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Smart Maintenance of Railway Infrastructure Using Wireless Sensor Networks

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Abstract: The railway infrastructure is a perfect blend of all branches of engineering. Technology has drastically increased, mainly in the Signalling, Civil, Electrical and Mechanical engineering streams. In the field of Signalling, it has leaped from Mechanical to Electronics Interlocking. Civil engineering has gone from manual track maintenance to high-end mechanized tools. In the field of mechanical engineering, it has progressed from wooden coaches to modern designed (LHB)coaches. In electrical engineering, the technology changed from steam loco to diesel and later electrically powered loco design. Nowadays, the loco is powered by nonconventional sources (like solar or wind). Hence, the maintenance of rail infrastructure with traditional methods of physical supervision is sluggish and prone to frequent failures. However, condition monitoring through manual verification by railwaymen helps in the upkeep of railway assets, but it is prone to human errors and subsequent failure of systems, which may result in disasters like derailments or head-on collisions. Signalling components (Point, Tracks, Signals, OFC, DNS, Dataloggers, EI, Block-working instruments etc.), Mechanical rolling stock (Carriage and Wagon), Electrical fitments (OHE, AT, DG, TSS/SP/SSP, locomotive etc.) and Civil Structures (Bridges, Culverts, rail-tracks, rail beds) all require regular maintenance. This paper introduces a "condition monitoring method Enhanced with Wireless Sensor Network" for railway infrastructure. It also clearly distinguishes the typical category of sensors, which are best suitable for condition monitoring of various types of railway assets. The proposed WSN-based technology will improve railway subsystem reliability, effectively reducing failure time and improving the operating ratio.

Introduction

Railroad transport imparts less frictional resistance to the wheel (without steering) than road transport. This makes railroad transport a more reliable, energy-efficient, environment-friendly mode. Growing global commerce and industrialization created opportunities for the logistics sector, with rail shipment of goods sharing 80% of the total railroad sector. Railroad transportation is much quicker than road transport.

Modern railway systems rely on sophisticated condition monitoring systems for fault diagnosis, renewal activities and railway vehicle dynamics condition monitoring (Ngigi et al., 2012; Kumaran et al., 2023). Condition monitoring of rail track geometry is examined by (Weston et al., 2015). A paper surveys WSN technology for monitoring railway systems, structures, vehicles and machinery (Hodge et al., 2014). A review of the on-board condition monitoring of systems for freight trains has been investigated (Bernal et al., 2018). An early warning system based on WSN for railway infrastructure with detection capabilities was analysed (Flammini et al., 2010). The state of A wayside condition monitoring system for railway wheels in online and offline mode is proposed by (Shaikh et al., 2023). Condition-based maintenance of railway signaling equipment where modern computer-based monitoring techniques have been

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explored (Fararooy et al., 1995). Presently stand-alone monitoring of railway systems is used, where we use specific sensors that generate alarms whenever parameters exceed a predetermined fault level, which has been studied (Chen et al., 2006). However, such local monitoring does not serve the purpose of monitoring the overall rail infrastructure as a whole (Kiran and Venkataramiah, 2024). Innovative condition monitoring of pantographs in live traffic conditions has been explored (Donnell et al., 2006). An Ad-hoc networking with wireless technology through distributed sensors is proposed (Akyildiz et al., 2002; Chong et al., 2007; Estrin et al., 2002; Tilak et al., 2002) in which the system constantly monitors machines and infrastructure. The set up of a wireless sensor network is required for overall condition monitoring of railway infrastructure comprising signalling equipment, telecom devices, civil structures and mechanical rolling stock. The sensor node communicates with the base station using wireless technology and transmission protocols (Bluetooth, Zigbee, Wi-Fi, Wimax, etc.). Intelligence in monitoring can be realized using WSN and data analytics as proposed by (Dierks et al., 2009). Occurring faults can be constantly monitored by WSN technology, as explored by (Hall et al., 1997; Chen et al., 2006). At the higher level, the complexity and functionality can be monitored through staircase of structure health monitoring system as proposed (Higuera et al., 2011). Many challenges with WSN exist, such as difficulty in identifying the complex behaviour of sensors as investigated (Rabatel et al., 2009).

At present, the condition monitoring of railway equipment is carried out with underground cables as shown in Figure 1. These copper cables are laid along the railway track from Central Relay Room to Field Location Boxes, which incur a heavy cost. All the Electronic components are placed in location boxes, where all cables are terminated.

The primary cause of system failure is cable cut or underground cable damage. The frequent failure of railway equipment led to the shutdown of train operations, which may result in huge financial losses to the nation. In traditional condition monitoring, the railway engineer reaches the failure site, finds the cable cut by manual trenching, and makes cable joints to attend to the failure. This old condition monitoring procedure is time-consuming, resulting in delayed train operations.

The purpose of the study here is to implement wireless sensor technology, which can completely replace underground cables. The paper presents an efficient condition monitoring system through the application of Wireless Sensor Networks. A real-time and autonomous data acquisition with supervision can be realized using a WSN-based condition monitoring system. The nodes may be placed in hazardous locations requiring no cables and free from EM interference. In this method, many wireless sensor nodes are deployed along different types of railway equipment to monitor the condition of railway assets. The Field nodes will communicate with the base station through the driving node. However, the proposed method meets challenges like limited power, processing, storage

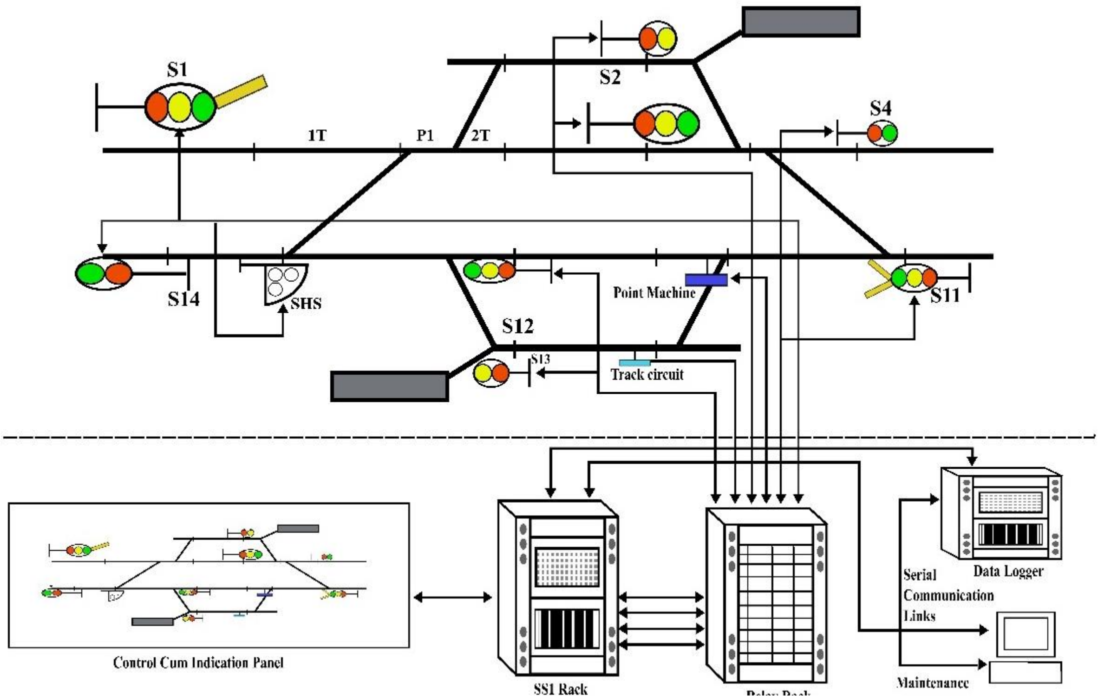

Figure 1. Railway Monitoring System through Underground Cables.

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capacity, heterogeneity, security, scalability, interference, reliability and node deployment.

Material and Methods

An appropriate Wireless Sensor Node is placed at each measurement location, and all the nodes are connected to each other, making an Ad hoc WSN. After Knowing various types of Sensros applications according to the type of railway infrastructure (Signal & Telecom, Civil, Electrical, Mechanical), an Adhoc WSN is created by nodes placed at each component.

The WSN node consists of basic components like a power source, microcontroller, ADC, transcriever, external memory, and sensors, as explained by the structure to be monitored. As shown in Figure 2.

power consumption. The specification and application of components used in typical wireless sensor nodes are given in table 1.

The proposed work explained in this paper is for condition monitoring of Signalling structure. Three important components must be monitored i.e., signal, point and track. The WSN source nodes are placed at each signal, point machine and detection point, respectively and they feed the driving node, which later communicates with the base station at the station control room. Hence, the field data of railway signal gears is provided to the Electronics Interlocking system for control of train movement. The setup of WSN-based smart monitoring is shown in Figure 3

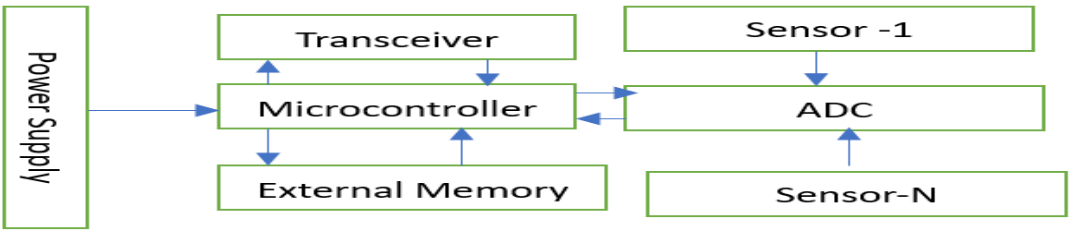

Figure 2. The Basic Building Block of a Wireless Sensor Node.

Table 1. Components details with parameters.

Sl. No	Component	Parameters	Applications
1	Power Supply	Secondary (rechargeable) Lithium battery with Energy density 1080 J/cm^3. Each single cell provides an open circuit voltage 1.0-1.5 Volts.	Such cells can be placed in series for higher voltages as per Node type.
2	Transceiver	Model: Xbee-802.15.4 Protocol: 802.15.4 Frequency: 2.4 GHz Transmitter power: 1m W Sensitivity: 92 d B Range: 500 m	To transmit and receive data bits, with Low power hardware wakeup function.
3	Micro Controller	TIMSP $_{430}$ --16 bit ,8 MHz	Used in Node WSN $_{430}$
4	ADC	10 Bit with Sampling Rate 200KBPS and Operating voltage 3.6V	Convert analog signal into digital data suitable for transmission.
5	Channel	16	Wireless channels separated with suitable Bandwidth
6	Data rate	250KBPS	Flat Sampling
7	Standard	IEEE 802.15.04	Wi-Fi, Bluetooth

The specification of components of Typical sensors, like Power supply, Transceiver design, Microcontroller, ADC data rate and Communication Protocol, are crucial to design. The power supply is the critical parameter for a sensor node as the battery gets depleted over time. The trans receiver is designed according to the range of network structure. The microcontroller should be competent enough to handle local operations. ADC is to be designed to trade the difference between the bit rate and

The data received from Adhoc WSN at the base station can also be utilised by the internet end user through the gateway and further data can be used for event logging of system failure. This failure report will be the most vital information for periodic and preventive maintenance of railway infrastructure. In this way, the health of the entire railway system can be monitored in real time.

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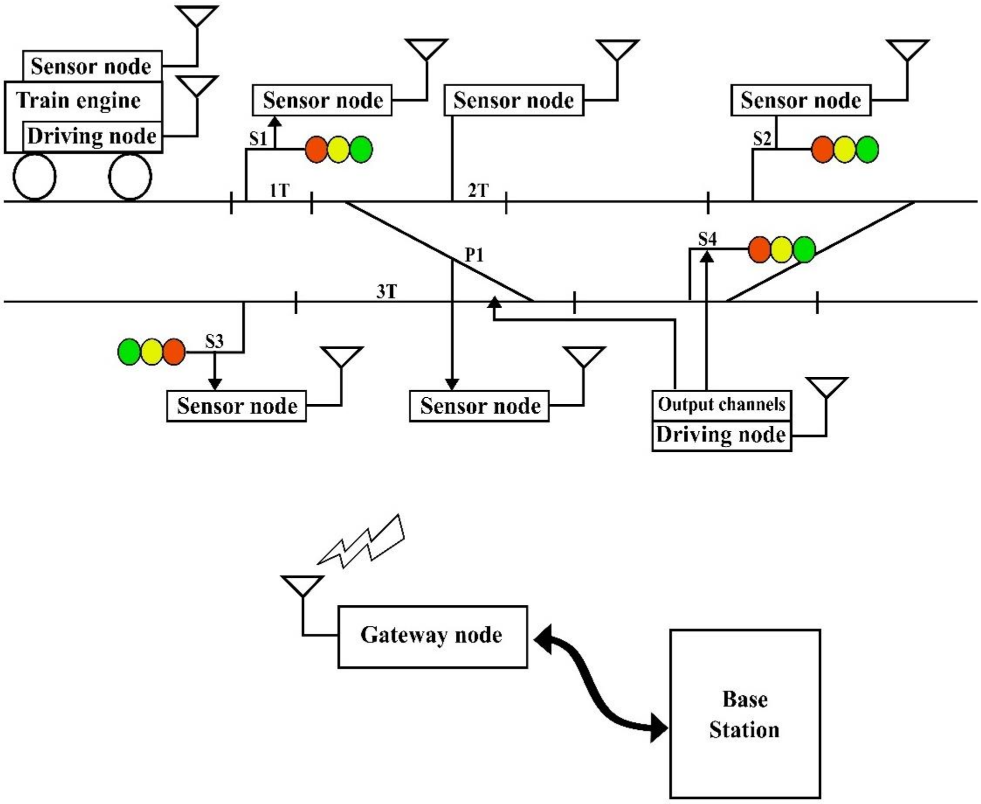

Figure 3. Smart Monitoring Model of Railway Signalling Infrastructure based on WSN.

Sensors used in Rail Infrastructure

i)Voltage Sensor

A voltage sensor is used to calculate and monitor the amount of AC or DC voltage level, input to the sensor is voltage, and the output may be a switch, analog voltage, current signal, or an audible signal. The applications of voltage sensors include power failure detection, load sensing, safety switching, temperature control, power demand control, and fault detection.

ii)Ultrasonic strain gauge

It is applicable to any material where deterministic surface roughness is present. It records elastic vibrations by passing the train over the railway track. Ultrasonic strain gauges, these SGs are easier to install and more accurate than a standard Strain gauge (peizo type).

iii)Temperature Sensor

These are simply thermocouples used in many railway applications to monitor the temperature of the atmosphere (or air temperature), railbed (Hall et al., 1997) bogie, chassis and some mechanical properties (Gruden et al., 2009; Rabatel et al., 2011; Reason et al., 2010; Reason et al., 2009).

iv) Strain gauge

The Strain Guage Measures local stresses and generates signals to detect the amount of strain applied. Examples are Resistance SG, Voltage SG and Vibration wire SG, which generate signals to detect the tension in the wire and are also used in vertical or lateral force applied to rails between two sleepers (Barke et al., 2005; Lagneback et al., 2007; Palo et al., 2012) on passing of the train.

v) Pressure transducer

It produces a signal to reflect pressure applied on the sensor. The application of the pressure transducer is Vertical displacement (Hault et al., 2009), which is used to measure railway track deformation.

vi) Piezometers

When external water exerts pressure on the internal water surface, it is detected by the internal pressure transducer. Essential applications are measuring positive water pressure under railbeds (Aw et al., 2007).

vii) TDR (Time Domain Reflectometer)

vii-a) Electrical TDR

Used to determine the characteristics of electrical lines by observing reflected pulses. It converts the travel time of high-frequency electromagnetic waves into volumetric water content. It also locates fault or discontinuity coordinates in metallic cables (twisted pair, coaxial) PCB or electrical path. If the cable has uniform impedance and is properly terminated, then the incident signal will be absobed and no reflected signals are returned. Suppose there is any fault in the cable, like cut or impedance variation due to EM induction in the RE area. In that case, part of the incident signal will be terminated and the remaining part will be reflected back to the source. It will not calculate the time distance of the fault like RADAR.

vii-b) Optical TDR

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It works on the same principle as electrical TDR, but an optical signal source is injected in place of electrical signals. It is used to detect fault or decibel loss in optical fiber cables.

Monitoring of Signalling Asset

The important Signalling gears are Points, Signals and Tracks. The track is controlled with help of Detection Points (DPs). Detection points are Digital Axel Counter devices, which work on the principle of electromagnetic flux change, sense the wheel's existence on the track, and send the wheel dip count to the central evaluator to prove track occupancy.

resulting in a fault in the interlocking system. However, using a sensor node at the signal unit can improve the loss of indication voltage. The voltage sensor, or Capacitive sensor or resistive sensor, is used to sense the voltage level of the LED and send fault level through ad hoc WSN to the base station.

#Track Circuits

The Track Circuit is a Section of a railway track monitored with DC relays circuited at entry and exit ends. It is used to detect the approaching train and supports signal interlocking in the railway yard (Chen et al., 2006; Pimentel et al., 2008; Yazdi et al., 1998). A track circuit is

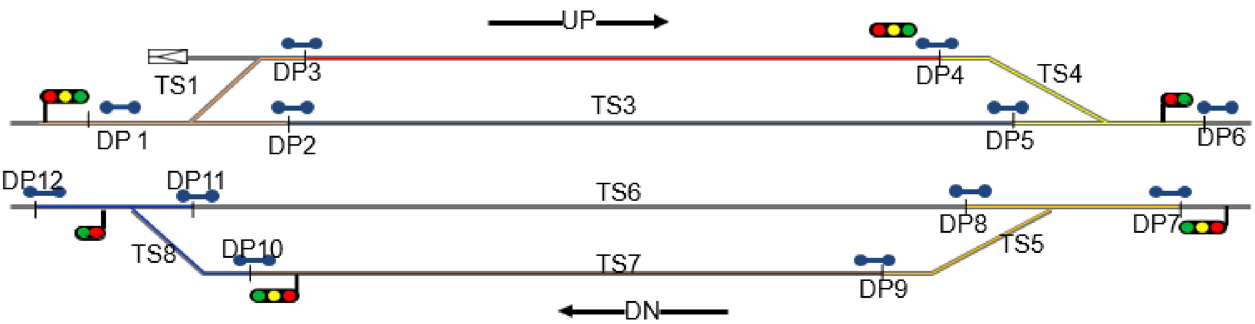

Figure 4. Multi Aspect Colour Light Signals (MACLS) are installed along railway tracks.

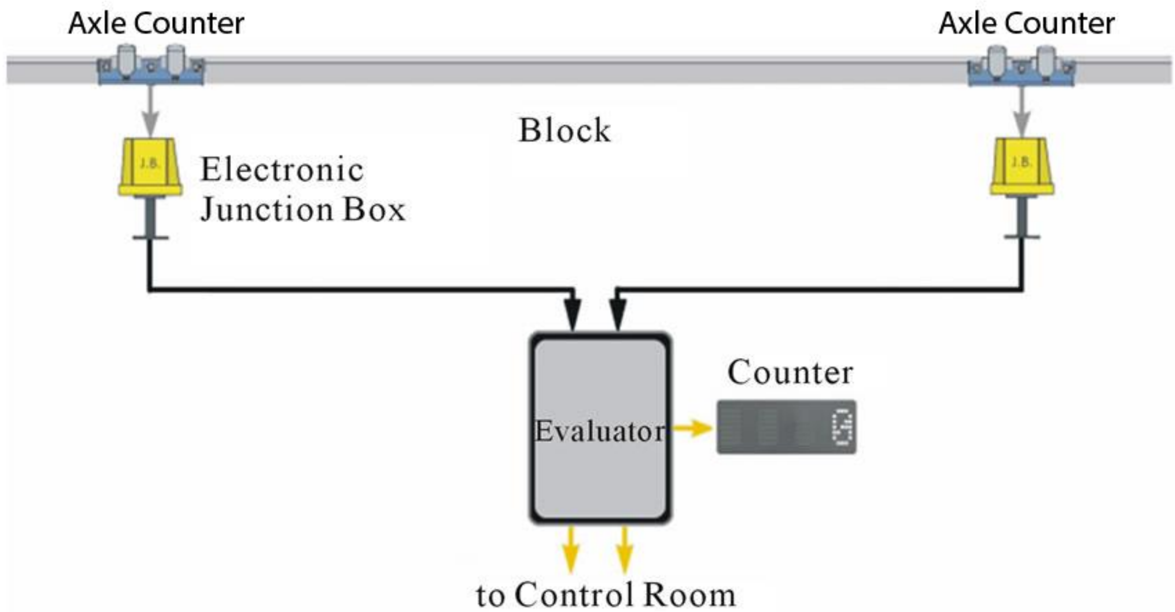

Figure 5. Track Section is monitored with two Detection Points (DPs) at Entry and Exit.

#Signals

Copper cables connect signals to the cable termination rack, and an LED indicates the signal aspect. Figure 4 depicts a typical double-line railway yard indicating DP (Detection Point) and Track Section (TS) with Multi-Aspect Colour Light Signals. A power supply of 110V AC is transferred to Signal unit. Further, the indication of lighting or blanking is sent via relay with a 24VDC given back to the relay room. The Copper cables for power supply and indication voltage are prone to a huge loss,

designed by dividing the railway track into segments with the help of joints. A DC power supply is connected at one end and an AC immunized relay is connected at the other end of the track section. When the train is not available on the track, the relay stays in pick-up condition. When a train hits the track section, the wheel axel shortens the path of the circuit and the relay drops, indicating occupied track. This relay status information is transmitted using a copper wired cable, Wireless sensors like MEMS (Pimentel et al., 2008), through ad hoc WSN. At present, train wheel

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detection is carried out with Axle Counter Devices, which are fitted on a track section's entry and exit points. These Detection Points (DPs) work on the principle of cutting Electromagnetic flux between two coils by the passage of the wheel (Sharma et al., 2023), as shown in Figure 5. If the difference in axle counts between entry and exit points is Zero, this track section is clear, and the next train can be received on this track. When the difference in axle counts between the track section's entry and exit points is non-zero, this track section is occupied, so no next train can be received on this track section.

#Point machine

This point motor (Shown in Figure 6) helps to decide whether the train's path is normal or reverse (Igarashi et al., 2006). The function of the point machine to detect and drive the switch rail toward the fixed rail also indicates the VDU (Video Display Unit) panel of the Station Master, whether the point is operated normally or reverse (Marquez et al., 2007; Hutchon et al., 2005). rolling stock while running the train remotely and in the workshop as well. Governments are planning a dedicated freight corridor to boost the transportation sector to achieve the decarbonization target (Kruger et al., 2007). GPS-based information about the health of rolling stock could help us in preventive maintenance. A wireless sensor network plays an important role in using suitable transducers to fetch data from the defect site. Hybrid monitoring system composed of WSN and gateways will certainly improve the efficiency of freight trains. An integrated wireless monitoring system may be explored for both Vehicle on track and Inhouse-Workshop infrastructure

Monitoring of Civil Structure

It is a fixed monitoring type, and the health monitoring of Rail infrastructure is very important, including Track, point and crossing, rail bridges, tunnels, track formation, peaks in (track, culverts etc (Kruger et al., 2007).

Figure 6. Point Motor is used to change the direction of Train Movement.

The interlocking of Signal and track circuit defines the rail path's making and the route's sequential release to be traversed by the train. Some point motor parameters, like obstruction current and supply voltage, motor driving torque, and noise, are due to electromagnetic induction in railway-electrified areas. Magnetic lock warp-type sensors are applied to detect misaligned rail switches and defects in switch dimensions due to temperature, explored by (Igarashi et al., 2006). A pair of such point motors are used to drive the rail track in the desired direction (Normal or Reverse).

Monitoring of Mechanical Rolling Stock

The rolling stock in railways means the machinery and tools required to operate trains on the track. It basically involves wheels, axle bogie, Engines and coaches. A systematic approach is required to monitor the health of

Traditionally, inspection is done through a motor trolly or rail car over a period of months, in which a civil engineer visually examines the location of defects intermittently, which requires experts to make a postmortem of this subjective report. Wireless sensors will examine the health of the complete infrastructure simultaneously and can generate live reports that are objective instead of subjective. This will help in the preventive maintenance of the rail infrastructure.

Low voltage warning sensors are fixed with the track to give track temperature to avoid rail fracture or deformation, and similar WSN sensors may be attached to the point machine to monitor the power supply to the DC motor, which drives the rail switch to change the path (Normal or Reverse) of the train in the yard (Bell et al., 2006). These sensors simply generate Yes/No or True/False type binary data. Piezo Electric sensors are

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preferred to identify cracks and detect the elongation of track. Acoustic emission sensing is explored by (Ledeozi et al., 2009; Nair et al., 2010). Track mounted sensors for condition monitoring of train wheels (Brickle et al., 2008), when there is a large gap between left and right axel load, the excessive unbalanced load may lead to defects in wheel formation, like flat wheel, hot axel, which may damage the track surface, or poor detection of flange for interlocking, which may lead to derailments. Fracture of track-wielded joints, damaged sleeper or railhead, FBG sensors are explored (Filograno et al., 2012) for train identification, counting of axels, speed and defining the dynamic loads.

There are two types of structure monitoring required with WSN technologies. Fixed Monitoring includes structures like Bridges, Tunnels, Rail tracks, Rail -bed formation, and Movable monitoring, which includes Train engines, train bogies, train wheels, Train pantographs and Train brakes.

Fixed Rail Structure Monitoring

Bridges

Bridges are the most critical structure Along the railway track. When a train passes over a bridge, the structure suffers from continuous stress and strain due to vibrations. Overall monitoring of health, a variety of MEMS are used to know the parameters of the concrete (Kruger et al., 2007). Optical sensors are utilized in the skeleton of the bridge design to study structural changes during repair (Kerrouche et al., 2008). It also utilises FBG (Fibre Bragg Grating) strain sensors. The data captured for strain may also contain noise.

Tunnel

It is very difficult to monitor and inspect the tunnel compared with bridge monitoring because of the secure data transmission in an autonomous tunnel environment (Mottola et al., 2008). The data transmitted by WSN may require a multi-hop mechanism through the relay node to the sink node outside and then to the base station (Bennett et al., 2008; Hault et al., 2009; Cheekiralla et al., 2005). The deterioration in tunnel structure was identified by (Hault et al., 2009), who utilized an inclinometer and linear potentiometric displacement transducer. The data is transmitted using relay nodes in a mesh topology. It also utilised repeater nodes to send the data from the tunnel to the outside deformation of tunnel architecture. It used RF transmitter with analog to digital converter and a laptop with the wireless modem to transfer the data to the server.

#Track

Unlike bridges and tunnels, tracks suffer from cracks according to the environmental condition of the area. Sometimes, titles or twists in the track are faced at many sensitive locations. It is produced by nearby earthwork like tunnelling or excavation (Shafiullah et al., 2007). Track movement over a range of time on vulnerable areas of soil condition is analysed (Aboelela et al., 2006). The effect of the train passing along the track is analysed by train mounted strain gauge explored by (Barke et al., 2005; Lagneback et al., 2009). Piezoelectric strain, FBG strain sensor, and Accelerometers were used (Berlin et al., 2013).

#Track bed and formation

Track formation, slop, rail bed, and cushion for blast are vital items to wear as ballast to roof up the track. Frequent trenching under the rail sleeper for signalling cable laying, Transmission Reception coils for DPs make the rail bed weak and vulnerable to track peaks and jerks in train movements. Repeated pressuring of subsoil and train reduces soil shear strength, weakening the rail bed. Pore pressure is measured with a vibrating wire piezometer. The data rate may be 0.1 Hz, but it is a very low rate, which can indicate the peak pore pressure under tear load at higher frequencies (more than 1 Hz). Higher frequency enables them to read more pressure under the running trains (more than 100Hz) (Konrad et al., 2007).

#Other track infrastructure

Many other accessories are required to design a track. A first important and vital component is the Fishplate. It is the metallic part of the rail used to connect and align two portions of the rail track (Ghosh et al., 2011). Loose and misaligned nuts/ bolts may tamper the Fish plate. This loose-fitting Fishplate and locking clips may cause serious derailment. WSN-based FBG strain sensor (Buggy et al., 2011) and Piezo resistive pressure sensors are proposed (Reason and Crepaldi, 2009) to be achieved using WSN technology. (Bruni et al., 2007; Ward et al. ,2011) provided in-service condition monitoring of train chassis rail tracks under bogies and proposed sealed protective nodes adhesive to the object being monitored.

Movable Rail Structure Monitoring

Some important infrastructure items are monitored during the movement of trains with rotating wheels. Real time condition monitoring of moving rail vehicles in block sections or station yard lines can be achieved using WSN technology. It has provided in-service condition monitoring of train chassis rail tracks under bogie and proposed sealed protective node adhesive for the monitored object. Some shock-absorbing sensors are used (Grudenet et al., 2009). In uncontrolled mobility like road transport, a sensor node on board moves freely with random motion and calibration of such WSN is difficult, While in controlled mobility like railway transportation, the Routes are predefined whether the train is received on a loop line or main line in the yard, hence a fixed limited trajectory make sensor node more confined and controllable, case is defined in (Basangi et al., 2007). However, the long-haul trains are miles long, so on board receivers need to be designed carefully. Movable monitoring may comprise the following main components.

#Mounted Body parts

These are basically structures mounted on bogie-like compartments of passenger trains, Goods wagons of freight trains and cabins of Engine. The safety of the mounted structure is very important. Any deviation from standard dimensions or train maneuvering parameters may result in loss of property or even loss of life. There is no power available on railroad wagons attached to the engines; WSN without a feed from the trains is examined (Reason et al., 2010). Daisy chain topology with WSN nodes at wagons and a main node at the engine acts as a Base station is explored by (Ghosh et al., 2011; Hutchon et al., 2005; Wolfs et al., 2006), which proposed on-board sensors that can detect substantial track defect with vertical deformations [dipped joints, loose fishplates) and lateral deformations like kinking, misalignments, twists, etc. Hot axel is a common fault in bogie wheels, which is generally detected in specially designated siding in the yard, but the same fault in the block section far away from the station can be detected with the help of WSN as performed in (Balas et al., 2010), Humidity test of the environment to detect changes inside the wagon is explored by (Shafiullah et al., 2007).

 # Running base Part

It is basically a train bogie on which the complete loaded structure is carried out from source to detonation. The bogie was designed with six or eight-wheel bogies per the requirement of the train set. Train bogie provides an asymptotic path to drive the whole train on straight and curved paths and ensures a jerk ride for passengers on board (Ward et al., 2011). They undergo rapid changes to guard and guide the train, exposing them to safety-related issues like hot bogie base or axle as executed (Mei et al., 2011). Traditionally, high temperatures of hot axles have been detected using HABD since the last decade, which generates alerts when a laser beam or RF wave detects certain threshold temperature values.

However, the heat generated due to many other sources, like leaking engine exhaust fumes and radiators, results in different temperature spots from different heat types. It also explored a set of four sensor nodes (Leung et al., 2012), three to sense bogie temperature, one to measure ambient temperature (Chen et al., 2008) placed Sensors on an axel box of the wagon, mount accelerometer and proposed a system to measure the vibration pattern on the bogie.

#Axles

Many factors contribute to torsional axel stress level over a long period, which is approximately four terms annually; axels deteriorate due to excess torsional or bending stress. Torsional stress is more critical as it may change the disturbed ideal wheel-rail contact position and the mechanical braking system. The bending stress develops mainly due to poor track quality, vehicle loading, and curve speed. A bespoke instrument with a strain gauge, telemetry system and digital signal processing is required.

#Wheels

Two basic defects developed inside the rail wheels, i.e., Flat Wheel and out of round Wheel defects, are detected by sensors on board; there are two degrees of freedom, lateral and yaw. Wireless sensors are not compact enough in hazardous conditions, as criticized in (Matsumoto et al., 2012). The piezoelectric sensors on a predefined segment of the wheel are placed. Changes in the wheel surface can be detected and produced in the form of electrical signals, such as a wear detection system introduced (Nuffer et al., 2006).

 # Braking system

Dedicated freight corridors have been developed to carry heavy haul freight transportation, including several locomotive powers. Hence WSN, WSN-based coordination of braking amongst all engines is explored (Song et al., 2010). It saves brake power and improves periodic maintenance. An air pressure sensor is attached to the Engine, a relay is used on the roof side, and an accelerometer with an ultrasonic sensor is placed on the track. The data regarding track infrastructure can be utilized for condition monitoring of the train braking system.

 # Overhead power system

The primary component is the train pantograph, which ensures continuous contact with the OHE live wire and maintains a balance between the Cetabnary and contact wires, ensuring current collection is required to drive the locomotive motors. The monitoring of force exerted between contact and the wire is to be monitored dynamically. The condition monitoring of the pantograph is performed (Boffi et al., 2006; Waki et al., 2007). Optical sensors are preferred to protect the data from electromagnetic induction produced by HT OHE live wire. Interferometric fiber is used to sense the stress between the Current collector and OHE. FBG sensor is used by (Willsch et al., 2005). UV sensors were studied by (Yilmazer et al., 2012) to detect peaks in arcing for the

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current collection. Waki also used a video camera to grasp overhead power line disturbances that had been developed by poor adjustment of the pantograph. It helps detect overheating on the powerline. The change in current in the tail transmission cable from the Pantograph to the onboard power unit is measured with a Passive magnetoelectric current sensor (Leung et al., 2012). It is also used in Solar Tracking and monitoring systems.

Results and Discussion

The multicore metallic cable is laid underground, near the track. However, there is a heavy risk of damage to the cable, which leads to data curation and power loss. Details of power loss are defined in section 4.1 below-

The resistivity varies according to the metal used in a conductor; Silver is 1.59 X 10-8 Meters, Aluminum is 2.82 X 10-8 meters, and the most popularly used Copper is 1.68 X10-8 ohm-meters.

Example: Power loss of the 3 core, aluminum, 35 square mm, cable of 1000 meter length carrying 50 Amp current flow.

$P_{(loss\text{-}kW)} = 3 \times 1000 \times 50^2 \times 2.82 \times 10^{-8} \times 1000 / 35$

$= 604285714.3 \times 10^{-8}$

$= 6.04$ KW

The table 2 below represents power calculation for typical cables used in Railway signalling systems.

Generally, bigger Railway yards have Cables laid for more than 15 Km for each Signal, Detection Point and Point Machine, which results in more multicore cables. This amounts to a huge power loss to the Electrical Power supply system.

Table 2. Power loss in signalling cables.

Sl. No.	Cable type	No. of Cores	Power loss per KM
1	Aluminium type Multicore	3	6.04 KW
2	Aluminium type Multicore	6	12.08 KW
3	Aluminium type Multicore	12	24.16 KW
4	Aluminium type Multicore	24	48.32 KW

Table 3. Comparison of Energy Consumed in Wired Method Vs Proposed method.

Railway Signalling Component	Power consumed in old Wired model (Watts)	Power consumed in proposed Model (Watts)	Power saving With Proposed model (Watts)
Signal	1056	300	1730
DP	620	380	582
Point	3150	1300	1850

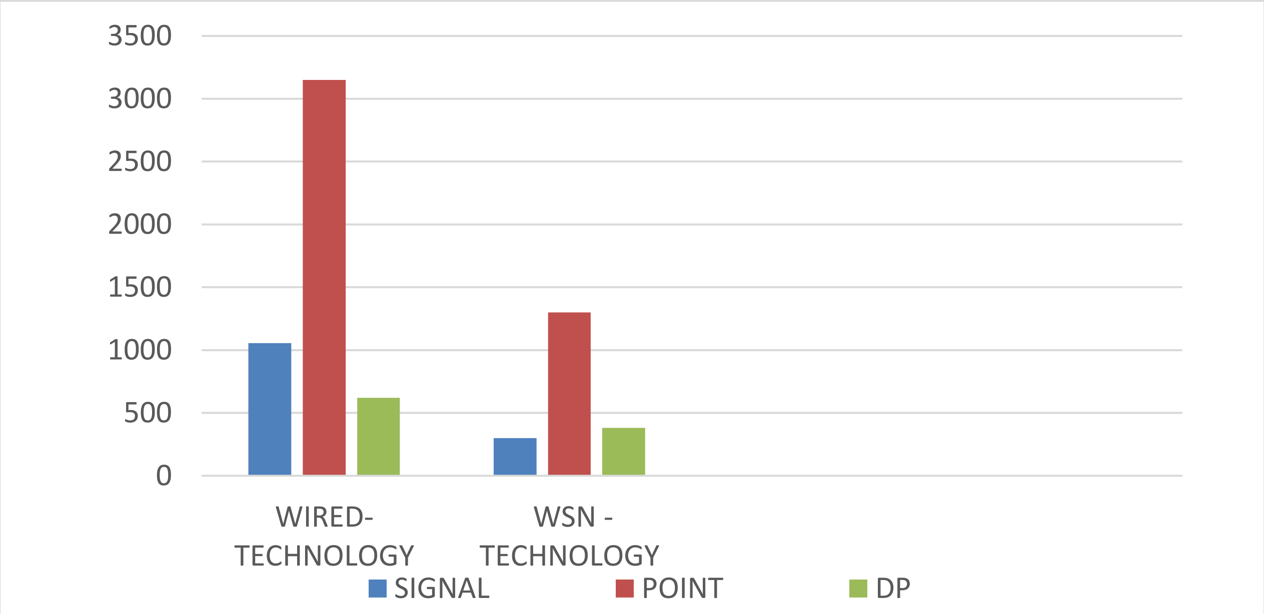

Figure 7. Power Saving with WSN-based Condition Monitoring of Railway Signaling.

#Calculation of Power Loss

Power loss in Multicore cable is equal to the product of several core N and loss in a single Core, $P_{(loss\text{-}kW)} = N \times 1000 \times I_{(A)}^2 \times \rho_{(\Omega\text{-}m)} \times l_{(M)} / A_{(sqmm)}$

The proposed method saves energy. The power consumption of three signaling components is described in Table III . a requisite amount of energy is also saved after using this technology.

Figure 7 depicts a comparison of power consumption in the underground cable method versus WSN-based condition monitoring in the operation of Signal Point and DP. As per the table, a huge amount of power is consumed, and there is a capital loss when laying the cables(Copper or aluminum) under the railway track using old wired technology. A considerable amount of power is saved with the introduction of WSN technology. The WSN-based monitoring of railway infrastructure will result in faster data transmission. It is a one-time investment and low-cost technology for the health monitoring of the railway system. There is no interference of electromagnetic interference and no requirement of trenching for cable laying in the railway yard. Reduced downtime of the train operation due to frequent cable cuts. Automatic failure management results in the system's reliability.

Conclusion

The paper reviews the range of WSN methods for condition monitoring of Railway infrastructures related to the scope of Signal and telecom, Mechanical and Civil engineering, and Electrical systems. The focus is practical technical solutions to replace wired technology with WSN technology. An engineering solution is to choose a particular type of sensor to detect object parameters, such as network topologies, considering energy-efficient protocols (Kanaujia et al., 2023). Traditionally, inspection of railway systems was carried out visually by engineers' visual and physical inspection (Kanujia et al., 2024), which was prone to errors.

Future Scope

The Same technology may be extended to other infrastructures like road transport, Toll management, Warehouses, etc. The data aggregated by the WSN server may be utilized for training and research to reduce maintenance manpower and Man-hours. The internet capacity may be utilized to extend the data to smartphones and other portable hand-held machines. These devices will generate reports anywhere in the control room, Fault Control Room, etc. The future scope is IoT (Kanujia et al., 2024), the latest trend in many other sectors like the smart grid. Wireless sensor Networks will be connected to the World Wide Web. Some other subsystems include the Train Information System, Train Management System, Freight Information System, and Integrated Passenger Information System. High-speed air Fibre may be explored for data connectivity, especially in developing the infrastructure of Bullet Train systems. WSN-based ad-hoc network may be utilized to detect whether forecast along the railway track using environment sensors (Temperature, Humidity, Air pressure, Vibrations of the track, Earth structure, etc.).

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Conflict of Interest

The author (s) of this research declare(s) that there is no conflict of interest regarding the publication of this paper.

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