspected rail for the user with high quality and safety in the shortest time. CrackCheck ensures that the rail bed structure inspection is faster, safer and more reliable.

**Recording of data and capturing image**

The device of picture recording system which are installed in a carrier frame on the bogie frame or vehicle frame of the carrier vehicle. Four high-resolution line scan cameras are mounted in such a way that they generate precise, high-quality graphical data on the left and right of the rail. The photograph is taken controlled along the optical path length by means of an incremental position encoder linked to the wheels and is independent of the speed. A central chain age system can control the fault pattern assignment to the current rail position.

**Benefits**

The optimised picture recording for the crack detection makes it possible to highlight even the finest crack structures. The resulting pictures are evaluated online by means of ultra-modern image processing algorithms. The fault patterns are classified automatically and the results are provided in a fault protocol immediately after inspecting the rails, archived in a database or forwarded to super ordinated systems.

![Figure 4-1: Cracks on concrete railway sleeper](image)

- High resolution cameras
- High recognition performance
- Low incorrect detection rate
- Easy operation
- Modular concept
- Low maintenance expenditure
- Proven suitability for railway vehicles.
Chapter 4. Solutions Provided by Different Companies

The crack check of concrete railway sleepers has been shown a great impact based on the AI technique like **image processing and pattern recognition.**

### 4.1.3 Mermec Group

MERMEC Group is an industry leader and innovator specialised in supplying integrated solutions for diagnostics, signalling and asset management to railways and rapid transit systems worldwide.

MERMEC Inc. is a developer and manufacturer of advanced measuring technology based on laser light sectioning and high-speed digital processing. MERMEC Inc. specializes in high-speed, non-contact measurement systems which are used by track owners and railway operators to provide key information to ensure safe operation and reduce maintenance costs. **ImageMap** has become the world leader in its field and continues to innovate to increase the profitability of railway operations. This group provide the follow measurement systems based on the modern digital image processing technique.

### 4.1.4 Track Surface Measurement System by Mermec Group

**Track surface inspection system**

Using high-speed cameras and based on no-contact, optical technology these systems allow acquisition, storage and real-time analysis of the recorded images. Enhanced algorithms carry-out measurements and classify defects according to their properties and/or their position in the rail structure.

**Benefits**

- TSIS is capable of detecting various problems along the line, from defects in the rail to inconsistencies in the ballast, fasteners or sleepers.

**Track surface measuring system**

This system is design to measure the height, volume and relative position of an object near the track. With the help of 2D and 3D visual reporting modes, this is allow the user to observe all the rails level, loose fastener, lack of ballast, sleeper position and able to measure the track behaviour.

**Benefits**

- This system increase the localization accuracy and improve defect localization.
4.1.5 Beena Vision

Beena Vision Systems is a technology development company that manufactures several innovative products based on non-contact measurement and machine vision technologies for railroad industry. Beena Vision Systems, Inc. is a company that has dedicated its efforts into the application of Machine Vision and Non-contact Measurement Technology in railroad and transportation industry. They provide products including wheel profile measurement system, rail profile measurement system, track parameter measurement, brake shoe measurement systems and so on.

4.1.6 Innovation in non-contact train and track inspection systems by Beena Vision

This system names trackview is a completely noncontact and track parameter measurement system. The system can automatically scan the rail for its profile and compare it to the reference rail profile. This system also deploys a laser range finder to compute the track gauge, cross level and rail cant.(23)

The system is a PDA based portable unit that can measure numerous spot with a single PDA charge. A complete software package is provided with this system with a GPS option for track position recording.

Specifications

- All non contact laser based technology.
- Accurate and Repeatable profile
- Measurements
- Gauge and cross level
- Rail profile
- Rail Cant
- Head and Side wear
- Wear Graph
- Curvature
- Instant report on rail and track condition
- Remarkably easy to use.
- User friendly interface.
- GPS measurements positions.

Benefits

- PDA based, easy setup.
- One man Operation
- Fast and easy track measurement system etc.

4.1.7 ENSCO

ENSCO is established in 1969 and it is situated in United States of America. ENSCO systems help customers improve the quality of their operations, while making travel safer. ENSCO’s staff is committed to research and development on their existing solutions such as Web-based data management, railroad track inspection systems, and large-scale system integration, along with other new solutions relating to railway engineering ENSCO has been a leader in the delivery of rail and track measuring
systems and vehicles for more than 35 years. They are the sole supplier and operator for all track inspection cars used by the United States Government Federal Railroad Administration (FRA) to enforce track safety standards on American railroads. ENSCO’s state of the art solutions have also been delivered throughout the world on both high speed and conventional railroads.

ENSCO provide products include Autonomous Vehicle/Track Interaction Monitor Deployable Gage Restraint Measurement System, RailScan Lite Hi-Rail Gage System, Portable Track Loading Fixture (PTLF) Rail Corrugation Measurement System, Laser Gage & Rail Profile Measurement Systems, Track Geometry Measurement System, VisiRail Track Bed and Rail Inspection System Track geometry measurement systems by ENSCO.

4.1.8 Evaluate Geometry Conditions of Track at Normal Operating Speed (24)

The TGMS measures track gage, curvature, crosslevel, warp, profile, alignment, and limiting speeds. Fully equipped with non-contact sensors, the TGMS measures and computes track geometry parameters at speeds of up to 217 mph (350 km/h)

ENSCO’s TGMS includes state-of-the-art computers and software for real-time track geometry analysis and production of online exception reports. Providing information for identification of immediate maintenance requirements, short-term maintenance scheduling, long-term maintenance planning, cost estimates, and budget requests, the TGMS provides track geometry inspection services to transit, industrial and rail communities.

ENSCO also offers portable versions of TGMS for accurate, reliable measurements over freight, transit and passenger service routes. The portable system, when installed on a fully loaded rail car, provides the railroad with the advantages of a full size heavy track geometry car without major capital investment and maintenance costs.

The ENSCO-developed laser and inertial based track geometry systems measure under actual traffic loads and meet Federal Railroad Administration (FRA) track safety standards. Systems can be installed on almost any rail vehicle including a loaded 100-ton freight car. Measurements can be made under all weather conditions. Strip charts and exception reports are produced in real-time to the FRA’s or the railroad’s own standards. Measurements can be made in revenue service—at track speeds of up to 217 mph—to save track time and locomotive/crew costs.

Benefits

- Provides fully-loaded track geometry
- Installs on car and measures under load
- Saves track time and operating costs
- Can operate on a revenue train at timetable speeds
4.1.9 ENSCO security services, provided by ENSCO

The Risk Analysis Process(24)

There is a variety of terminology applied to risk analysis, but all risk analysis boils down to a measure of the severity of a threat versus its probability of occurring. The components of risk analysis are criticality, threat, and vulnerability assessments. These three assessments come together to form the risk analysis process.

Criticality Assessment

It is vital to understand the components of an operation, the interrelationships, and the critical paths. The criticality assessment identifies those components or series of components that are vital to continued operations.

Threat Assessment

The ENSCO assessment process looks at the full spectrum of threats. We have the capability to look at everything from accidents to weapons of mass destruction attacks. Threats are assessed for likelihood of occurrence to help ensure risk is properly determined.

Vulnerability Assessment

A vulnerability assessment is an evaluation of the current security, system, personnel, technology, plans, and procedures to assess the protection of critical assets. ENSCO’s vulnerability assessment approach employs an industry-specific subject matter specialist to ensure all critical areas are identified.

Methodologies

ENSCO’s process can be qualitative or quantitative, and combines the results of the vulnerability and criticality assessments to create a measure of severity, and the results of the vulnerability and threat assessments to create a measure of probability. The intersection of severity and probability is the measure of risk associated with that particular threat. A risk analysis can be either quantitative or qualitative depending on the quality of the data. The more precise the measures of threat probability and consequences, the more qualitative the analysis. When hard data is lacking, a quantitative analysis can still be conducted, but the experience of the analyst in assessing probability and consequences plays a larger role.

Products provided by the companies

4.1.10 Different types of sleeper provided by P-TEC

The company named P-TEC has provided products like railway pre-stressed sleepers for light track, high-speed track, heavy-haul track and ballastless track systems(25).

The company provide both hardware and software services in this area like :

- Sleeper statistics analysis
- Individual sleeper design
- Required engineering support for planning sleeper production.
- Installation and setting of production.

The company provide supplies and calculations of different sleepers to the area

- Normal rail sleeper
Chapter 4. Solutions Provided by Different Companies

- Light rail sleeper
- Heavy haul sleeper
- Monoblock sleeper
- Slab track sleeper
- Turnout sleeper
- Craneway sleeper

The calculations of these sort of sleepers is based on international standard. And the sleepers can be designed according to the different defined specification and based on their loads.

So, in this case concrete sleeper, it is better to taken into account to accept any of these sleeper by the railway industries based on the problem in concrete sleeper.

4.1.6. Concrete sleeper provided by Abetong

Abetong has been a pioneer in the development and production of pre-stressed concrete railway sleepers since 1950. A continuous programme of research and development will ensure them to keep their position. Their main speciality is track technology. They provide training and technical support as well.

- The mainline concrete railway sleepers are produced according to a special system known as the Abetong long line method.
- The main goal is to design concrete railway sleepers that are in harmony with the other components that make up a railway track. Optimisation of the entire track as well as the single concrete sleeper is therefore in focus.

4.2 Rail Fastener

There are some companies which provided some solutions and products based on rail fastener. The rail fastening system provided by one of those companies has provided the support to this area very well. Other company provides another system which is also provide a good solution of the rail fastening problem as well. The companies which provide this facilities in this area are namely PANDROL, VOSSLOH etc.

4.2.1 PANDROL

Pandrol has specialised in the design and manufacture of resilient rail fastening systems and associated installation equipment since 1937, and supplies over 240 railway systems in 91 countries worldwide. Today it is the world leader in its field, supplying more than twice as many resilient fastenings.

4.2.2 Rail Fastening System

Different generation of PANDROL rail fastening systems and their consequences:

- PANDROL fastclip

The Pandrol FASTCLIP rail fastening is a pre-assembled system, developed in response to the growing need for fast, efficient track installation and reduced maintenance costs. FASTCLIP has been adopted by 35 railways in 16 countries, making it the fastest growing rail fastening in the world.
Chapter 4. Solutions Provided by Different Companies

- **PANDROL VIPA-SP**

  A second-generation, optimised design from the VIPA family has been developed to reduce secondary noise and vibration through a two part resilient pad system. The overall size of the assembly has been reduced to allow for retrofitting onto existing systems, which in turn has reduced the weight of the assembly.

- **PANDROL FASTCLIP ‘FD’**

  Incorporating many of the advantages of the FASTCLIP FC system, FASTCLIP FD is a simplified system for railways operating low or medium density operations on rail sections of 50kg or below and at speeds generally less than 120km/hr.

**Benefits**

- FASTCLIP is a switch on-switch off system which was developed in response to the growing need by contractors and railway operators for fast, low cost track installation and reduced maintenance costs.
- VIPA-sp was developed to address vibration and noise problems, particularly for urban transit systems, in a cost effective way.
- The PANDROL FASTCLIP FD railway fastening has been developed to support main line track and traffic conditions where levels of dynamic loading, tractive and thermal forces are not as high as those found on typical high speed and heavy haul railways.

### 4.2.3 Vossloh

Vossloh Fastening Systems is a global leader in the production of track fastening systems. High-speed, heavy-haul, urban transport or standard lines are all equipped with their cutting-edge products.(28)

### 4.2.4 Track Fastening System

This company provide a high speed rail fastening system

- The Skl 21 high-speed tension clamp permanently clamps the rail to the concrete sleeper by means of the outer spring arms.

This high-speed tension clamp has fatigue strength of 2.5mm for five million load cycles. Therefore it is possible to use rail pads with a static stiffness greater or equal to 30kN/mm. The highly elastic rail pad is protected from over-stress by means of a small nose in the front of the angled guide plate.

- Slab tracks meet all the requirements for combined high speed and heavy load traffic.
- The 300 rail fastening system for slab tracks, which can be pre-assembled, is suitable for all methods of slab track installation. The highly elastic intermediate plate substitutes for the elasticity of the ballast bed.
4.3 Rail Overhead

4.3.1 DTK
Deutzer Technische Kohle (DTK) is a supplier of rail infrastructure measuring and monitoring services. Established in 1991, the company is well-known to public transport operators. DTK carries out its measurements in regular service and under normal traffic conditions. So, the result of the measurement shows the real value which is necessary to take effective prevention.(29)

4.3.2 Rail Infrastructure measuring and monitoring
DTK's overhead-line monitoring system measures the stagger and height of the overhead wire, the shocks between overhead wire and contact strips, and the strength of electrical current and its direction for each contact strip.

Overhead wire voltage, contact force and contact resistance, rise and fall of the wire, wire wear, geographical coordinates, and interaction between pantograph, bogie and track can also be measured.

Benefits
Pantographs have to ensure a continuous current transfer between overhead wire and vehicle. DTK's inspections allow for the necessary adjustments to meet this condition.

4.3.3 Wire and catenary check by bvSys
WireCheck is an automatic measurement system, which determines at high speed the thickness of the contact wire or the remaining height of one or more parallel contact wires. WireCheck ensures that the contact wire inspection is fast, safe and reliable With the aid of pioneering sensors and the most modern image processing technologies.(22)

Recording of data
The sensor system is installed in device modules suitable for railway vehicles on the roof of the measuring vehicle on both sides of the contact wire. Each sensor contains a high-energy, laser-based illumination unit, which makes it possible to acquire, store and evaluate graphical data online at a speed of up to 160 km/h. The patented sensor system generates high-quality graphical data across the entire inspection area where the contact wire can be located.

The positions of the visible edges of the contact wire and its sliding surface are determined from this graphical data. The comparison of the edge positions determined by the left and right sensor provides the thickness (visible diameter) and the remaining height of the contact wire. The thickness of the contact wire is specified for each centimetre of the wire in order to be able to detect contractions of the wire.

Catenary check by bvSys
CatenaryCheck is an automatic inspection system, which inspects the catenary and catenary cross span at high speed. In view of the ever increasing railway line occupancy it is imperative that an objective status of the inspected railway line be available to the user with the most modern technology, high quality and safety in the shortest time. With the aid of pioneering sensors and the most modern image
processing technologies CatenaryCheck ensures that the contact wire inspection is fast, safe and reliable.

**Recording of data of catenary and cross catenary**

The sensor system is installed in device modules suitable for railway vehicles on the roof of the measuring vehicle on both sides of the contact wire. Each sensor contains a high-energy, laser-based illumination unit. At a speed of more than 120 km/h, digital line scan cameras continuously record graphical data of the entire catenary, store this data and make it available for the later evaluation.

A special recording technique enables the catenary cross span to be recorded by means of digital line scan cameras from both sides at a speed of up to 120 km/h. The process ensures that optimal image quality is provided for the subsequent processing steps, which makes even the finest details of the catenary cross section visible.

### 4.3.4 Mermec Group

MERMEC Inc. is a developer and manufacturer of advanced measuring technology based on laser light sectioning and high-speed digital processing.

MERMEC Inc. specializes in high-speed, non-contact measurement systems which are used by track owners and railway operators to provide key information to ensure safe operation and reduce maintenance costs. ImageMap has become the world leader in its field and continues to innovate to increase the profitability of railway operations. This group provide the follow measurement systems based on the modern digital image processing technique.(27)

**Catenary inspection and electric arc detection by Mermec**

- Catenary inspection

Due to a vast power supply requirements in the area of rail overhead it is necessary to identify and monitor the catenary in a regular time interval. That is why the company propose a cutting-edge technology for the condition monitoring of this catenary systems for the accurate and extensive diagnosis of this equipment.

- Electric arc detection

In the area of overhead the electric arc detection system detects the presence of electrical arcs and their duration at speed of up to 320 km per hour based on the no-contact optical technology provided by the company.

### 4.4 Railway Ballast

#### 4.4.1 Rail.One

RAIL.ONE is one of the leading manufacturers of concrete sleepers in Europe, and delivers innovative track systems for mainline and urban traffic, in Germany and throughout the world. This company provide technique for ballasted and ballastless track systems. (31)

#### 4.4.2 Ballasted Track System

Concrete sleepers on ballast represent the primary basis of track construction, in Germany and around the world. The main advantage of prestressed-concrete sleepers is their flexibility. For newly constructed lines or the refurbishing of existing tracks:
these sleepers offer fast and reliable solutions for any application. RAIL.ONE has developed the two system types TBS and LIS especially for the application fields of tram systems, surface commuter trains, and underground railway systems. The benefits of concrete railway sleepers are provided by the company by implementing their developed systems are the following:

In high operational loads, it provides its full performance capability.

- Cost-effective optimization of the track system.
- Assurance of operational continuity
- Possibility of enhancing track elasticity by the use of special intermediate and sublayers.

4.5 AI based Analysis in context of companies

There are a lot of companies providing support and solutions to the railway industries. In most of the cases their solutions and systems are based on the AI techniques. Companies like bySys, Mermec, Beena Vision, Ensco and so on, provide their systems and solutions based on AI techniques. In many cases they use vision based technique for inspection purpose. In case of sleeper the crack check is done by the BvSys’s railway inspection system based on the machine vision system. And other system like measuring the contact wire and its positions and inspection of the catenary system is done by also machine vision based system on the high resolution line cameras. Mermec group on the other hand use modern digital in image processing techniques to continue their condition monitoring techniques and doing the inspection of the testing object. Beena Vision use non-contact measurement and machine vision technologies the inspection process. Ensco use real time track geometry analysis and laser based systems to run their system like track geometry analysis and other systems based on the rail. BvSys also taken into account the modern image processing techniques and for wire check and automatic inspection system for catenary check. On the other hand there are some other companies named P-Tech, Rail-one, DTK, Vossloh and so on, they use the engineering based techniques now a day to monitoring the condition. By the study of this work it can be clearly stated that AI based systems performed well than other like engineering and manual systems. So, the companies who are doing this sort of business and still now don’t adopt AI techniques to develop their systems needs to be combined both the AI and engineering techniques to establish their system more effectively and efficiently.

By studying these works done by the researchers and different companies it can be demonstrate that AI based techniques supports this transportation domain very much and makes the monitoring process easier for the skilled railway engineers.
Chapter 5: **White papers provided by different companies**

I have studied and reviewed some white papers which have provided by different companies. And these white papers also provide better direction to this area to maintain its security and reliability.

5.1 ‘Enhanced tie condition Inspection Using the Hand held Recording System ’ by Allan M.Zarembski. President of Zeta-Tech Incorporation.

In this Paper it has been mentioned that to maintain efficiently and effectively railroad’s, the maintenance staff must have accurate knowledge of the exact condition of this area. And for this reason, the paper proposes to supplement the traditional track inspector with a broad range of computerized equipment. Due to the automated track inspection systems to monitor, these computerised equipments measure and record the condition of the track to a new generation of computerized hand held devices for the accurate recording and subsequent analysis of track condition data. And this inspection system covers to monitor the track structures, including rails, ties and track geometry.(32)

These new tie inspection tools have evolved in two different directions:

- The first one is towards a new generation of vehicle mounted inspection systems, the track strength inspection vehicles which have recently been introduced. These vehicles are designed to locate “weak spots” in the track, corresponding to locations of inadequate tie and/or fastener strength.
- The second one is that these new inspection tools has taken is that of hand held (computerized) data collection and analysis systems that allow the tie inspector to record the condition of each tie individually.

For this second direction a system needs to be developed named ‘’TieInspect ‘’. TieInspect,developed by ZETA-TECH Associates, Inc. of Cherry Hill, New Jersey is a computerized crosstie inspection system designed to aid the tie inspector in accurately and efficiently collecting tie condition data based on the inspector’s (and individual railroad’s) condition criterion.

This system provides a database system which can store the monitoring condition of the previous and current tie condition. This system monitor the condition of the sleeper like good, bad and average.

This ‘’tieInspect ‘’ can inspect all type of sleepers like wood, concrete and steel sleeper.

The data which is stored in the database then subsequently downloaded (via a serial connection) to a Windows 95or NT computer for analysis, display, and storage.
The TieInspect system done its inspection by two different way:

- In the first way the system record the condition of different tie condition in three categories good, bad and average condition.
- And by the second way only the bad ties recording with their bad clusters.

In second mode two numbers are taken in per mile one is the bad tie count and another is cluster count.

Impact of this system

This sleeper inspection system which is collects and stores data in a database which is primarily stored in the palmtop computer and then this data download in any host computer to make decision about analysis, storage and others long term planning. The host computer of this system provides the flexibility to any inspector to make a database based on the inspected data for the future and for taking any strategic planning.

This system provide a enormous facility to the maintenance staff to make any maintainance needs immediately in this fields and if there any needs for further maintenance for the future also the staff can do this by the analytical and real time data from this system.

5.2 Routine ballast inspection using ZARR (Zetica advanced rail radar)

The layer which is designed for the ballast, the main function of this area is to distribute the loading force to the surface of the track to ensure and preserve the smooth ride. Different types of ballast have the different types of activities. And in this case ZARR utilises ground penetrating radar to continuously map changes in the thickness and quality of the ballast layer. (33)

Measures of ballast layer geometry and identification of discrete faults

In this process the raw data collected by the ZARR from a GPR, summarises this information in a number of indices to provide a statistical representation of data which serves the engineers to problem trackbed areas.

By comparing the difference between the ballast thickness versus a desired depth, the ballast depth exceedance (BDE) index is defined which provides a visual indication of the spatial variation in ballast thickness. This information is helpful for the engineer to identify the layer thickness and its irregularities. The BDE presented by a bar code style strip chart.

From this inspection it can be clearly stated that the cause of track geometry anomalies can be clearly related to ballast layer irregularities and wet beds.

As an indicator of subgrade erosion, small wavelength variations in the ballast subgrade interface can be significant. In this inspection system, a layer roughness variations index (LRI) is provided for characterising subgrade erosion as well as larger scale ballast pocket indications. And LRI threshold can be used to prioritise maintenance and to measure changes in time. The trackbed quality index is derived from a weighted ranking of a series trackbed GPR metrics including layer thickness and layer roughness variations.
Priortising of ballast cleaning

For the reason of ballast cleaning and trackbed maintenance or renewal GPR (ground penetrating radar) can be used to provide an indication to the areas on the network.

Regular monitoring with GPR allows decisions to be made on timely and cost effective interventions to extend the ballast life. This allows the development of a robust ballast management strategy and prioritisation between sites which can result in significant cost savings.

Finally, the benefit of the use of ZARR is to provide specification accuracy leading to more cost forecasting certainty and the correct allocation of resources. The number of revisits to correct problems can also be significantly reduced. Beside this, a number of safety benefits can also be achieved such as reduced exposure of staff to the hazards of working trackside, less risk of striking buried services or other hazards during intrusive site works and reduced risk of rough ride or derailment by focused repairs to discrete faults early in their evolution.

5.3 Strategies for preventing derailment by ENSCO

In general derailment means the loss of guidance between the wheel and the rail.

The problem is identifying as a biggest problem in the railway transportation which may cause the total damage of the train and can take a lot of valuable life within a moment. So, to prevent this problem, ENSCO has made a study on it, the reason of this problem and propose some preventive measure as well in this area. (34)

The study identify some specific causes for this problem

- The operator who are responsible for taking care of the track needed to concentrate on the measurement of the track and the wheel and the rail. this thing can address human error in this area.
- Another cause based on infrastructure, like broken rail resulting from environmental temperature extremes, loss of truck fastener, bolt failing to hold the track gage under load. This sort of failures they identified as track component failure. By considering the vehicle, the broken wheel or any type of suspensions components like centre plates or side dampers can lead the problem named derailment.

So, in this cases, it can be said that the derailment is not based on only one type of failure like component or based on the vehicle, the problem is based on the overall structure and some calculations as well.

- The interaction of the track with the vehicle is called vehicle track interaction is essential to continue the service in an effective way. This maintenance is based on the response of the vehicle to deviations in the track geometry, either by design or because of component degradation.

Other scenarios like climb resulting from excessive lateral forces at the wheel/rail interface as compared to vertical forces at the same interface, gage widening and rail rollover, vehicle lateral instability, high wheel loads and their effect on switch components and the forces on the rail that can be generated by hollow worn wheels also lead to the problem of derailment.
A wheel when it is on the track, in this case a guidance is provided by the steering ability of the coned to change the direction of the track. The forces which is generated on the rail track by the wheel generate two forces namely the lateral force and the vertical force.

![Figure 5-1: Forces of wheel rail contacts.](image)

Another problem that is the excessive wheel/rail interaction forces are not limited to wheel climb scenarios. For instance, if the lateral force generated by the flange contact between the wheel and the rail is relatively high, this force can cause lateral rail displacement. This rail displacement produces is called as gage widening and can lead to a wheel/rail separation.

![Figure 5-2: Gage Widening](image)

**Rail rollover** is one of the most common sources of accidents especially when the vehicle travels over the spiral transition between tangent, or straight, track and the full body of a curve.

![Figure 5-3: Rail rollover](image)
As a wheel passes over the switch point and the tip of the stock rail, a high lateral pressure on the tip of the switch point will be generated. This can lead to battering of the switch point and the eventual fracture of the stock rail. This high wheel loads make effects on switch components. Another is the wheels of rail vehicles are tapered in order to allow for the wheelset to steer down the track. This problem grow the probability of the problem like vehicle lateral instability. When a wheel exhibits significant wear on its tread to the point where a rut is formed around the circumference of the wheel around the center of the tread, it is said to be a hollow worn wheel.

Two conditions of concern can exist with hollow worn wheels. As the tread wears, the tip of the wheel flange "moves" further away from the top of the rail, creating a condition where the top of the flange is considered to be high and can strike switch components. Hollow worn wheels also adversely affect the steering of the truck and can increase the potential for derailment.

For reduce the above mention possibility for derailment the following strategy has been proposed by the company.

At first to minimise the human error it is essential that operators need to be vigilant in enforcing their training requirements for all personnel. Operators must be able to objectively analyze and, when necessary, modify policies and training when issues arise to mitigate the chances of human error leading to a derailment.

- It is essential to make reliable track and vehicle inspection practices to prevent the derailment. To developing their inspecting strategy, operators must be proactive.
- Railroads and transit operators must also aggressively perform maintenance as required. An operator with optimal inspection practices are only part way through an effective derailment prevention strategy.
- A sound friction management program should be established to address rail wear and friction throughout an operation.
- In addition to being aggressive about performing maintenance on track infrastructure upon awareness of issues, additional steps can be taken with the right-of-way that can provide protection against derailments.
- The characteristics of a vehicle's suspension system are critical to its susceptibility to wheel unloading and derailment.
A soft primary suspension will provide better steering of the truck over curved track, hence reducing applied lateral forces on the track that cause derailment. However, the use of very soft primary suspension may affect the vehicle's lateral stability.

5.4 High tech with railway fastener by the Port authority Transit Corporation (PATCO) Direct Fixation assemblies. (35)

The Delaware River Port Authority (DRPA), the owner and operator of the PATCO High Speed Line, is undertaking the replacement of the existing direct fixation fastening system on the Westmont, Lindenwold and Collingswood Viaducts. The existing track fastening system is the original installation. The construction of the structures was completed in 1969. Based upon routine inspection reports, overall the structures are performing adequately. It was noted that the grout pads located under the direct fixation fasteners were deteriorating and routinely being replaced in kind. Owing to the deterioration of the grout pads and the existing direct fixation fasteners, the DRPA Consultant, HNTB, performed an industry review of direct fixation fastener systems to determine which products could be used to solve this maintenance problem.

DRPA, PATCO and their Consultant, HNTB, decided to build a hundred foot test section comprised of the existing revenue track which included an expansion joint, as a method of proving reliability under normal operating conditions.

An industry review of Direct Fixation Fastener (DFF) products and current technology was performed for application on PATCO’s viaducts. This review considered existing vertical geometric constraints, overall stiffness, dynamic properties, electrical isolation, the interaction of the fastening systems with the viaduct structures, and the noise and vibration characteristics of five products. A review of the original 1969 design drawings and other documentation was also undertaken. The drawings showed that the original trench for the direct fixation fasteners is one inch in total depth. HNTB calculated the height available for each direct fixation fastener product with the assumption that all the grout pedestals vary in height. The goal was to determine the geometry constraint for the new fastener. This becomes the most critical constraint in the DFF selection process. The PANDROL PANGUARD unit met all the criteria, including being the best for noise and vibration.
Chapter 6: Future Work

The main objectives of this work are to review condition monitoring or inspection techniques from different aspects. So, the monitoring techniques in most of cases it has been observed that machine vision techniques take the major part to do this operation. As a result it was identified during the survey that image analysis techniques and algorithms developed for applications in this area.

A future objective of this kind of work would be that people focusing on building image analysis algorithms for the automatic interpretation of NDT data, should be careful in selecting a more general approach that might offer flexibility for extending the solution.

Unlike ultrasonic, thermal images, rail track profile and images of the rail surface, sleeper images, fastener, ballast and a lot of other details. Different objects with different shapes, colours and shadows can also be encountered, which is a difficult problem to solve.

Most of the reviewed work using image analysis for solving problems of this area and rail surface inspection problems focuses on rail surface, rail profiles, rail fastener, ballast etc where crack detection and other equally faulty problems have been the prime target of analysis. Problems concerning rail surface etc are a lot simpler than the sleeper inspection problem, which has been proposed above. This is the due to the fact that the surface of the rail is much smoother than the sleeper and data acquisition is much simpler.

The railway track infrastructure inspection area is directed to the inspection of sleeper, ballast, fastener etc. So, better solutions within the area would also enhance the current state-of-the-art technology in solving problems concerning railway track infrastructure inspection; as all the areas within the rail inspection domain would be studied to a reasonable extent. Hence a huge potential lies in the area to carry out much interesting work.

Some systems have already developed based on AI techniques in the area like railway sleeper, fastener, ballast and overhead. So, the railway industry has to be always up to date with new AI based systems. These systems can make a big difference in this transportation area. So, AI techniques are playing a good and important role at present and hopefully in future these techniques would provide more automated and robust systems in this transportation domain.
Chapter 7: Discussion and Conclusion

AI techniques have been used in a variety of disciplines such as medicine, engineering, entertainment etc. NDT is one such area that has been using AI techniques for the automatic interpretation of NDT methods without any human operator. AI techniques ensure a fast, reliable classification of flaws and better ways of data interpretation. Techniques such as neural networks, expert systems, machine vision, case-based reasoning etc. have been used to handle a variety of problems in the area.

By the analysis of some research work, by reviewing some white papers and some well proposed system by different companies it can be assure that the AI techniques provide an enormous evolution in this area. Specially, AI techniques based on machine vision, neural network and case based reasoning provided a great feature. The systems developed by the AI based techniques are great support for the maintenance staff and the decision makers.

With the help of NDT the overall monitoring and analysing process now more easy than before. This testing process ensures the inspection without making any harm of the test object.

Now a day, companies provide solutions and products to the railway industry so that it is easy to maintain and manage the railway sector in an organised way. The maintenance and management is essential because the problems which have already been found cause a great harm in the industry by damaging the component. So, the systems provided both researchers and companies has to take into account by the railway sector to minimise the risk and maximise their service to the customers.

It is clear that the traditional approach of monitoring techniques of the railway isn’t effective, secure and error free than the AI based techniques. Because, in traditional approach there are manual approaches with hand held devices to capture the image and condition of data testing object. The operator who has handled this device isn’t well trained to perform this sort of monitoring task. As a result the inappropriate images have been captured by the devices which can govern some errors in the analytical data. By adopting this manual system, there is a huge possibility that the solution with some errors. And the manual monitoring process isn’t real time; as a result the unexpected events occur in this area sometimes by adopting this process. On the other hand the adoption of AI techniques most of the cases the monitoring work is done by the automated machine which is attached to the vehicle to capture the exact image and data in a real time manner. The images and data captured by the automated machine then analysed by skilled personnel with the help of AI techniques with NDT technique. It can be stated that these analytical approach compared with traditional approach make a big difference in this area.

The inspection of railway objects based on AI techniques is accomplished with the support of NDT by avoiding the harm of the testing object and to get more reliable test data. To follow-up this idea of NDT, the machine vision techniques are mostly use to do this inspection which hold high resolution camera to capture the image and critical part of the inspected object.

NDT methods employed with most common other NDT methods like GPR (ground Penetrating Radar), ultrasonic and ultrasound technique. As, the inspection process perform in good and bad weather condition, so the data which will get also be
different in these case. In the case of ultrasound technique there are possibilities of getting data in a good weather and in a bad weather. So, it will be better to get data in a good weather condition with the proper instrument so that to get maximum level of outcome without any harm of the testing object.

Moreover, different companies proposed and developed different inspection systems for the reliability of this transportation domain. Their systems will be more effective if the companies adopt relevant AI techniques for more effective systems to provide to the railway transportation. Because the systems developed by the AI techniques shows that these that these can totally reduce the major problems in this transportation area.

AI techniques are essential now a day for the development of the real time monitoring system and for making effective decision. For this reason it is expected that the overall operating system of railway transportation should have to be AI based system because of the great advantage of these.

Another important thing require to consider in this transportation domain is that the possibility of damage number of human life when major accident occur. So the real time inspection is essential to detect problems of the inspected object to avoid any accident and take a quick precaution without any damage occurs.

The solutions and products provided by different companies and white papers have already proved their efficiency in this area by implementing these solutions in different railway organisations. In this case, the derailment strategies provided by the ENSCO can be mentioned. This strategy actually shows a great performance to prevent this problem.

There are some considerations can be taken into account for some specific purposes for the better operation of the AI techniques which I have reviewed in this thesis work.

- When the inspection is conducted by the machine vision technique it is essential to ensure the better camera which holds good resolution with it to capture the image of inspected object from its core and the condition of inspection is another good consideration. If the surroundings of inspection are well enough with the proper device then there is a better possibility to proper data.
- System based on frequency, it is essential to make sure the better frequency because in frequency based systems, the sound produce by this system will be good if the inspection is performed in the good weather condition.
- In case based systems, it is important to consider that the cases they have been identified for the development and the previous cases which need to be consider because if any cases of current problem is matches with the previous then this have to be taken by matching the previous one.
- In case of laser based method, it is essential that better lightening effort to get the most appropriate data. Because based on this technique the data has been extract from the testing object to reduce the problem which has been detected.
- The automatic interpretation of data by using the NDT methods aims to perform the inspection of the testing object without any harm of this object.
Finally, it can be expected that this paper may be a good background for the further development and analysis in this transportation domain. By concerning the proposals which are proposed for the future development in this area would be a good support for effective condition monitoring process.
References

[4] Siril Yella, Mark Daughtery (University of Dalarna, Sweden), Narendra K gupta (Napier University Scotland), ‘Condition monitoring of wooden railway sleepers’
[18]. S. Östlund1, A. Gustafsson2, L. Buhrkall3, M. Skoglund41 ‘ Condition Monitoring of Pantograph Contact Strip Kungliga Tekniska Högskolan, Stockholm, Sweden ’.
[26]. http://www.railway-technology.com/contractors/rail/abetong/ Concrete Railway Sleeper
[27]. http://www.pandrol.com/ Rail fastening system Rail Fastening System
[29]. http://www.mermecgroup.com track and surface measurement system.
[32]. Allan M. Zarembski ‘ Enhanced tie condition Inspection Using the Hand held Recording System ’. Condition Monitoring System of Sleeper
[35]. http://www.pandrol.com/ high tech rail fastener system