Incorporating predictive maintenance algorithms to anticipate maintenance needs based on sensor data

Introduction

In densely populated areas as in cities, the availability of parking spaces is often less than the availability of vehicles which leads to a shortage of parking space . Studies showed that in worldwide traffic dense environment, 30–50% of the drivers look for free parking space . Based on previous studies, drivers use between 3.5 and 14 min to find a parking space . Examples of consequences are: the frustration of drivers, accidents, lost business opportunities, congestion and increased air pollution. Congestion can be observed when traffic density is increased, which is observed during peak traffic periods . A city with a population of ∼50,000 inhabitants contains an average of 250 parking spaces in a parking lot which would generate an annual cost of ∼216,000 US dollars .

Reviews on smart parking sensors and technologies

Smart parking tools	[19]	[24]	[18]	[22]	[21]	[20]	[23]
infrared sensors	•	•	•			•	•
ultrasonic sensors	•	•	•		•	•	•
inductive loop detectors	•	•	•				
parking guidance systems		•	•			•	
radio frequency tags		•	•		•	•	
magnetometer	•	•	•			•	•
microwave radar	•	•					
GPS		•	•	•	•		
machine vision	•	•	•	•	•	•	•
vehicular *ad hoc* networks				•	•		
multi-agent systems		•	•	•		•	
neural network					•	•	
fuzzy logic				•	•		

Existing smart parking applications were searched using mobile application stores and web search engines. There are hundreds of parking applications available in the mobile application store. However, in this paper parking applications which provide real-time parking occupancy information and navigational directions to a reserved parking space are selected. All the referred applications support reservation which is possible only in closed parking lots. Smart parking applications also provide navigational directions to the reserved parking space in a closed parking lot.

Smart parking sensors

There are various sensors which facilitate in detecting parking occupancy information and these are mentioned in the following sections. Sensors are one of the common tools which were widely tested in several previous literatures. Descriptions of these sensors are mentioned in the following sections

Passive infrared sensor

These sensors detect changes in energy and when a vehicle occupies a parking space, these sensors identify the change in energy and detect occupancy [25, 26]. The sensor observes a change in energy when a vehicle is placed or a person standing above the sensor. Based on the amount of energy change, it can be used to isolate outliers. However, these sensors are sensitive to environment and they would not be accurate when there is snow or rain. Passive infrared sensors should be placed under the ground or on the ceiling. Therefore, they require high investment for procurement and maintenance of these sensors. These sensors would be suitable for closed parking lots which are inside buildings and are not suitable for outdoor open parking lots.

Active infrared sensor

These sensors would emit infrared energy and detect any object or vehicle by the amount of energy reflected [25, 26]. They are also sensitive to environmental changes such as rain or snow. Therefore, they should be placed in all the parking spaces and require high investment and maintenance. Deploying sensors in all the parking spaces would help to attain parking occupancy status. These sensors are usually placed overhead and are suitable for indoor closed parking lots. As these sensors are sensitive to environmental changes, it is not suitable to open parking lots.

Ultrasonic sensor

These sensors would emit sound waves between 25 and 50 kHz and detect objects based on reflected energy. They are usually mounted on the ceiling and are sensitive to environmental changes such as rain and snow [27]. Therefore, they are suitable for indoor parking lots rather than open parking lots. Based on the distance at which waves are reflected it can distinguish between a vehicle and a person. In order to get parking occupancy status, these sensors should be placed on top of every parking space. These sensors would be available for low cost but installation and maintenance of multiple sensors and connecting them to a grid would be expensive in the long run. Wireless ultrasonic sensors are also used to gather parking occupancy information. They are connected using wireless sensor networks such as ZigBee protocol or other similar networks [28]. However, wireless sensors involve periodic maintenance costs. In another study, ultrasonic sensors are used on a drive-by vehicle and parking occupancy information is collected at regular periods [29]. Real-time parking occupancy information cannot be attained using the drive-by vehicle.

Inductive loop detectors

These detectors are installed using underground wiring system and they use principles of electromagnetism to detect the presence of a vehicle [25]. They are commonly used at the entrance and exit to know the count of the vehicles which can be used to know the availability of parking spaces. These detectors are expensive to install and maintain [26] and they are commonly used in indoor parking lots to get the count of available parking spaces. An accurate count of vehicles would be provided using these detectors in a closed parking lot and these are in use at multiple commercial parking lots. However, individual parking occupancy status cannot be attained using inductive loop detectors.

parking guidance systems

Parking guidance systems is another smart parking system which provides information about number of parking spaces available on display screens and these are usually placed near the parking lots as the driver can see and decide the parking space to occupy [28, 30]. Inductive loop detectors or visual camera can be used at the entrance and exit of a parking lot to know the count of the vehicles in a parking lot which would be displayed on the screens. However, they do not guide the driver to a particular parking space which is found empty. Therefore, there is every possibility that the driver would cruise for several minutes before finding an empty space to occupy. The driver can make a decision about the parking lot only after viewing the display screens [27]. Since sensors or visual cameras would be deployed only to get the count of vehicles, the expenditure for installation and maintenance would be minimal making them suitable for open parking lots.

Radio-frequency identification (RFID)

Radio frequency tags are used to identify vehicle. Each vehicle will be given a radio frequency tag for identification. A transceiver and antenna would be installed at the entrance of a parking lot to identify the tag and allow the vehicle to occupy a parking lot [31]. These are suited for closed and indoor parking lots which are controlled. It is not suitable for an open parking lot as they are freely available. RFID is used to authorise movement of vehicles at a parking lot. However, it neither provides individual parking occupancy status nor facilitates the driver in finding a vacant parking space.

Magnetometer

These sensors detect the presence of vehicle by detecting the change in electromagnetic field. They need to be in close proximity to the vehicle, therefore, they are placed beneath the surface. They are not sensitive to the environment [25]. These are suitable for both open and closed parking lots. There are wireless sensors with a battery life time of few years which can be used to detect real-time parking occupancy information. The sensors should be placed under every parking space to know the occupancy of parking spaces. However, it is expensive to install and maintain these sensors on a large scale.

Microwave radar

A microwave radar transmits microwave beam and based on the reflected signal it estimates the velocity of the moving target. However, it does not detect stationary objects. In order to eliminate this restriction, dual microwave Doppler radar can be used to detect both moving and stationary vehicles [32]. These can be mounted or placed beneath the surface for vehicle detection. These radars are not sensitive to environment and can be used in open and closed parking lots. They should be placed in every parking space to detect parking occupancy status making them expensive to install and maintain these microwave radars on a large scale.

Predictive maintenance :

The introduction of Industry 4.0, new technology and demands within the industry, also requires a signifcant increase in the level of maintenance [8], and, as a result, PdM has been highlighted. The work on PdM has contributed in changing the traditional view on maintenance, from being a costly unwanted necessity into seeing maintenance as a competitive advantage. The two main objectives for industrial maintenance are to deliver a high availability of production equipment and low maintenance costs [32], and PdM is expected to have a signifcant impact on these objectives with the introduction of Industry 4 technologies. PdM is also showing its importance to lean manufacturing and total productive maintenance (TPM). Lean manufacturing seeks to improve on productivity, quality, focus on the elimination of waste and to be customer oriented, and share similar goals as Industry 4.0 [33, 34]. TPM also includes the goal of elimination of waste, reduces costs and downtime through an improved maintenance function [35]. For both lean manufacturing and TPM, PdM can provide several ways of performance improvements, e.g., through better predictions reducing unnecessary maintenance, such as early replacement of components (identifying RUL) orincreased production downtime due to equipment failures. PdM can also improve maintenance plans and procedures [36]. An overview of PdM system architectures, purposes and approaches is given in Ref. [37], and a defnition of PdM is provided by EN 13306:2017 [38]: “Condition-based maintenance carried out following a forecast derived from repeated analysis or known characteristics and evaluation of the signifcant parameters of the degradation of the item.” The standard EN 13306:2017 [38] classifes PdM under the umbrella of preventive maintenance and condition-based maintenance (CBM), but PdM goes beyond CBM by adding a forecast to the maintenance being carried out. PdM aims to maximize the life of equipment and reduce both planned and unplanned downtime, and, as a result, minimize maintenance costs. This is possible by analyzing data collected from components and equipment and using those analyzes to predict when a part will fail, enabling to perform maintenance actions at the right time. In terms of Industry 4.0, PdM is claimed to be central for asset utilization, services and after-sales [10]. For asset utilization, PdM is expected to decrease total machine downtime from 30% to 50%, and extend operation lifetime from 20% to 40% [10]. PdM combined with remote maintenance for services and aftersales, is assumed to reduce maintenance cost from 10% to 40% .

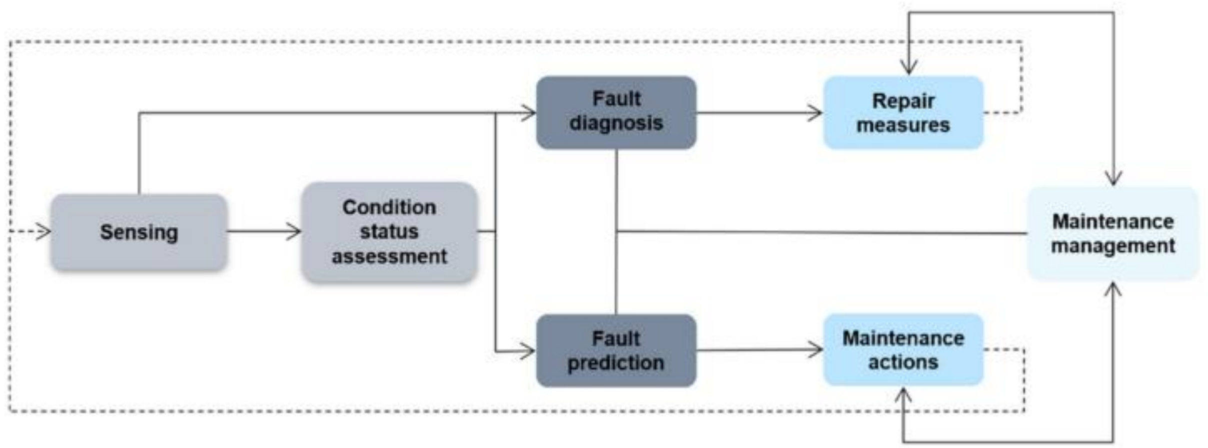


Fig. 1 PdM structure with its main elements, redrawn from Ref. [3]

PDM Algorithm:

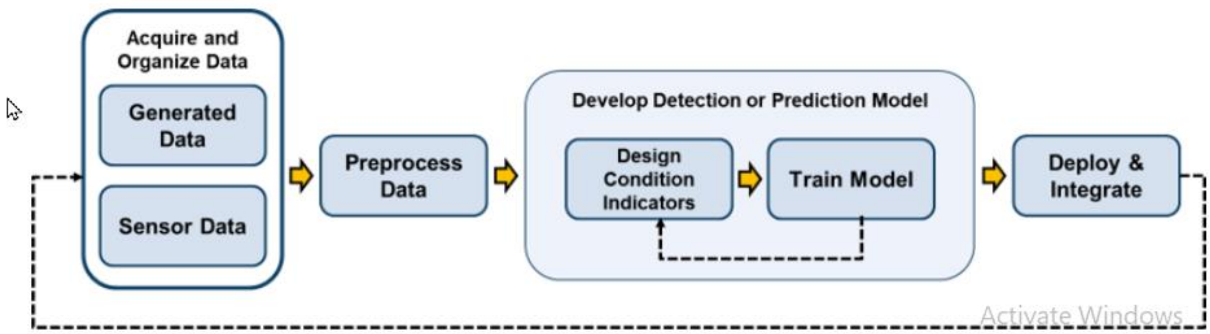
A predictive maintenance program uses condition monitoring and prognostics algorithms to analyze data measured from the system in operation.

Condition monitoring uses data from a machine to assess its current condition and to detect and diagnose faults in the machine. Machine data is data such as temperature, pressure, voltage, noise, or vibration measurements, collected using dedicated sensors. A condition monitoring algorithm derives metrics from the data called condition indicators. A *condition indicator* is any feature of system data whose behavior changes in a predictable way as the system degrades. A condition indicator can be any quantity derived from the data that clusters similar system status together, and sets different status apart. Thus a condition-monitoring algorithm can perform fault detection or diagnosis by comparing new data against the established markers of faulty conditions.

Prognostics is forecasting when a failure will happen based on the current and past state of the machine. A prognostics algorithm typically estimates the machine's *remaining useful life* (RUL) or time-to-failure by analyzing the current state of the machine. Prognostics can use modeling, machine learning, or a combination of both to predict future values of condition indicators. These future values are then used to compute RUL metrics, which determine if and when maintenance should be performed. For the gearbox example, a prognostics algorithm might fit the varying peak vibration frequency and magnitude to a time series to predict their future values. The algorithm can then compare the predicted values to a threshold defining healthy operation of the gearbox, predicting if and when a fault will occur.

A predictive maintenance system implements prognostics and condition monitoring algorithms with other IT infrastructure that makes the end results of the algorithm accessible and actionable to end users who perform the actual maintenance tasks. Predictive Maintenance Toolbox™ provides tools to help you design such algorithms.

The following illustration shows a workflow for developing a predictive maintenance algorithm.



Anticipating maintenance needs based on sensor data :

Predictive maintenance (PdM) typically uses data from sensors that monitor various conditions on equipment. As sensors collect data, algorithms analyze that data to predict when maintenance work will be needed.

Types of sensors used in PdM

For the process of collecting data, facilities can use various types of sensors. Some of these include:

- Vibration analysis, which is most often used on rotating machinery.
- Ultrasound analysis, which uses sound to identify potential issues with equipment.
- Infrared analysis, which is used on equipment where temperature is a good indicator of issues.

Each of these types of sensors collects data readings used in PdM.

Sensors, data collection, and condition monitoring

The readings collected by sensors may be logged into a CMMS or other form of software. Whenever those readings become abnormal, it's a sign that things aren't quite right.

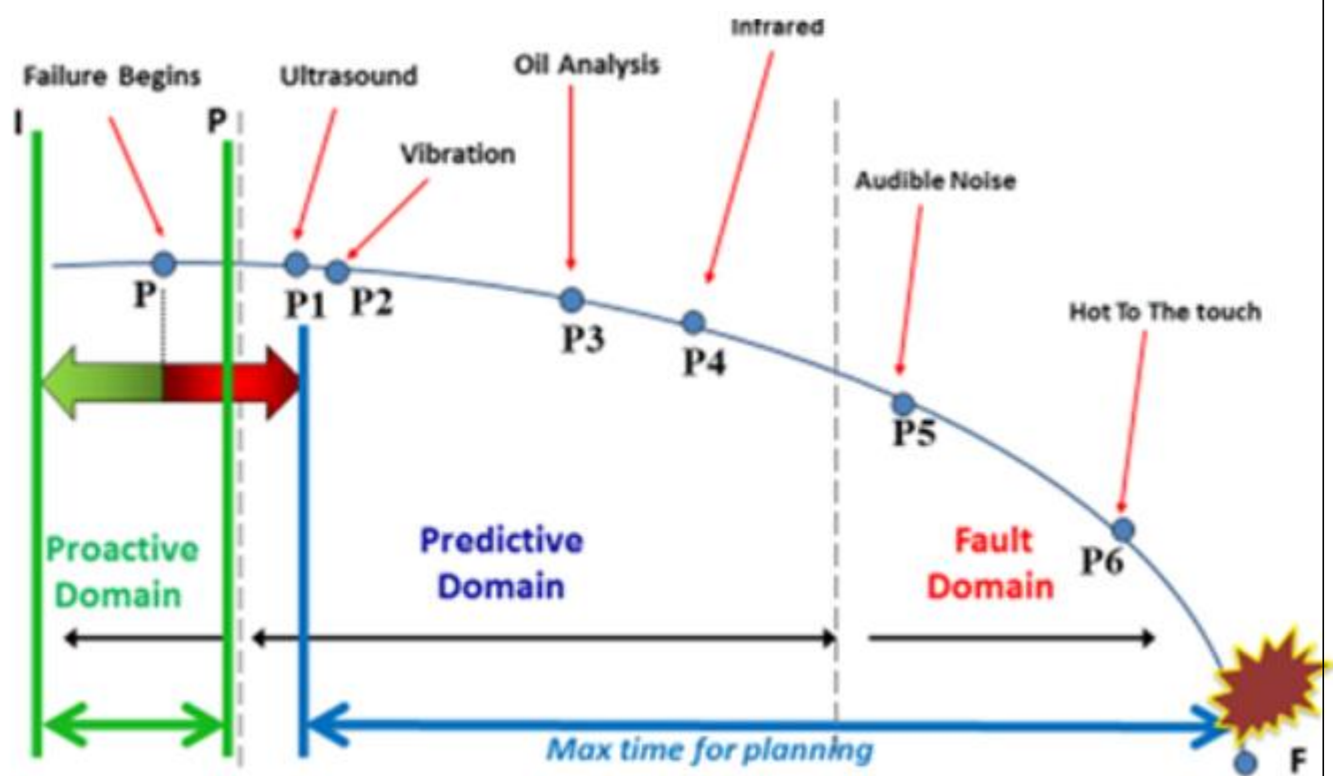
Different types of readings may indicate different problems. For instance, a certain amount of vibration in one part of a turbine may indicate worn bearings, whereas other readings might mean there's an imbalance or loose part. The point is when the readings from the sensors reach a certain threshold, it triggers a work order.

This is the basic premise of condition-based maintenance. However, PdM takes this a step further.

Predictive maintenance using sensors

Predictive maintenance not only uses sensors to monitor the current state of an asset, but it also involves following trends to predict when issues might develop in the future. If a certain trend in measurements from your sensors indicates a future problem, you can schedule maintenance to prevent that problem from developing.

For instance, if a mixer tends to exhibit slightly more vibration than normal a week before the bearings need lubrication, a model of the data from the sensors will show that. From there, a work order can be created in advance to make sure the bearings are oiled at the right time.



Summing up the process

To sum up the process:

- Sensors collect data from assets.
- Software (such as a CMMS) logs and tracks that data.
- Trends in the data predict when certain maintenance tasks will be necessary.
- A PdM work order is created when certain parameters are met.

Conclusion:

All the existing smart parking technologies and applications are not suitable for open parking lots due to varying environmental conditions and high expenditure. As there are no immediate economic gains from providing smart parking services in an open parking lot, expenditure plays an important role in the choice of smart parking technologies. Parking guidance system which is one of the existing smart parking technology can be used to get the count of available parking spaces in open parking lots. Machine vision is another technology which uses the visual camera to acquire real-time parking occupancy information on open parking lots due to its minimal expenditure. The usage of the visual camera is dependent on regulations supported by the country which needs to be considered prior. However, there is no single ideal technology suitable for parking occupancy detection. Based on the type of parking lot and size, a different combination of smart parking technologies and sensors can be used for efficient and financially viable parking occupancy detection. In order to further improve parking efficiency, navigational directions should be provided to a vacant parking space. Therefore, in order to address this challenge further research in the use of deep learning and multi-agent systems would help to provide real-time parking occupancy information along with navigational directions to available parking space in an open parking lot.

Thank You