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Abstract: In the range of recent years, sensing technologies has expanded widely, whereas sensor devices have become cheaper. This led to rapid expansion in condition monitoring of systems, structures, vehicles, and machinery that are using sensors. Wireless sensor networks can now be used for monitoring the railway infrastructure such as bridges, rail tracks, track beds, and many track equipment along with vehicle health monitoring such as chassis, bogies, wheels and wagons. The wireless sensors network technology for monitoring in the railway industry is used for analyzing systems, structures, vehicles, and machinery. Main focus is on practical engineering solutions, identification of sensor configurations and network topologies.

Keywords: Condition Monitoring, Decision Support Systems, Event Detection, Preventive Maintenance, Wireless Sensor Networks.

I. INTRODUCTION

Experts estimate that the railway industry will receive US$300 billion worth of global investment for development, upgrading, and expansion over the five years from 2009 [43]. Ollier [98] noted that effective management of rail infrastructure will be vital to this development, upgrading, and expansion, particularly if coupled with a move to intelligent infrastructure [39]. A key part of the management will be condition monitoring. Condition monitoring detects and identifies deterioration in structures and infrastructure before the deterioration causes a failure or prevents rail operations. In simple condition monitoring, sensors monitor the condition of a structure or machinery. If the sensor readings reach a predetermined limit or fault condition, then an alarm is activated. However, this simplistic approach may lead to a large number of false Alarms and missed failures [36]. It only provides local analysis but does not take advantage of the superior capabilities when the sensors are networked and their data processed collectively. Integrated data processing allows an overall picture of an asset’s condition to be achieved and overall condition trends to be determined [7]. Sensor devices are mounted on boards attached to the object being monitored; examples include track, bridges, or train mechanics. One or more sensors are mounted on a sensor board (node) (see also Fig. 2).

The sensor nodes communicate with the base station using a wireless transmission protocol; examples include Bluetooth and Wi-Fi. The base station collates data and transmits it to the control center server possibly through satellite or GPRS. There are variations on this setup. In some systems, the sensor nodes may communicate directly with the server rather than via the base station. In other systems, the user accesses the data directly via the base station. In recent years, networking technologies such as wireless communication and mobile ad hoc networking coupled with the technology to integrate devices have rapidly developed. The new technologies allow vast numbers of distributed sensors to be networked[5],[6],[37],[45],[60] to constantly monitor machines, systems, and environments. Wireless sensor networks (WSNs)[5],[34] are wireless networks of spatially distributed and autonomous devices.

Fig.1. WSN Setup for Railway Condition Monitoring

They use sensors to cooperatively monitor infrastructure, structures, and machinery. A typical WSN for railway applications is shown in Fig. 1. Each sensor node generally has a radio transceiver, a small microcontroller, and an energy source, usually a battery (see Section II-C for more detail). WSNs and data analytics allow the railways to turn data into intelligence [43]. They provide decision support through continuous real-time data capture and analysis to identify faults[52]. The data from distributed systems such as sensor networks are constantly monitored using classification [56],[57], prediction[55], or anomaly detection[60] to determine the current and future status of the distributed
network. Lopez-Higuera et al. [58] developed a staircase of structural health monitoring, where the higher the level, the higher the complexity and functionality. The simplest Level 1 systems detect the presence of damage without locating it, whereas Level 2 provides location information. A Level 3 system is able to grade the degree of damage and a Level 4 system can estimate the consequences of the damage and remaining service life. Finally, a Level5 system will comprise complex hardware, custom algorithms and software to allow the diagnosis and/or the prognosis and even to recommend the solution to a problem. WSN monitoring provides continuous and near real-time data acquisition and autonomous data acquisition (no supervision is required); increased frequency of monitoring compared with manual inspection; improved data accessibility, data management, and data use compared with non-networked systems as all data can be collected and processed centrally.

The ability to combine data from a wide variety of sensors; intelligent analysis of data to “predict and prevent” events using intelligent algorithms; the ability to turn data into information about the status of important structures, infrastructure and machinery a global data view that allows trending information to be determined where degradation is happening slowly over a relatively long period of time. WSN monitoring can be used to:

- Maintain process tolerances;
- Verify and protect machine, systems and process stability;
- Detect maintenance requirements;
- Minimize downtime;
- Prevent failures and save businesses money and time;
- Request maintenance based on the prediction of failure rather than maintenance running to a standard schedule or being requested following an actual failure.

There are a number of challenges with WSNs. They generate large amounts of data at rapid rates and often on an ad hoc basis. Data may be produced from multi sources that have to be fused. The systems and structures monitored using sensors often exhibit complex behavior, which is difficult to understand and interpret [12]. Hence, the data must be carefully managed to provide a view of the system status. Sensor data are very noisy and sensors themselves can become defective wherever they are installed. Sensor data may contain errors, particularly where the sensors are subject to harsh conditions as this exacerbates sensor and communication failures. Sensor networks often have to be installed in challenging environments to be able to monitor structures and infrastructure. For example, Palo [99] noted that their system had to work in extreme conditions in Sweden, with a temperature range between +25°C and −40°C and with large quantities of snow. Grudén et al. [55] mounted sensors on the train’s bogies to monitor bogie temperatures and noted that train environments are very harsh environments for electronics with high accelerations and large shocks. The sensors need to be carefully located to ensure their measurements are useful and do not replicate the measurements of other sensors, which can skew the distribution of the collected data. The type of sensor used needs to be carefully considered to ensure the maximum value and the best quality data. WSNs can use a set of homogeneous or heterogeneous sensors. Sensors are often located away from energy supplies, thus require either batteries or some form of local energy generation to power them. If there are errors in transmission across the WSN, then data may be missing. These last two points form a paradox, WSNs need to minimize energy usage yet communication needs to be maximally efficient and communication requires energy. This survey paper describes WSNs for railway condition monitoring focusing on systems described in the academic literature. In this survey, “sensor” refers to an individual device such as an accelerometer or strain gauge. “Node” refers to a whole sensor unit that comprises the sensor, power supply, a data transmitter/receiver, and a microcontroller. Section II of the survey discusses the design and range of sensor devices, Section III analyzes the network topology and transmission techniques, and Section IV reviews the sensors used in the literature to monitor railway equipment and structures. Section V draws conclusions, and Section VI examines future work in the area of railway monitoring.

II. SENSOR DESIGN

There are a number of sensors types used in railway condition monitoring for analyzing the different aspects of structures, infrastructure, and machinery. The commonly used transducers convert energy from one to another. In case of sensors design, the device converts a measured mechanical signal into an electrical signal. Most of the railway sensors fall under the umbrella type of microelectro mechanical systems (MEMS). They are cheap and efficient [5]. Sensor design requires a tradeoff between the functionality and power consumption, with functionality often coming at the cost of power. The Condition monitoring systems in railways are often deployed in remote or inaccessible locations where there is a absence of wired power supply. Hence, the sensors must receive power from either the batteries or by the local energy generation.

A. Sensor Nodes

Sensor devices are mounted on boards. These boards form a platform combining the mobile computing and wireless communication, routing and error detection with sensor devices as shown in below Fig. Many of the sensor nodes are moving toward enabling data interrogation and autonomous data processing to identify anomalies. The boards generally comprise one or more wireless sensors, a microcontroller, transceiver, data storage, and a power source.

B. Sensor Power

Many of the scientists investigated ambient energy harvesting technology for powering of the WSNs. Piezo electric materials can produce electricity in turn to respond to the mechanical strain such as the strain exerted on the track. Piezoelectric materials having the property of robustness that are able to withstand harsh environmental conditions, and capable of delivering a large amount of
energy. Piezoelectric harvesters derive energy from the vertical displacement of tracks, ties, and sleepers as they use inductive coils for harvesting. The Electromagnetic harvesters such as induction coils have the higher power density than the piezoelectric. Basically there are two built and designed prototypes of a vibration based electromagnetic system. Where the first prototype is used for the movement of the springs to generate linear motion in magnets to produce a voltage [7]. And the second prototype converts the linear motion of the wagon’s suspension coils into rotary motion then it magnifies and rectifies the motion to turn a generator.

Fig.2. Sensor Node.

III. NETWORK DESIGN

Wireless Sensor Networks (WSN) enables continuous real-time capture of a data. However, WSNs need to be able to handle the harshness of the outdoor long term condition monitoring; mostly in hostile environments and it must minimize the energy usage as the nodes are not connected to any wired power supply. They typically use lower-power sensors powered by the batteries although many authors are investigating alternative power supplies such as a local energy generation. Hence, the network to enable data capture has to be carefully designed for overcoming these factors and prevents from occurring transmission errors, missing data, or corrupted data, latency, network outages.

A. Base Station

Base station controls the sensor nodes which act as a gateway for the data transmission to a remote server. The sensor node uses a short-range of communication such as Wi-Fi or Bluetooth for transmitting the data to the base station. The base station uses long range of communication such as GPRS or satellite for transmitting the collated data back to the server at a center control. It has powerful processor and memory than the sensor nodes for allowing it for collating the data from multiple sensors. Hence, the base station requires more power.

B. Relay Nodes

Sensor nodes are energy-constrained nodes, thus they are having only a short transmission range. If they could not reach to the base station, then the higher capability of relay nodes may be used. This is a particular issue in the restricted environments such as railway tunnels, along with the length of trains or along with the railway tracks. Relay ensures the secure connectivity by relaying the data signal from a sensor node to the base station by using wireless multi hop paths via one or more relay nodes. Network nodes can be multifunctional. Hoult [4] and Shafiullah both used sensor nodes that also function like as relay nodes for transmitting the data.

C. Network Model

WSN for railway applications follows the open systems interconnection model i.e OSI model. A typical WSN has five layers in a protocol stack with the three planes [1] [2] to transmit data from the sensor nodes to the base station. The five layers from lowest to highest are the physical layer that defines how the sensors transmit their data to the network. Next is the data link layer which specifies the network topology and connects different nodes to each other. This is a key layer in railway monitoring WSNs as it may be difficult for monitoring environments such as tunnels or moving trains. The network layer does the job of routing the data through the network in form of packets. Railway WSNs are energy constrained hence, routing has to be clearly designed to work within the available energy supply. Transport layer is responsible for controlling the sending and receiving of the data. Finally, the application layer allows the application software to access the data. The size of the transmission will vary from bits in the lowest layer, segments in the transport layer, bytes and frames in the data link layer, packets in the network layer and data in the highest layer.

D. Sensor Network Topology

The Sensor Network topology is constrained by the requirements of the monitoring and by the physical environment. Therefore, they developed some models to predict the signal strength at each node in a tunnel. The natural topology choices are available for WSNs in rail applications such as star, tree, and mesh topologies. In star topology, there is a single base station that can send and receive messages to or from a number of remote sensor nodes. This topology is simple and the point-to-point connection will result in fewer transmissions and fewer collisions as it has low communication latency. A tree topology consists of hierarchy of nodes, with the root node that serves client nodes that, in turn serve other lower level nodes. In a tree topology, the nodes are grouped at each level. Messages can pass from the sensor nodes through the tree branches to the root. In case of mesh topology, any node within the network can communicate with any other node in the network that is within the transmission range.

E. Communications Medium

Various communication techniques used in WSNs in railways [3] such as inter sensor communications and sensor to base station transmission is generally short range communications. The base station transmits the gathered data back to the control center, and this will require a longrange communication. WSNs can use technologies based on the standard mobile telephony or broadband techniques such as Wi-Fi, wireless personal area networks or WiMax and ZigBee which enhances IEEE 802.15.4 [7] by including the authentication, data encryption for security, and data routing and forwarding. An important recent communication has
been GSM-R which is an adaptation of GSM telephony for railway applications. This is designed for information exchange between the different trains and control centers.

IV. MONITORING SYSTEM

The data can be monitored by searching for the thresholds known problem signatures identifying unknown events or identifying drift over a long period of time. Condition monitoring can be performed continuously or periodically. In the basic condition monitoring, the system is only capable of distinguishing between the normal and abnormal conditions. The topology of WSNs often varies over time. The monitoring can be done in two ways: fixed monitoring and movable monitoring

A. Fixed Monitoring

In fixed Monitoring wired sensors can be used for monitoring. However, wired systems are more expensive, time consuming to install, inflexible, and the trains have to be stopped during their installation [5]. Earlier the fixed WSNs were very much simple such as attaching sensor nodes to the railways to monitor the railway temperature or low-voltage warning sensors that are used to monitor the power supply to motor at points. Modern WSNs provide the semiautomatic or automatic analysis of the sensor data to examine the structural changes and to improve the durability of structures. Hence, WSN monitoring should reduce the overall maintenance cost.

1. Bridges: Bridges can suffer from the structural defects that are exacerbated by the vibrations of passing trains and constant strains. The Human inspection of bridges is very difficult and much of the structure could not be accessible. WSN enables constant monitoring of the whole structure including the internal structure of the bridge. The monitoring systems often comprise of two units. The first unit is a low power. It detects the approach of a train and wakes the second unit. The second unit generates the measurements whereas the bridge is under the load to assess the bridge’s health. To allow the structural analysis Kerrouche incorporated the optical sensors into the fabric of bridges during the bridge repairs. The Fiber Bragg grating (FBG) strain sensors are used with grooves cut in the bridge fabric such that to house the optical fibers carrying the FBG sensors [1].

2. Tunnels: Tunnels can lead to rapid corrosion damage and other defects thus, monitoring of tunnel is essential. Monitoring of tunnels has many similarities as compared to bridge monitoring. However railway tunnels are often difficult to access and inspect. An added complication of tunnel monitoring as compared with the bridge monitoring is a data transmission in a confined environment. Data generated by sensors inside the tunnel have to be transmitted using any suitable relay mechanism from the various sensor nodes to the outside. Cheekiralla coupled each pressure transducer with a microcontroller, power conditioning hardware and RF transmitter, analog-to digital converter. The base station was located near the tunnel with a RF receiver unit connected to a laptop. The laptop had a wireless modem to periodically send data to the server.

3. Rail Tracks: Railway Track monitoring systems also plays an important role in maintaining the safety of the railways. Monitoring of bridges and tunnels uses sensors for identifying and analyzing defects in large structures. In contrast track monitoring also involves identifying and analyzing defects in long narrow metal rails. Tracks can crack and displace like bridges but can also twist and tilt. Filograno used FBG sensors for train identification, axle counting, speed and acceleration detection, wheel imperfection monitoring, and dynamic load calculation by placing them into different positions on the track. Condition monitoring protects both trains and track, also increases the track and train reliability and allows a repair to be scheduled.

B. Movable Monitoring

Wireless Sensor Networks are able to monitor the condition of a range of mechanics, systems and environments using on-board sensors to measure the different parameters such as temperature, shocks, tilts, and humidity. Measurements can be taken during normal train service that allows in-service condition monitoring of the train chassis and mechanics and the rail track that the train is running on. The sensor nodes used for movable monitoring are oftenly mounted on the train bogies or carriages. These locations are susceptible to high levels of vibration thus, the sensor nodes have to be protected.

1. Train Engines, Passenger Carriages and Wagons: The Wagon or container failure could lead to damage of the rail infrastructure or the environment and could be even result in loss of life thus, it is important that the wagons, containers, and their respective contents are also monitored. Additionally, the freight trains use unpowered and unwired railroad wagons, thus an on-board WSN can analyze the condition of the freight wagons without power. In engine, the sensors analyzed the health of locomotive engines by measuring their parameters, including water temperature, oil temperature, engine temperature; switch statuses, fans statuses, and rotations per minute and traction motor currents.

2. Train Bogies: The train bogies perform a number of tasks, mainly to guide the train on both straight and curved tracks, to safeguard the train’s dynamic stability, and to provide a comfortable ride for the passengers. Most commercial condition monitoring systems for rail vehicles analyze the bogie system. Train axles and bogies run hot during train journeys. Hence, it is possible to identify faults such as hot wheels caused by brake drag or extraneous heat sources such as leaking engine exhaust fumes. Mei and Li and Tsunashima proposed systems for the measurement of bogie vibrations and mounted accelerometers on the bogies and also placed them on axle boxes of train carriages to measure the lateral acceleration. Mei and Li used robust inertia sensors mounted onto the bogie frame to monitor vibrations and ground.
3. Train Axles and Train Wheels: As generating excess heat, excess strains may be exerted on axles that causing deterioration. The number of factors affecting the stress means that establishing a baseline to create a model necessitates measuring the torsional axle stress levels over a long term, ideally over the four seasons of a year [6]. Similarly, the axle bending stress levels always vary due to the track quality, vehicle loading, braking and traction effects and curving speeds. Train wheels wear over time and can also suffer flat wheels and out-of-round wheels. Wheel problems can also be detected by the sensors on board and the train analyzing the wheel surfaces or analyzing forces on the train bogies and wheels. The wheel-sets and bogie each have two degrees of freedom. The fused data from speed sensors and piezoelectric accelerometers attached to train wheels [7]. Using data modelling, they were able to detect skidding if the integral of the acceleration measured by the accelerometer differed from the speed of the carriage. They also calculated the wheel adherence as a function of the carriage weight, carriage velocity, brake cylinder pressure, and the skid amount from the skid model.

V. CONCLUSION

Accidents are the major causes for traumatic injuries. Wireless sensor network which continuously monitors the railway track through the sensors and detect any abnormality in the track. The sensor nodes are equipped with sensors that can sense the vibration in the railway track due a coming train. The geographical positioning sensors are placed on the trains. These sensors send the train’s geographic location. Until recently, railway inspection has been visually performed, but this only examines objects superficially and intermittently, and the analysis needs to be interpreted by an expert, who can be subjective. Sensors are objective and can provide data from the entire object (including internally) to allow the whole object’s health to be fully assessed and to analyze its durability and remaining life time. A broad range of sensors are used in railway monitoring to provide an extensive range of data and allow monitoring of different structures, vehicles and machinery. The main challenge for WSNs in railway applications is determining the best measurement technologies to use. The WSN must be reliable and accurate to enable effective condition monitoring in harsh and inaccessible environments but must also be cost effective. It must be possible to translate the sensor data from the WSN into relevant and clear information to enable decision support in the railway infrastructure maintenance lifecycle. The paper divides railway condition monitoring into fixed monitoring for immobile infrastructures such as bridges, tunnels, tracks and associated equipment, and movable monitoring for vehicles and their mechanics. Fixed monitoring uses sensors to monitor vibrations, stresses and sound waves passed through structures (acoustics) caused by passing trains (short term monitoring) and also changes in stresses, pressures and sound waves passed through structures over the longer term (long-term monitoring). One of the key issues for fixed monitoring is network topology.

The topology is constrained by the requirements of the monitoring and by the physical environment. Sensor nodes can be arranged in either an ad hoc or a preplanned configuration. Determining the optimum node placement is a complex task and often requires a tradeoff. The network configuration can be optimized against a number of different constraints. A network may minimize relay nodes, may need to ensure a minimum level of service (include a certain level of redundancy), minimize energy usage to preserve battery life, or may need to ensure accessibility of the nodes. The communication mechanisms, for example, Bluetooth, Wi-Fi, GSM, or satellite also need to be evaluated to ensure coverage and reliability and the routing protocol to ensure data is successfully transmitted from sensor node to base station to control center. Another issue is powering the sensors as fixed monitoring often requires placing sensor nodes in inaccessible locations, for example, in tunnels, on bridge trusses, or in rail track beds. Many sensors use batteries but replacing batteries in inaccessible locations may not be possible. Authors have considered ambient energy harvesting such as converting vibrations caused by passing trains into energy or using solar power. These energy harvesters may be accompanied with energy storage such as capacitors. Authors have also reduced sensor energy usage using event detection where a single cheap sensor detects approaching trains and wakes a larger sensor network to commence taking measurements of a bridge structure.

Movable monitoring uses sensors to monitor temperatures, vibrations, stresses, forces, currents, and sound waves in vehicles and their mechanics particularly bogies and chassis. These locations are susceptible to high levels of vibration and EMI; thus, the sensors have to be rugged or protected. One of the key issues with movable sensor monitoring is communication due to the mobility of the sensors. Movable rail monitoring either transmits the data from the movable nodes to a static node when the static node is in range, or the movable nodes form a network with a base station within the network which transmits the data over a suitable mechanism, such as satellite or GSM. This paper focuses on the sensor technology used to generate condition monitoring data to enable practical condition monitoring systems. These data must be managed and turned into useful information to generate useful information. Condition monitoring systems must store large quantities of data to build models for analysis. The data must be validated first to ensure that they are correct and error-free (sensor faults, noise, null values, communication errors, etc.). This process may even be performed in the sensor node’s microcontroller; thus, only valid data are transmitted thus minimizing the transmission load. Algorithms need to be robust as WSN data is noisy, can be intermittent, may contain errors, has many interdependencies and the data volume is very high. The WSN data can also be stored and analyzed over longer time periods to identify long term progressive faults such as a slowly developing crack. Some systems incorporate contextual data that describe the ambient conditions, which will affect the object monitored.
These contextual data can be built into models to improve the coverage and accuracy of the model and to help provide explanation of condition monitoring decisions. Elia et al. [44] included: train speed, position along the line (longitude and latitude from GPS system) and wind speed and direction when analyzing bogie vibrations, whereas Rabatel et al. included structural criteria (route) and environmental criteria (weather, travel characteristics, travel duration) when analyzing bogie temperatures. These data can then be processed in a number of different ways to generate information. Once data are collated, they can be analyzed using robust algorithms to identify faults in near real-time.

VI. RESULTS

VII. REFERENCES


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