Project Title: Sensor selection for PHM

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Objectives: The objective of this project is to tell how to select an optimal sensor system for PHM application.

Introduction:

There are several available methods for PHM implementation in electronic products and systems, including the use of expended devices, such as “canary” and fuses that fail earlier than the host product to provide advance warning of failure; monitoring and reasoning of parameters that are precursors to impending failure, such as shifts in performance parameters; and modeling of stress and damage in products utilizing exposure conditions (e.g., usage, temperature, vibration, radiation) combined with physics-of-failure (PoF) models to compute accumulated damage and assess the remaining life. In all of these approaches, the monitoring of parameters or conditions is a fundamental step. These parameters or conditions may be generated through the whole product life cycle including manufacturing, shipment, storage, handling and operation. Conditions may include temperature, vibration, shock, pressure, acoustic levels, strain, stress, inert environments, humidity levels, contamination, usage frequency, usage severity, usage time, power, and heat dissipation. Sensor systems are integrated with the electronic product to be monitored in order to measure these conditions.

This project will investigate the current sensor systems for PHM, the emerging trends of the sensor systems, and discuss the considerations of the sensor selection to tell how to select an optimal sensor system for PHM application.

Approach:

This project introduces the common sensors and their sensing principles; analyzes the PHM application and tell what we should consider when we select the sensor system. The project also surveyed currently commercially available sensor systems which can be potentially used for PHM. The characteristics of them are identified. The emerging trends of the sensor system also are concerned in this project to show the direction of future research and development.

A sensor is defined as a device that provides a usable output signal in response to a specified measurand. A sensor generally translates non-electrical, physical, chemical or biological phenomena into electrical signals utilizing some physical or chemical effects. Widely used in both analog and digital instrumentation systems, sensors provide the interface between electronic circuits and the “real world,” where events take place.

From the point of view of sensing (transduction) principles, sensors are classified into three major groups: physical, chemical and biological. The physical principles or effects involved in detecting a signal include thermal, electrical, mechanical, chemical, biological, optical (radiant), acoustic and magnetic. Examples of sensor signal parameters or measurands for PHM are listed in Table 1.

Table 1: Examples of Sensor Signal Parameters for PHM

Domain	Examples
Thermal	Temperature, heat flux
Electrical	Voltage, current, resistance, inductance, capacitance, dielectric constant, polarization, electric field, frequency
Mechanical	Length, area, volume, velocity or acceleration, mass flow, force, torque, pressure, and sound
Chemical	Contaminant, atmospheric gas, fuel spills, trace chemical vapors
Biological	Humidity, pH, bacteria, biological molecule
Optical (Radiate)	Intensity, phase, wavelength, polarization, reflectance, transmittance, refractive index
Magnetic	Magnetic field, flux density, magnetic moment, permeability

A sensor system will typically have sensors, onboard analog to digital converters, onboard memory, embedded computational capabilities, data transmission, and power supply, as shown in Fig.1Fig. Every sensor system will not necessarily contain all these elements, and not all sensor systems are suitable for the implementation of PHM. Thus, there is a need to determine sensor systems that can best be used for PHM. In this section, the desired attributes of sensor systems for PHM applications are presented.

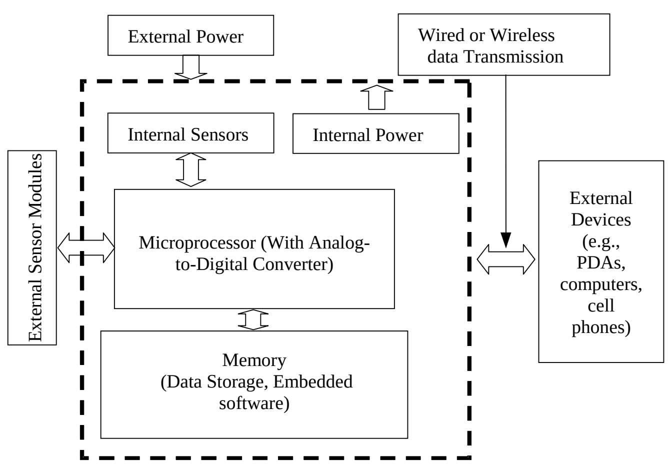

Fig.1: Integrated Sensor System for In-situ Environmental Monitoring

Fig.2 shows a general procedure for sensor system selection. The first step is to identify the application and all the requirements for the sensor system. Then, sensor system candidates are identified and evaluated.

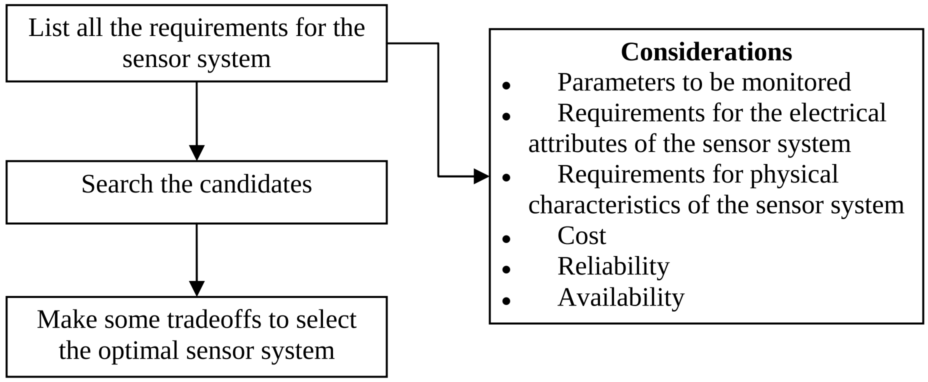

Fig.2: Sensor System Selection Procedure

The requirements of a sensor system for PHM depend on the specific application, but there are some common requirements that should be considered, such as the parameters to be measured, the performance needs of the sensor system, the electrical and physical attributes of the sensor systems, reliability, and cost.

For specific PHM applications, user needs concern about all the above considerations. One important thing is that user must determine the priority of the considerations based on which some tradeoffs will be taken to select the optimal sensor system for the specific application.

A survey was conducted to identify the state-of-the-art and the availability of the sensor systems for PHM. The search only included commercially-available sensor systems having features desired by PHM.

The survey results show the characteristics of 16 sensor systems from 10 manufacturers. The sensor system characteristics include the sensing parameters, power supply and power management availability, sample rate, onboard memory, data transmission method, availability of embedded signal processing software, size, weight, and cost. The data for each sensor system was collected from the manufacturer's website and product datasheets, e-mails, and evaluations of demo products.

Key findings from the survey are that the state-of-the-art prognostic sensor systems:

- can autonomously perform multiple functions using their own power management, data storage, signal processing, and wireless data transmission
- have multiple, flexible or add-on sensor ports that support various sensor nodes to monitor various parameters such as temperature, humidity, vibration, and pressure
- have onboard power supplies, such as the rechargeable or replaceable batteries
- have onboard power management, such as the operation modes (active, idle and sleep) transformation and the programmable sample modes (continuous or threshold) and rate. These management strategies combining with the low power consumption circuitry and novel battery techniques enable the power of the sensor system to last longer time.
- have diverse onboard data storage capacity (flash memory), from several KB to hundreds of MB.
- have embedded signal processing algorithms, which enable data compression or simplification prior to data transfer.

In terms of the emerging trends of the sensor system, ensor technology is headed towards extreme miniaturization, wireless networks, ultra low power consumption, and battery-free power. As electronic components and systems continue to decrease in size, sensors to monitor their environment and operation will also become smaller and weigh less in order to be integrated. The fabrication of MEMS and NEMS in silicon and other materials will offer significant advantages or integration with electronics, fabrication of arrays of sensors, small size of individual devices, and lower costs [4].

Another trend that is expected to revolutionize sensors for PHM is ultra low power circuit. With the development of the new materials, new manufacturing technology, the ultra low power circuit design that is emerging will reduce power consumption. For example, in 2005, Intel Corporation was developing an ultra low-power derivative of its high-performance 65 nanometer (nm) logic manufacturing process that would enable production of ultra low-power chips.

Another trend that can extend the lifespan of the sensor systems is the battery-free power supply technology or energy harvesting technology. It is a process to extract energy from the ambient or from a surrounding system and convert it to usable electrical energy. Current energy harvesting sources include sunlight, thermal gradient, human motion, body heat, wind, vibration, radio power and magnetic coupling.

In the future, it will be possible to scavenge energy from other energy sources around the sensor systems to realize battery-free operation [5].

Another emerging trend in sensor systems for PHM is the development of distributed sensor networks (DSNs). A DSN consists of multiple sensor nodes that are capable of communicating with each other and collaborating on a common sensing goal. The advantage of DSNs is that it allows data from multiple sensors to be combined or fused to obtain inferences that may not be possible from a single sensor. This is referred to as multi-sensor data fusion. The sensor nodes in a DSN are organized into a cooperative system. The nodes can communicate with each other and have the ability to self-organize after being deployed in an ad hoc fashion. DSNs of 1,000 or even 10,000 nodes are anticipated in the future.

The development of the wireless transmission technology will realize long-distance, high transmission-rate, and more-security data communication for future sensor systems with other sensor systems or the base stations [6]. Furthermore, future smart sensor node will be highly intelligent with much more functions than today's. They will have built-in diagnostics and prognostics capabilities, which will make the entire wireless sensor networks more functional.

Deliverables:

- The review of the sensor principles
- The considerations and guidelines of the sensor selection
- The state-of-the-art of current sensor system
- The emerging trends of sensor systems

Project Status:

The survey, considerations for sensor selection and trends of the future sensor system are shown in a chapter of CALCE PHM book.

We are focusing on preparing an online database of sensor systems for PHM, and we are working with other research labs (e.g., ARL) and ePrognostic Systems, LLC to produce a state-of-the-art PHM sensor system. This project will finish in Jun 2008.

Estimated Schedule:

Tasks	**Oct-Dec 2007**	**Jan-Mar 2008**	**Apr-June 2008**	**July-Sept 2008**	**Oct 2008**
Task 1	Finish the sensor chapter of CALCE PHM book				
Task 2	Online database of sensor systems for PHM				
Task 3	Produce a state-of-the-art PHM sensor system.				
Task 4					
Task 5					
Report and review					
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