Prognostics and Engine Health Management of Vehicle using Automotive Sensor Systems

Deepali A. Dekate[1]

[1]PVPIT, Department of Electronics & Telecommunication,
University of Pune, Maharashtra, India
deepali_dekate@rediffmail.com

Abstract: ***Currently, automotive electronics and sensor systems are partially integrated. Therefore, these are major issues in providing comfort, safety and communication. Prognostics and Health Management (PHM) includes certain technologies and methods that would access the reliability of the product in its actual life cycle conditions, in order to determine the reasons of failure and mitigates system risk. Today, the development of diagnostic are prognostics techniques, which use accurate degradation procedures by appropriate sensor selection, fusion, still remains a vital & issue of prime important. Also, an unified monitoring & prognostics approach that prevents failure by analyzing degradation features is suggested as a general framework to overcome the unsolved issues and challenges. Thus, PHM is an enabling discipline consisting of technologies and methods to assess the reliability of a product in its actual life cycle conditions to determine the advent of failure and mitigate system risk. Sensor system is needed for PHM to monitor environmental, operational and performance-related characteristics. The gathered data can be analyzed to assess product health and predict remaining life.***

Keywords: Diagnostics, Sensor Fusion, Sensor Systems, Prognostics and Health Management (PHM).

1. Introduction

Diagnostics – It is the process of determine the state/ability of an item to perform its function(s).

Prognostics – It is predictive diagnostics which includes determining the remaining life or the time span of proper operation of as item.

Health management – It is the capability to make appropriate decisions about operational use/system configuration and maintenance actions based on diagnostics/prognostics information, available resources, and operational demand.

Basically, a large number of systems under operation such as vehicle systems may experience gradual degradation with their physical properties or performance. In order to meet the reliability requirements for these systems, maintenance is usually conducted before the system components actually need to be replaced, or only after the system has failed. Also, traditional maintenance measures are either purely reactive or blindly proactive.

Further, the reliability and safety of the critical automotive components, such as anti-lock braking system, fuel injection system and alarm system, are among the most significant concerns in the automotive industry.

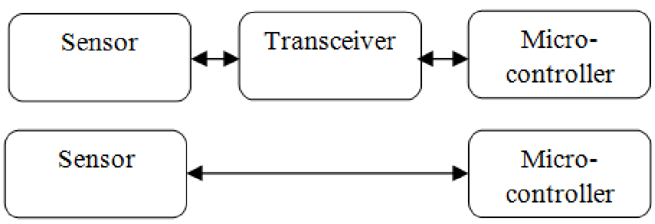

Figure 1: Sensor Communication.

Now as automotive systems becomes more complex, the reliability of these critical parts is important concern in improving the overall system reliability and quality of the system functionality. Nowadays, condition based maintenance, which depend on on-board monitoring, has been of more importance. The objective of condition-based monitoring is to make a time based maintenance decision based on the update degradation information of each system from the sensors and other components.

The feasibility of this type of maintenance has been increased with the availability of the accurate sensors, which will provide continuously, the update information about degradation at lower cost and embedded systems that have powerful computational capability. Also, an advanced technique utilized in condition-based maintenance is prognosis, which has importance in predicting the remaining useful life of a component or a system, via on-board sensing, processing of information data and other associated algorithms.

Prognostics and health management (PHM) generally combines sensing and interpretation of environmental, operational, and performance-related parameters to assess the health of a product and predict remaining useful life. Assessing the health of product provides information that can be used to meet several critical goals:

1. Providing advance warning of failures.

2. Minimizing unscheduled maintenance, extending maintenance cycles, and maintaining effectiveness through timely repair action.

3. Reducing the life cycle cost of equipment by decreasing the inspection cost, downtime and inventory.

4. Improving qualification and assisting in the design and logistical support of fielded and future system.

Figure 2: Detection, Diagnostic and Prognostic

Basically, the ability to provide electronic diagnostics information for various vehicle systems is well known. In comparison, the nature of the data available during normal vehicle operation is less known. This data can be utilized using appropriate algorithms to provide prognostics to indicate the future system problems.

A challenge with vehicle utilizing complicated systems it how to extract diagnostics data, evaluate it to expose possible issues and determine how to fix these issues. Also, it is vital to know the general condition of a vehicle before on a critical or dangerous mission.

Further, the effectiveness of prognostics is mainly dependant on the sensors capability of processing the data and of identifying the failure indicators prior to the actual failure. As this capability progresses, the application of areas, especially in the development of the modern vehicle electronic components and sensor systems.

This paper addresses the probable concerns of failure prevention in vehicle electronics and sensor systems and suggested a unified monitoring and prognostics approach that prevents failures by analyzing degradation features.

Key positives of PHM

- Fault detection.
- Fault isolation.
- Advanced diagnostics.
- Prognostics/condition-based maintenance.
- Useful life remaining prediction.
- Component life tracking.
- Performance degradation trending.
- Selective fault reporting.
  -only tells operator what needs to be known immediately.
  -inform maintenance of the rest.
- Aids in decision making and resource management (operation and maintenance).
- Fault accommodation- reconfiguration, operational execution.
- Information reasoners.

Merits of PHM

- Enhance system availability, mission reliability, and safety.
- Reduce maintenance manpower, spares, and repair costs.
- Eliminate scheduled inspections.
- Condition-based removals.
- Maximize lead time for maintenance and parts procurement.
- Automatically isolate faults.
- Eliminate/Minimize false alarms.
- Provide real time notification of an upcoming maintenance event.
- Catch potentially catastrophic failures before they occur.
- Detect incipient faults and monitor until just prior to failure.
- Opportunistic maintenance to reduce down time.

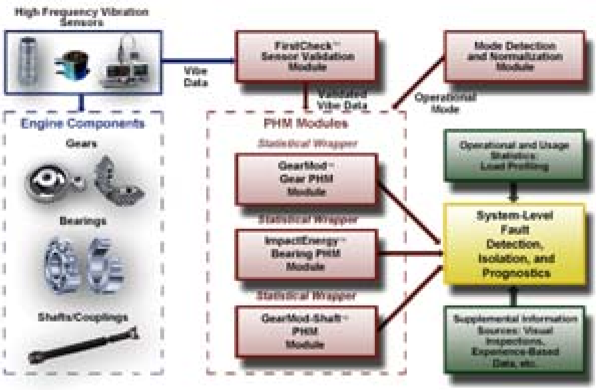

Figure 3: PHM module

2. PHM Implementation

- The ability to monitor has been around for a longer time, but now we have the technology to really do something with it.
  - Ability to predict future health status.
  - Ability to anticipate problems and required actions.
  - Advanced algorithms.
- Evolution of diagnostic capabilities coupled with the added functions, capabilities and benefits offered by new technologies,
  - Maximize benefit from limited specialized sensors
  - Take max advantage of the 'smart' digital end product.
- PHM is designed into 'end product'.
- Reaches across the entire product-system of 'Systems Architecture and Design'.
- New technologies are being researched and released.
- Hardware & software utilized for implementation.

In this paper the consideration for sensor system selection for PHM applications, including the parameters to be measured, the performance needs, the electrical and physical attributed, reliability, and cost of the sensor system, are discussed. The state of art of the sensor system for PHM and the emerging trends in technologies of sensor system for PHM are presented.

This paper addresses various realistic issues related with failure prevention in vehicle electronics and sensor systems.

3. Sensor systems

The control of the modern system basically, requires more accuracy, diagnosis, reliability, availability and durability. Now, the values to be sensed should usually be measured as close as possible to the process to be controlled.

From an ECU point of view, one can classify two types of sensors: the offshore sensors and local sensors. The offshore sensors should sense the physical values at a location away from the control unit. It may require the power supply and communication with the sensor. For the case of local sensors, the power supply and communication link are embedded inside the ECU.

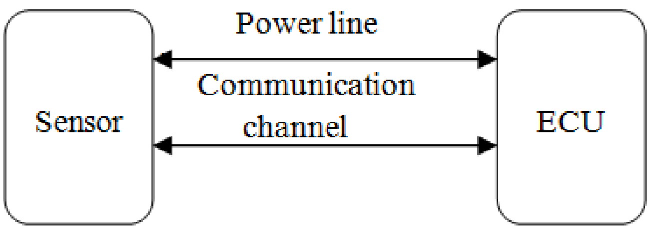

Figure 4: Offshore Sensor

To conform the information coming from a sensor, the complete loop must be investigated the power-line, the sensor itself and the communication channel. In past years, unidirectional allows the transmission of sensor data to the ECU was the only requirement for the data connection to a sensor element with increased functionality sensor systems bi-directional communication is required. This allows changing the mode of the sensor during operation, in order to allow the variation of the parameters, for the selection of different signal sources.

Figure 5: Schematic for the transmitters and receivers of a sensor data channel.

A generic sensor system will typically have sensing elements, onboard analog-to-digital converters, onboard memory, embedded computational capabilities, data transmission and a power source of supply. The internal sensor element, onboard memory and onboard processers are typical internal devices. The external memory, computer and external sensor module are typically external devices.

The power sources can be internal, external, or a combination of both, and they provide power for the entire sensor system. Not every PHM sensor system will necessarily contain all these elements and not all sensor system is suitable for the implementation of the PHM. The user needs to understand the requirements of the PHM application to choose an appropriate sensor system.

4. Sensor system performance

The common performance attributes of the sensor systems are,

- Measurement range.
- Dynamic range.
- Accuracy.
- Sensitivity.
- Repeatability.
- Resolution.
- Frequency response.
- Hysteresis.
- Linearity.
- Response time.
- Stabilization time.
- Sampling rate.

5. A defined Sensor Fusion approach

Basically, the functional relationship between the degradation rate and the operating conditions is determined by modeling the data obtained from the sensors, which enhances the prognostic capabilities with time-varying operating conditions.

This approach consist of following several steps,

- Develop a sensor technology and methodology for better on-board degradation detection.
- Develop a procedure to correlate the degradation features to the underlying the damage.
- Select the degradation features that reflect the damage efficiently.
- To search and find out the evolution of the optimally selected features under various operating conditions.
- To enhance the applicability of current predictive tools, in order to predict the remaining life of the components.

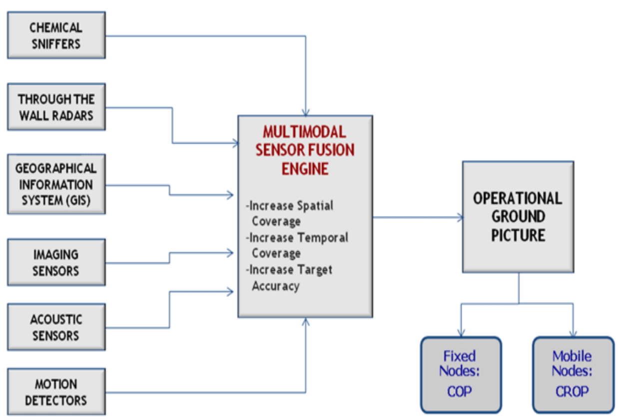

Figure 6: Multimodal Sensor Fusion Engine

Vehicle condition monitoring is a decision-making problem; particular action needs to be executed from observation regarding a certain phenomenon. Because of the diversity of failure type, we usually measure many kinds of quantities that promise to be effective to different failure. Measurement taken using single sources are not fully reliable and are often incomplete due to operating range and limitations that characterize each sensor.

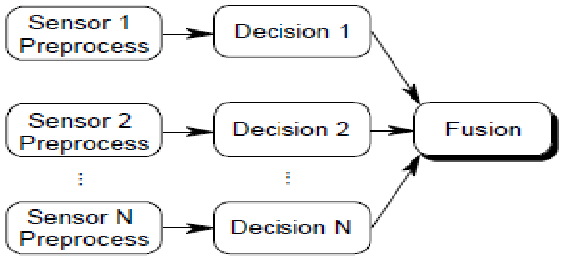

Figure 7: Distributed Fusion Structure

In vehicle condition monitoring, vibration, acoustics and oil detection sensor are applied. However, sensors reading are uncertain because internal and external sources add noise or cause malfunction of the sensor. Consequently, the system's diagnosis results are affected. It is therefore desirable to find a way to avert the negative effects of the shortcoming of the sensors.

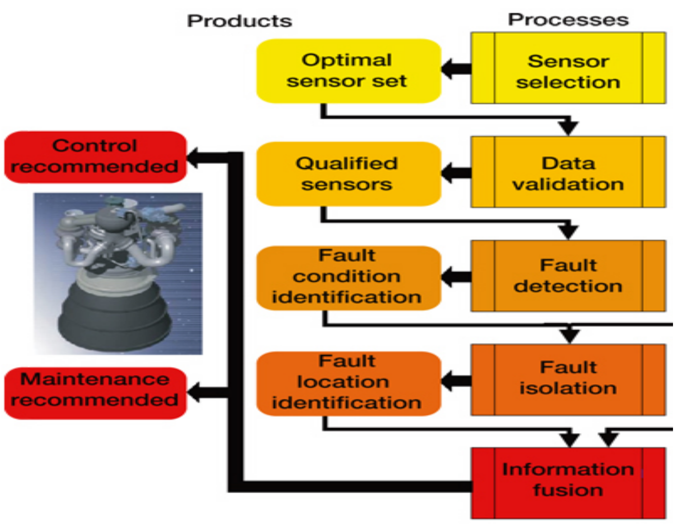

Figure 8: Relation between Product and Processes

Although sensor signals are inevitably corrupted by noise, yet even when two or more sensors are operating within their limits, fusing their measurements can provide a more robust or reliable reading than that provided by any one sensor. This is because signals tend to be correlated between sensors whereas noise is uncorrelated. It is also important to account for the sources of uncertainty and propagate them to the final diagnosis of the system state. Data fusing seeks to combine data from multiple sensors to perform inferences that may not be possible from a single sensor.

In distributed fusion structure, each sensor gives its own decision and the fusion is based on decision rather than raw information, so data transmission load is greatly reduced.

6. The Diagnostics and Prognostics system

This system is designed to collect, process, store the information from the vehicle's bus.

1. Collecting the data:

Data can be collected from following sources,

- Proprietary network traffic -

This is normal data found on vehicle during ordinary operation and does not represent any requests made from the diagnostics system. In order to use this type of traffic, agreements will need with ECM manufacturer for disclosure of the translation tables.

- Diagnostics network traffic -

Diagnostics information can be collected from the diagnostics system as described below,

Diagnostic data can be emissions or non-emissions related. It seems that related data and trouble codes can be useful where the vehicle emission are nor a large concern.

- Requested network traffic -

The networks discussed provide the information on a by request or periodic basic. This can be emissions or non-emissions related. It can include items such as temperatures, speed, and pressure and fluid levels.

2. Processing the data:

The data collected will be processed according to the information including prescribed priority, compiled repair data bases. The priority and action desired are different, if a vehicle is been test driven after a repair, in dangerous area.

3. Distributing the information:

Once the information is collected and results are calculated, it becomes important to distribute this to those who can use this information. It is important that the operators do not have an information overload and must be properly prioritized.

7. Diagnosis systems

Each module provides diagnostic information to a particular module, usually the ECU, with contact to the outside world through a standard connector.

This connector is used not only for diagnostics purpose but also to reprogram the FLASH memory in various modules and to collect data for prognostics using the normal data traffic flow.

8. Diagnostics control module modes

A module can be in two modes,

1. Standard – the module and vehicle operate normally and network traffic consists of ordinary data needed for the operation of a vehicle. Data present on the various buses is useful for prognostics. This data is useful to manufacturer.

2. Diagnostics – the module is put into the diagnostics mode by a scan tool that will make queries of the electronic control module. The electronic control module will send information to the scan tool, concerning problems with the vehicle.

9. Diagnostics protocol

1. Public diagnostics protocols: Diagnostics can use a government mandated standard such as OBDII (On-board Diagnostics version II) as specified by CARB (California Air Resources Board).These are normally concerned with vehicle emissions. The method and information needed to access and decipher them is public knowledge.

2. Proprietary diagnostic protocols: Diagnostics not prescribed by the government are usually proprietary to the vehicle or sub-systems manufacturer. Each vehicle manufacturer or major supplier has its own proprietary diagnosis system and this information is usually kept confidential.

10. On-Board Diagnostics Version II:

CARB specified that all automobiles sold in California after 1994 must provide a system doe generic reading of emissions related trouble codes.

OBDII specifies a vehicle warning light called MIL (malfunction indication lamp). This light displays a message similar to "service Engine Soon" to the vehicle operator. Pending errors will not illuminate the MIL but are available to the scan tool. If a pending error code exists for predetermined time duration, it will be turned into a DTC (Diagnostic Trouble Codes) and the MIL will be turned on.

The scan tool receives these error codes and displays the meaning of the codes depending on the scan tool design.

11. Diagnostic Trouble code (DTC)

Diagnostics are standard messages sent to the Duetch connector, when an affected module declares a fault. These messages will be requested by a special scan tool with the appropriate software, to send and receive messages.

A DTC consist of,

- Suspect Parameter Number (SPN)
- Failure Mode Identifier (FMI)
- Occurrence Count (OC)
- Conversion Method of SPN (CM)

1. SPN – This is the number of the fault. Examples are Brake Switch (597), Injector Cylinder (651).

2. FMI- It indicates the nature of the fault. This includes Data valid, Data Erratic, voltage high/low/shorted and circuit open.

3. OC – This value is the number of timer the fault has occurred. A fault will normally occurs at a certain number of times before it turns into a DTC and reported as such. This is called a pending code.

Figure 9: DTC Scan Tool

The ECUs test using algorithms on the data receiver from devices such as oxygen sensors to determine, if they are defective. These error algorithms will check a number of times, to ensure can result from insufficient operating temperatures, few driving cycles or spurious signals. In case of false errors, the pending code will be erased or the occurrence count lowered and the testing process restarted. A DTC is created when the defect will result in emissions greater than 150% of the allowed levels.

4. CM – It indicates conversion method of SPN. This is one-bit and is usually '0'.

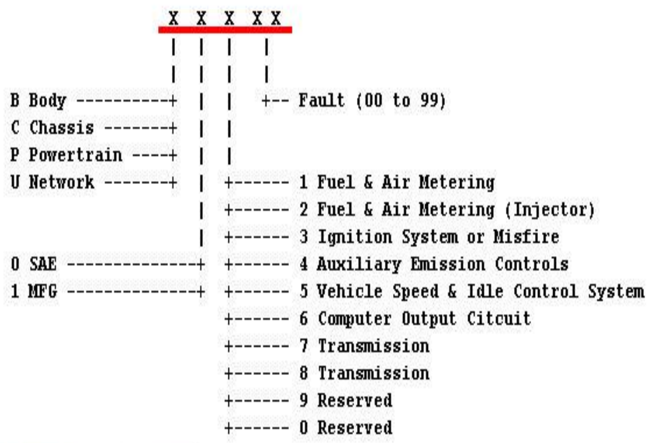

Figure 10: DTC Frame

Next, an example of a DTC is this one, with a problem with the vehicle's accelerator pedal,

- SPN = 91……...(Accelerator pedal position)
- FMI =3……(Pedal voltage is above normal)
- OC =5……...(Trouble has occurred 5 times)
- CM =0…(Use version 4 of SPN conversion)

Diagnostics Messages:

Diagnostic messages are the messages sent to the vehicle system to request certain information. Here, the examples are,

- DM1: Send all active DTCs and MIL status.
- DM2: Sends previously active DTCs.
- DM5: Report diagnostic readiness.
- DM11: Clear/reset all active DTCs.
- DM14: Access ECU module memory.

Malfunction Indication Lamp (MIL) -

The ubiquitous “service Engine Soon” lamp has been useful in some vehicles to provide additional information. In each of these conditions, a DTC will also be issued.

Figure 11: A typical MIL view

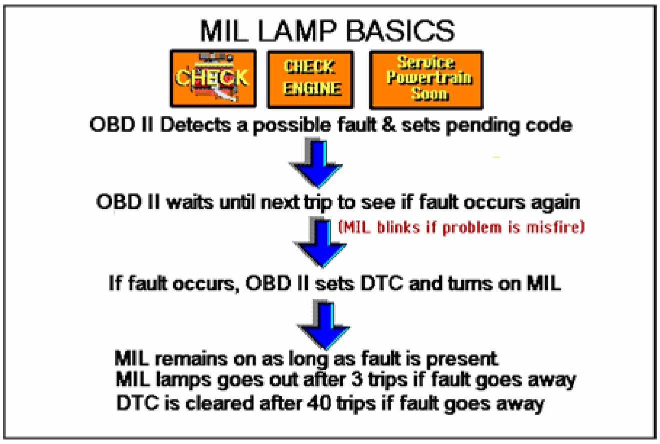

Figure 12: MIL Lamp Basics

Red Stop Lamp - A DTC has been issued that is catastrophic or a hard failure and so severe the vehicle should be stopped immediately.

Protect Lamp - This lamp is used to alert the operator to a problem that in not electronic in nature. These are usually of a mechanical nature. These are usually of a mechanical nature such as high engine temperature.

12. Needs and challenges

Basically, monitoring a component’s degradation and predicting the evolution of this degradation allows us to prevent the degradation and unexpected failures from occurring usually in practice, difficulties in implementing these techniques, arise due to the lack of understanding of the underlying component degradation. So, in order to overcome these difficulties, the study of failure conditions is to be done. This study will explore the root cause of failures, such as fatigue, fracture, wear and corrosion.

Recently, the research on fundamental understanding of the underlying degradation is being conducted for many critical electronic components. However, most of these techniques for physical damage detection was developed based on the laboratory-based instrumentation and hence cannot be used for embedded or remove prognostics. Also, the other challenge in prognostics is detecting the component degradation that has very little damage, but it is critical for just-in-time failure prevention.

Thus, to build sensors that can detect a small damage, into the electronic module will be of significant practical value for the advancement of prognostics.

Next, algorithms for degradation detection and prediction are developed, which are based on degradation features from sensor signals. However the current maintenance approaches are in relation with failure diagnosis, which can be used as a recent approach for investigation of cause of a failure. Sometimes, an engine controller can indicate a fault but may not provide the measure of the actual damage. To reduce the risk of failure, maintenance is to be carried out in a more proactive way.

Further, the accuracy of the existing prognostics algorithms developed based on these older techniques may not be satisfactory due to significant uncertainties, and our judgment in degradation rate of a component depends on operating conditions. The prognostics algorithms that ignores time-varying operating conditions, will lead to significant prediction errors. In order to overcome this, understanding of the physics of the underlying degradation is to be done, and a methodology that correlates the degradation features to the physical damage and also feature fusion are need to be developed.

Also, as a further enhancement, using the information regarding the degradation rate which is a function of the operating conditions, will enable the current predictive tools, in order to deal with prognostics that involves time-varying operating conditions.

13. Difference between Diagnostics and Prognostics

Diagnostics	Prognostics
It is the process of determining the state or ability of an operation to perform its function	It includes determining the remaining life or the time span of an operation
Only fault detection	Fault detection and isolation
No condition based maintenance	Condition based maintenance
No prediction of remaining useful life.	Prediction of remaining useful life.
No tracking of component life	Tracking of component life
No performance degradation trending	Performance degradation trending
No fault reporting	Selective fault reporting
Not helpful in decision making and resource management	Aids in decision making and resource management
No fault accommodation and reconfiguration	Fault accommodation and reconfiguration
No system availability and mission reliability	Enhanced system availability and mission reliability
No change in maintenance man power and repair costs	Reduced maintenance man power and repair costs
Scheduled inspection is required.	Eliminate scheduled inspection
No condition based removals	Condition based removals
No fault isolation	Automatically isolates faults
It will not Provide real time notification of an upcoming maintenance events	Provide real time notification of an upcoming maintenance events
No Catching of potentially catastrophic failures before the occur.	Catch potentially catastrophic failures before the occur.
No Detection of incipient faults prior to failure.	Detect incipient faults and monitor until just prior to failure.
No opportunistic maintenance.	Opportunistic maintenance to reduce downtime.

Difference between Public Diagnostic Protocol and Proprietary Diagnostic Protocol

Public Diagnostic Protocol	Proprietary Diagnostic Protocol
Use of government mandated standards.	No standards are mandated by government
Use of OBD concepts	OBD concepts are not used
It is concerned with vehicle emissions.	Not concerned with vehicle emissions.
This protocol is available to all.	This protocol is not available to all.
No information is kept confidential.	All the information is confidential

14. Conclusion

The innovative approach proposed in this paper integrates a feature-based smart prognostics method that is helpful in predicting component degradation. This proposed integration will bring an innovation to predict failures of critical electronics components for next-generation automotive electronic systems.

Also, the various performance parameters related to diagnostics and prognostics are discussed and compared. This contribution will also put lights on advancements on reliability theory and which will further advance the current prognostics capabilities via on-board monitoring.

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Author Profile

Deepali A. Dekate was awarded Bachelor degree in Electronics Engineering from University of Nagpur and currently pursuing Master's degree in Electronics & Telecommunication with specialization in VLSI & Embedded Systems. Her research area includes automotive diagnostics & prognostics, network prognostics, engine health management and onboard/remote diagnosis technologies.