© 2016 IJSRST | Volume 2 | Issue 6 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Sensor Technology & IVHM in Fighter Aircraft

Lakshman Singh
Defence PSU Hindustan Aeronautics Limited, Avionics Division-Korwa, Amethi, Uttar Pradesh, India

ABSTRACT

Fighter Aircraft being of national importance so is fast readiness at air-bases, maintenance & repair activity play very important role. In this paper we had discussed different technology of sensors for authenticated & secured data communicated from different location of fighter aircraft for speedy maintenance with *Integrated Vehicle Health Management (IVHM)*[1] methodology. Paper brief the need of different sensors & their properties for IVHM. With the brief discussion in tabulated form for different *sensor technologies*[2] used in IVHM, paper goes to detail analysis of *Surface Acoustic Wave (SAW)*[3] sensors and explored its wide range applications in Aircraft technology.

Keywords : Integrated Vehicle Health Management (IVHM), Sensor Technologies, Surface Acoustic Wave (SAW)

I. INTRODUCTION

A fighter aircraft is more than a great looking flying machine equipped with lethal weapons & mind-blogging array of avionics & optoelectronics system. It is a fountainhead of cutting edge technologies, from the new composites to advanced designing, situation awareness & electronic warfare system, high end software, communication systems & optoelectronics systems. Buying an aircraft or it manufacturing under TOT or indigenous is nothing but dealing with a superb piece of machinery & keeping it running, so user should be able to control every aspect of the evolution of the aircraft & it systems. It is not just about a having a fighter aircraft equipped with advance avionics systems but also its maintenance. The primary goal of an aircraft is to complete its designated mission and most of the systems on board are allotted distributed functionalities towards achieving-the same. However down the line there exists the need for a system which monitors the status of the platform itself and thereby supplements roles like crew alerting or maintenance scheduling.This although does not figure in the primary roles but if the impact of this on the overall serviceability and mission capability of aircraft is accounted for, it presents astonishingly high criticality.

In this regards for fast readiness of aircraft at air-bases, maintenance & repair activity play very important role. Hence, adherence to laid-down time frame should be the most important focus area for aircraft maintenance. This again would depend upon the infrastructure, manpower, domain knowledge & methodology used. Here we are going to discuss the total solution for speedy maintenance via analysing the collected data of aircraft health by different sensors. In this context paper discuss different technology of sensors for authenticated & secured data communicated from different location of fighter aircraft. The Integrated Vehicle Health Management (IVHM) is a methodology where collection & analysing the data of sensors can made.

II. METHODS AND MATERIAL

Configurations & Basic Structure of IVHM systems:

IVHM systems are highly integrated systems that include advanced smart sensors, diagnostic and prognostics software for sensors / components, reasoning algorithms for subsystem and system level managers, advanced on-board and ground based mission and maintenance planners, and a host of other software and hardware technologies. These hardware and software technologies will be embedded in the aircraft subsystems, maintenance operations, and mission operations elements, and do provide both real-time and life-cycle vehicle health information which will enable informed decision making and logistics management.

Knowledge databases of the vehicle health state will be continuously referred to for reporting of critical failure modes, and routinely updated and reported for life cycle condition trending.

One of the primary goals of Integrated Vehicle Health Management (IVHM) is to detect, diagnose, predict, and mitigate adverse events during the flight of an aircraft, regardless of the subsystem from which the adverse event arises. In this regard various sensors are used to collect the aircraft critical parameters. These parameters are then analyzed by on-board and ground processors.

The major functionalities of the IVHM system are

Data acquisition/ measurement: This includes data collection from various systems or sensors installed across the board.

Data extraction: The data collected needs to be processed to convert it in to a form suitable for analyses. This also needs to include aspects like noise removal and multiplexing

Data Interpretation: The available data needs to be analyzed using various analytical models and compared with the database before arriving at decision w.r.t system health. Various diagnostics and prognostics algorithms are to be executed to interpret the data available.

Action based on the interpretation results: Thisincluded logging data and informing the concerned systems and personnel about the same.

Interaction: The analyses results and recommendations need to be shared with the ground maintenance crew for taking rectification action. Also the data base update needs to be undertaken based on ground crew maintenance actions taken.

The aims of IVHM are to enable better management of vehicle and vehicle fleet health.

- Improve safety through use of diagnostics and prognostics to fix faults before they are an issue.
- Improve availability through better maintenance scheduling
- Improve reliability through a more thorough understanding of the current health of the system and prognosis based maintenance
- Reduce total cost of maintenance through reduction of unnecessary maintenance and reduction of unscheduled maintenance

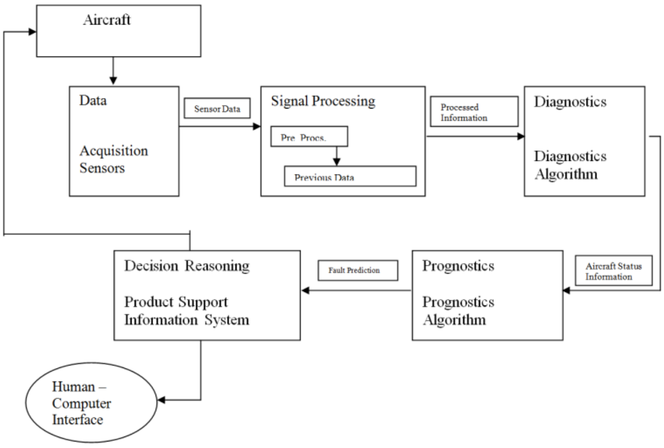

Figure 1. Block diagram of Basic Structure of IVHM

2.1 Fault Diagnosis:

Fault diagnosis can be defined as the process of detecting, isolating, and identifying an impending or incipient failure condition while the affected component (subsystem, system) is still operational even though at a degraded mode.

There are numerous techniques available for implementation of Fault diagnosis. These can be analytical methods or embedded real time intelligence ones or either statistical methodology.

All these require formulating highly matching process or semi quantitative or approximate system models. From a modelling perspective the IVHM system needs to embed either highly accurate process models, semi-quantitative models, or qualitative models. A simpler system could also be based on the past system performance data alone to arrive at fault diagnosis.

Fault diagnosis methods are divided in two types based on the procedure that is adopted for the arriving at previous state; one is model based and the other is data based, based on the process knowledge that is required a priori. The priori process background knowledge applied is the key factor in determining the fault diagnosis procedure. All procedures depend on the information correlation between the observed failures and precursor indications of that failure. This can be done by having a reference database which is built based on the system details and design. This requires the developer to understand the basic operational process of each system. Previous results obtained with the process are other source of database. Such database is known as shallow or past performance based knowledge. In model-based methods, the priori knowledge is categorized in to qualitative and quantitative subgroups. The fundamental knowledge of the system is the base for formulating the model. In quantitative models the mathematical dependencies between the inputs and outputs are implemented and these replicate the actual system. However the qualitative model expresses these as qualitative functions.

For the data-driven methods the extensive data generated from past performance of the system is the key base. There is certain degree of commonality between the two techniques but the knowledge of the system process is the key basis for fault diagnosis.

2.2 Prognosis

Prognosis is the ability to predict accurately and precisely the remaining useful life of a failing component or subsystem. It is the Achilles' heel of the condition-based maintenance/prognostic health management (CBM/PHM) system. Prognosis entails large-grain uncertainty. Long-term prediction of the fault evolution to the point that may result in a failure requires means to represent and manage the inherent uncertainty. Uncertainty representation implies the ability to model various forms of uncertainty stemming from a variety of sources, whereas uncertainty management concerns itself with the methodologies and tools needed to continuously "shrink" the uncertainty bounds as more data become available.

Prognosis can be generally classified into-

1. Usage Based Prognosis: This approach incorporates reliability data, life usage models and varying degrees of measured or proxy data. Forecast is based on actual usage when possible. Incipient fault detection may not be available due to sensor or fault mode coverage limitations.
2. Condition Based Prognosis: This approach incorporates utilizing the assessed health or diagnostic fault classifier output to predict a failure evolution. Feature trending or physics of failure based prediction can be then used. Incipient fault detection and diagnostic isolation is absolutely necessary in this.

Prognosis techniques typically combine measured data with data driven embedded model in standalone or combination with a mathematical model to arrive at the predicted condition of the system being monitored. The prognosis based on the physical model takes in to consideration the mathematical model along with the historical database and typical patterns exhibited by the system during faults to arrive at accurate predictions. The algorithms for these need to be built to cover all possible anomalies or failures that can be expected from a system, Hence a very detailed knowledge of the systems is required to generate the prognostic algorithms. Prognosis is also instrumental in arriving at the balance useful life of the systems in order to decide if immediate grounding for maintenance is needed or ops can be continued till next major grounding.

3. Sensors for IVHM:

The diagnostics and prognostics in IVHM is totally depend on the data collected by sensors. The sensors are the backbone of the IVHM technology. Sensor data are preliminarily processed to remove artefacts and noises and then manipulated to extract fault features. The techniques commonly used to ‘clean’ the types of data derived from IVHM sensors include, e.g. low-pass filtering and time synchronous averaging. Fast Fourier transform and short time Fourier transform-based methods are very popular approaches in the extraction of condition indicators, while wavelet theory finds extensive application as both deionising method and feature extractor.

In addition to conventional monitoring and control sensors, several special and tailored made sensors are used for IVHM, such as Accelerometers and Gyros, Strain gages, Infrared cameras and Thermocouples, Chemical sensors, Humidity sensors, pH sensors, Fibre Optics, Piezoelectric Materials Sensors, Eddy Current, Corrosion Sensors, MEMs Devices and specially the new emerging Surface acoustic wave (SAW) sensors.

Properties of IVHM sensors

The important properties of IVHM sensors are

1. Lightweight and small size
2. Low input power requirement
3. Insusceptible to electromagnetic interference
4. Reliable and accurate
5. Compatible with onboard pre-processing unit
6. Compliance with MIL standards
7. Airworthiness
8. Compatible with latest aircraft technologies
9. Easy reparability
10. Upgradeability in case of obsolesces.

3.1 Sensors Technologies used in IVHM

Sensors Technologies	***Parameters***	***Health Monitoring Area***
Accelerometers and Gyros	Vibration monitoring	Assess the condition of moving parts. All rotating components vibrate and the extent of vibration can evaluate a component's health and effectiveness. Extreme vibration usually indicates poor alignment. Can be used to control fatigue damage.
Strain gages	Mechanical loading	Provide information about the amount and location of applied stresses over a component or structure
Infrared cameras and Thermocouples	Temperature profiles	This technology is used to evaluate the efficiency of heat transfer components, such as the thermal protection systems of a aircraft
Chemical sensors	Gas and ion detection	Used for composition and corrosion monitoring to assess the level of degradation in components and structures
Humidity sensors, pH sensors	Lubrication contamination	Lubrication monitoring methods are used to detect changes in viscosity or the presence of particulate contaminants. Detecting and addressing contamination and viscosity breakdown early on can preclude component wear.
Fiber Optics	Mechanicho-Optical Parameter	Fiber optic sensors can be tailored to measure strain, temperature, and pressure. They are most widely used for measuring strain and temperature,
Piezoelectric Materials Sensors	Aircraft Structural Parameter	Piezoelectric sensors can detect energies emanating from impact events and defect generation, including crack formation and delimitation.
Eddy Current	Material Defect	This method is only effective on conductive materials and can detect cracks, corrosion, heat-effected areas, and thicknesses. It may be used for large-scale inspection with the use of a mobile hand held device.
Corrosion Sensors	Aircraft Structure corrosion	Linear polarization resistance (LPR) sensors measure a solution's electrical conductivity, which is indicative of its corrosion reaction rate.
MEMs Devices	Electro-mechanical Parameter	MEMs devices include strain gages, accelerometers, temperature sensors, humidity sensors, and corrosion sensors. In addition, wireless MEMs devices using radio frequency communications have been implemented.
Surface acoustic wave (SAW)	Moving objects and parts	They do not need additional power supply for the sensor elements and may be accessed wirelessly, enabling the use in harsh indoor/outdoor environments. It is achieved simply by connecting an antenna to the input transducer

As discuss above for different technology of sensors the Surface acoustic wave (SAW) sensors are passive sensors that can be controlled wirelessly, enabling remote monitoring in ruthless environments and works in wide range of frequencies. They are extremely versatile sensors that can enumerate nearly any quantity useful for Aircraft health monitoring. Temperature, pressure, strain and torque can be sensed inherently and through some special process of SAWS, Chemical vapors, Biological matters, Humidity, UV radiation and electromagnetic fields can also be sensed.

4. Surface Acoustic Wave (SAW) Sensors:

Surface acoustic wave (SAW) sensors are used for identification and measuring of physical quantities such as temperature, pressure, torque, acceleration, tire-road friction, humidity, etc. The SAW sensors are passive elements (they do not need power supply) and can be accessed wirelessly, enabling remote monitoring in harsh environment. They work in the frequency range of 10 MHz to several GHz. They have the rugged compact structure, outstanding stability, high sensitivity, low cost, fast real time response, extremely small size (lightweight), and their fabrication is compatible with CMOS and micro-electro-mechanical (MEMS) integrated circuits technology.

5. Basic Principle and Operation of SAW Devices:

The operation of the SAW device is based on acoustic wave propagation near the surface of a piezoelectric solid. This wave can be trapped or modified while propagating. This basic property of surface acoustic wave is use as a sensor & transmission of data to receiver end. A basic SAW device consists of two IDTs (Inter Digital Transducers) on a piezoelectric substrate, one at transmitter end to excite the surface wave electronically , the excited wave transmitted through small depth of surface, whose properties changes with the variation of substrate properties (like temp., strain, material properties etc.).With this variation wave receive at other end IDT where we transmit it to ground station via antenna & analyse the received data to find out the changes in properties of substrate.

The commonly used substrate crystals are: quartz, lithium niobate, lithium tantalate, zinc oxide and bismuth germanium oxide. They have different piezoelectric coupling coefficients and temperature sensitivities. With the same principle we can find out the characteristic changes of aircraft structure at ground station.

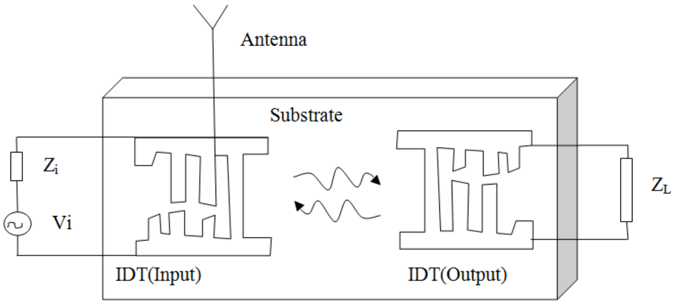

Figure 2. Basic Structure of Surface Acoustic Wave (SAW) Sensors

A sinusoidal voltage *v* of frequency *f* applied to the input IDT forms an electric field which, through the piezoelectric effect causes a strain pattern of periodicity 2*d*, where *d* denotes the distance between the centres of the electrodes. If the frequency *f* is such that 2*d* is close to the surface wave wavelength, surface wave will be launched in two opposite directions away from the transducer. The surface wave causes the corresponding electric field in the output transducer and thus the voltage at the impedance Z_L.

$$\begin{aligned} Vo &= Vi \sin(\omega t + \varphi) \\ &= Vi \sin\{2\pi f (d/v) + \varphi\} \\ &= Vi \sin\{2\pi f (\lambda/2v) + \varphi\} \quad (\text{for } \lambda = 2d) \\ &= -Vi \sin\varphi \qquad : \text{Maximal Output} \end{aligned}$$

As we seen that the distance 2*d* is equal to the wavelength, the magnitude of the output voltage is maximal. The corresponding frequency is then called the centre or synchronous frequency of the device. Let *fo* be the synchronous frequency, then

$$fo = Vo/p \qquad \text{(synchronous frequency)}$$

Where *Vo* is the propagation velocity of a wave in the substrate and *p* is the wavelength of the wave transuded by the piezoelectric substrate which is equal to the pitch of fingers of IDT. The synchronous frequency is both determined by material selection and the design parameters. The magnitude of the output voltage decays as the frequency shifts from the centre frequency. It means that, basically, a SAW device is a transversal band pass filter. This property is very useful for data collection in IVHM.

Another important parameter of IDT is its bandwidth (BW). The BW should be as small as possible in order to minimize the interference with the response of nearby sensors. The BW of the device can be described as follows

$BW = 2fo/N$
(Where N is the number of pairs of fingers of IDT)
$= 2Vp/Np$
$= 2Vp/L_{IDT}$

Where L_{IDT} is the total length of the IDT (in the primary direction of wave propagation), which is equal to the number of pairs of fingers N in the IDT multiplied by the pitch p of the IDT. As the BW is dependent on L_{IDT}, there are some restrictions on physical size of the SAWS. The typical frequency range of a SAW device is 10MHz to 3GHz, corresponding to pitches of approximately1 um to 300 um.

III. RESULTS AND DISCUSSION

6. Applications of SAW Sensor:

The surface acoustic wave sensor is an extremely versatile sensor that can quantify nearly any measured. Due to the sensitivity of the surface acoustic wave to even the slightest perturbations, small effects caused by many different phenomena can be detected. The application can be divided into inherent (Basic) and extended (Special) applications.

6.1 Inherent applications:

The basic surface acoustic wave device, can inherently measure temperature, pressure, strain, torque, and mass-loading.

6.1.1 Pressure, Temperature, Strain and Torque Sensing

Pressure, strain, torque and temperature can be sensed by the basic device, consisting of two IDTs separated by some distance on the surface of a piezoelectric substrate. These phenomena can all cause a change in length along the surface of the device. The change in length will vary the spacing between the interdigitated electrodes, altering the pitch. As the pitch determines the synchronous frequency (fo = Vo/ p), the output signal will show a frequency-shift. This can be measured as either an elapsed-time or a phase-change, depending on the type of operation. Since the input signal frequency will not vary, but the synchronous frequency of the device will vary, the amplitude of the output wave will decrease. As such, signal attenuation could be measured as well.

When a diaphragm is placed between the environment at a variable pressure and a reference cavity at a fixed pressure, the diaphragm will bend in response to a pressure differential.. A surface acoustic wave pressure sensor simply replaces the diaphragm with a piezoelectric substrate patterned with interdigitated electrodes. Strain and torque work in a similar manner, as application to the sensor will cause a deformation of the piezoelectric substrate. A surface acoustic wave temperature sensor can be fashioned from a piezoelectric substrate with a relatively high coefficient of thermal expansion in the direction of the length of the device.

6.1.2 Mass

The accumulation of mass on the surface of an acoustic wave sensor will affect the surface acoustic wave as it travels across the delay line. The velocity v of a wave traveling through a solid is proportional to the square root of product of the Young's modulus E and the density $\rho$of the material.

$$v \propto \sqrt{E/\rho}$$

Therefore, the wave velocity will decrease with added mass. This change can be measured by a change in time-delay or phase-shift between input and output signals. In the case of mass-sensing, as the change in the signal will always be due to an increase in mass from a reference signal of zero additional mass, signal attenuation can be effectively used.

6.2 Extended Applications

The inherent functionality of a surface acoustic wave sensor can be extended by the deposition of a thin film of material across the delay line which is sensitive to the physical phenomena of interest. If a physical phenomenon causes a change in length or mass in the deposited thin film, the surface acoustic wave will be affected by the mechanisms mentioned above. Some extended functionality examples are listed below:

6.2.1 Chemical Vapours

Chemical vapour sensors use the application of a thin film polymer across the delay line which selectively absorbs the gas or gases of interest. An array of such sensors with different polymeric coatings can be used to sense a large range of gases on a single sensor with resolution down to parts per trillion, allowing for the creation of a sensitive "lab on a chip."

6.2.2 Humidity

Surface acoustic wave humidity sensors require a thermoelectric cooler in addition to a surface acoustic wave device. The thermoelectric cooler is placed below the surface acoustic wave device. Both are housed in a cavity with an inlet and outlet for gases. By cooling the device, water vapor will tend to condense on the surface of the device, causing a mass-loading.

6.2.3 Ultraviolet Radiation

Surface acoustic wave devices can be made sensitive to optical wavelengths through the phenomena known as acoustic charge transport (ACT), which involves the interaction between a surface acoustic wave and photogenerated charge carriers from a photoconducting layer. Ultraviolet radiation sensors employ the use of a thin film layer of zinc oxide across the delay line. When exposed to ultraviolet radiation, zinc oxide generates charge carriers which interact with the electric fields produced in the piezoelectric substrate by the traveling surface acoustic wave. This interaction decreases the velocity and the amplitude of the signal.

6.2.4 Magnetic Fields

Ferromagnetic materials, such as iron, nickel, and cobalt, exhibit a characteristic called magnetostriction, where the Young's modulus of the material is dependent on magnetic field strength. If a constant stress is maintained on such a material, the strain will change with a changing Young's modulus. If such a material is deposited in the delay line of a surface acoustic wave sensor, a change in length of the deposited film will stress the underlying substrate. This stress will result in a strain on the surface of the substrate, affecting the phase velocity, phase-shift, and time-delay of the signal.

6.2.5 Viscosity

Surface acoustic wave devices can be used to measure changes in viscosity of a liquid placed upon it. As the liquid becomes more viscous the resonant frequency of the device will change in correspondence. A network analyser is needed to view the resonant frequency.

7. Assessment of SAW Sensors:

Though surface acoustic wave sensors can detect a wide variety of phenomena, there are other, specific sensor options available for each of these phenomena. Surface acoustic wave devices are, in most cases, small, rugged, cost-effective sensors. Though the options for piezoelectric substrate with higher electromechanical coupling factors are generally higher in cost, the incredible sensitivity they offer is very attractive.

SAW sensors are also able to operate in a very wide temperature range, though problems with temperature drift depending on substrate choice may require additional sensors and/or circuitry for temperature correction. All SAW sensors can be operated wirelessly by coupling the input IDT to an RF antenna and replacing the output IDT with a reflector. For systems which require no other components than the SAW sensor, the measurements can be taken completely passively. Unfortunately, SAW sensors generally require more signal processing than most devices. Waveforms must be compared for either frequency shifts, phase-shifts, time-delays, or attenuation. However, because of the possibility of wireless sensing, a distributed network of sensors can be measured and analyzed by one centralized data acquisition and processing system.

IV. CONCLUSION

Aircraft maintenance is an area of significant importance because maintaining an aircraft in a good condition increases aviation safety and improper maintenance contributes to a significant proportion of aviation accidents and incidents. The aviation industry could not function without the contribution of maintenance activity of aircraft. New sensor technologies expand our ability to detect flaws and impending failures in components, and provide us with new possibilities in performing maintenance with the help of Integrated Vehicle Health Management (IVHM). Within the last twenty years, the aviation industry has quickly moved ahead with applying these new technologies to maintenance programs.

V. REFERENCES

[1] ISO. Geneva, Switzerland, 2002, ISO 13374-1, Condition monitoring and diagnostics of machines – Data processing, communication and presentation – Part 1: General Guidelines

[2] Jared Kirschner, Surface Acoustic Wave Sensors (SAWS): Design for Fabrication. Micro-electromechanical systems, December 6, 2010

[3] Aaseng, G.B. Blueprint for an integrated vehicle health management system. In proceedings of the 20th Digital Avionics Systems Conference, Daytona Beach, Florida, USA, 14–18 October, vol. 1, pp. 3.C.1-1-3.C.1-11

[4] Jennions, I.K, Integrated Vehicle Health Management: Perspectives on an Emerging Field

[5] Lord Rayleigh (1885). "On Waves Propagated along the Plane Surface of an Elastic Solid"

[6] K. Sritharan, C. J. Strobl, M. F. Schneider, A. Wixforth and Z. Guttenberg. "Acoustic mixing at low Reynold’s numbers"

[7] E. Benes; M, Gröschl; F. Seifert (1998). "Comparison Between BAW and SAW Sensor Principles"

[8] R. Weigel; D. P. Morgan; J. M. Owens; A. Ballato; K. M. Lakin; K. Hashimoto; C. C. W. Ruppel (2002). Microwave acoustic materials, devices, and applications.

[9] Kumar, Sanjeev, Gil-Ho Kim, K. Sreenivas, and R. P. Tandon. ZnO Based Surface Acoustic Wave Ultraviolet Photo Sensor Journal of Electroceramics

[10] Indian Financial Sector Reforms: A Corporate Perspective”, Vikalpa, 23(1), January-March 1998

[11] Technology transfer in the Indian public research system by Prabhu Ram