Wireless Sensors for Potential Military Aircraft Structural Health Monitoring

DEFENCE R&D DÉFENSE

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OBJECTIVE

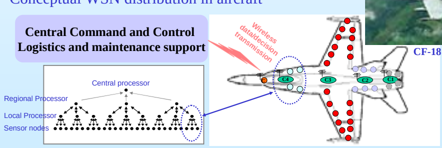
Evaluation of wireless sensors (WS) and sensor networks (WSN) for integration into military aircraft for reduced life cycle cost, increased flight safety, enhanced performance and increased aircraft availability.

INTRODUCTION

The Canadian Forces (CF) continue to encounter significant challenges in maintaining and increasing the availability of its aircraft fleet. Integration of advanced sensors, sensor networks and in-situ structural health monitoring and prognostics capabilities are expected to reduce such on-going fiscal and operational pressures and provide the CF with on-demand decision making capabilities for its fleet's life cycle management. The concerns presented by aging wires and the desire to reduce air platforms weight for efficient mission performance has provided serge in the evaluation of wireless communications (e.g. wireless sensors, sensor networks and Radio Frequency IDentification devices (RFID)) as an alternative to the traditional approach. Wireless communication has dominated the cellular sector and wireless devices can be seen across the civilian and consumer sectors as well. Only in recent years that this technology has gained momentum for potential integration into air platforms for sensor data acquisition and transmission. Concerns regarding the security of data, the data transmission rate and frequency, the power requirement, the 'smart sensor' integration, etc continue to be in the mind of the end-user as they integrate such technology on legacy and emerging platforms. This work intends to evaluate three wireless systems, based on both the 916 MHz ASK Pulse code and the Zig Bee 2.4 GHz 802.15.5 standards, for potential integration into an aircraft environment for structural health-monitoring. The anticipated WSN will integrate 'smart' sensor concept while providing added flexibility for data, information, and knowledge accumulation.

A WS, also known as a mote (reMOTE), smart dust, smart sensor or sensor node, consists of a sensor and instrument packages that are microprocessor driven and include advanced features such as communication, limited data processing and self monitoring. Whereas, a WSN consists usually of a large number of these small-scale nodes and have limited data processing and storage, wireless data communication and transmission, and sensing capabilities. This is also known as a network of RF transceivers, sensors, machine controllers, microcontrollers and user interface devices with at least two nodes communicating by means of wireless transmissions.

Conceptual WSN distribution in aircraft



CF-18 Hornet

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WSN ADVANTAGES

Wireless Sensor Networks (WSNs) offer numerous advantages over traditional networks, such as elimination of costly wires, enhanced monitoring precision and larger area coverage. Additional benefits are the wealth of information that can be gathered from the process leading to reduced downtime and improved quality, increased distributed intelligence leading to complete knowledge of a system, subsystem or component's state of awareness and health for 'optimal' decision making.

Summary of Some Wireless Sensor Systems

Manufacturer	Product Line		Size (mm x mm x mm)	Weight (g)	Power Source	Sensor Capacity	Software	Range	RF Data Packet Standard	Cost (app)
			Criterion for Evaluation							
Crossbow Technology Inc.	MICAz Motes		58 x 32 x 7 *(excluding battery pack)*	18 *(excluding batteries)*	2-AA Batteries	Sensor board required	TinyOS but advanced programming skills required	75 m to 100 m	IEEE 802.15.4	$3500 *(KIT)*
Analatom Inc.	Smart Tape		Tape thickness of 100 µm		Uses CR 2032 coin cell	3 to 8			IEEE 802.15.4	
MICROSTRAIN Inc.	V-Link		63 x 87 25 *(including mounting tabs and screw terminal block input connector)*	97	-9V External Battery -3.6V Lithium ion internal battery	4	AgileLink or SDK for custom software	70 m line of sight or 300 m with optional high gain antenna	IEEE 802.15.4	
	EmbedSense		Outside coil diameter is 36 mm with overall thickness of 6 mm		Power induced by induction coils - *Magnetic field*	1		0.05 m between the node and the interrogator		
	SG-Link	916 MHz SG-Link 3	35 x 38 x 6	58	9V External Battery or 3.6V Lithium ion internal battery	3	WDL and customized software using SDK	30 m line of sight		$2245 *(KIT)*
		2.4 GHz SG-Link	58 x 49 x 26 *(w/o antenna)*	46	3.7V Lithium ion internal rechargeable battery or power harvesting techniques under development	1	AgileLink or SDK purchased separately for custom software	70 m line of sight or 300 m with optional high gain antenna	IEEE 802.15.4	$2100 *(KIT)*
Ember Corporation	EmberXXX		7mm x 7mm 48 QLP					37 mm to 50 mm	IEEE 802.15.4	
RFID	Passive		Varies depending on application and manufacturer	Tag weighs same as paper	Power by RF signal from the interrogator		Depends on application and manufacturer	<5m	Standard Under development	$0.40 to $1 per tag
	Active		Varies depending on application and manufacturer	Varies	Power source built into the tag		Depends on application and manufacturer	Up to 100m	Standard Under development	$5 -$7 per tag

Not considered for Aircraft SHM; Require further development; Considered for aircraft SHM; Future area of R&D

WIRELESS SYTEMS & EVALUATION CRITERIA

MicroStrain 916 MHz SG Link-3 | MicroStrain 2.4 MHz SG Link | Microchip PICDEM Z Board Zig-Bee based wireless Board

Microstrain's 916 MHz SG-Link and 2.4 GHz SG-Link Wireless Strain Monitoring Systems are evaluated for:

Reliability: Comparing wired and wireless strain data with theory

Reproducibility: Comparing consistency in different trial data

Stability: Determining the Long-term stability of the output data

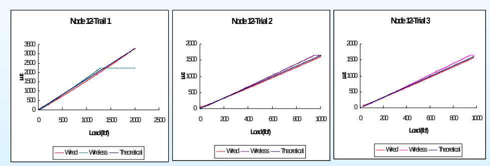
Power requirement: Determining the longevity of the battery in the stream mode

SYSTEMS EVALUATION

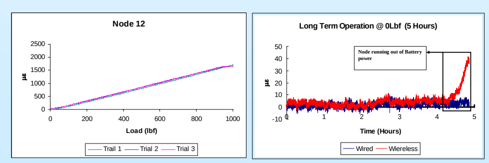
The SG-Link Nodes (916 MHz SG-Link 3 node and 2.4 GHz SG-Link Strain Node) are in principle identical with the 916 MHz SG-Link 3 Node having one of the earliest wireless sensing technologies, it accommodates 3 sensors compatible with Wireless Datalogger (WDL) and comes with Software Developer's Kit (SDK). The 2.4 GHz SG-Link Strain Node can accommodate 4 sensors (1 differential input, 1 single ended input, built-in internal temperature and a battery sensor), compatible with AgileLink and Software Developer's Kit (SD). The experimental setup is as shown and the theoretical and experimental evaluation is presented only for the 2.4 GHZ SG-Link Strain Node.

Sensor node inside a compartment of a wing structure | Experimental Set-up and system configuration

System Reliability

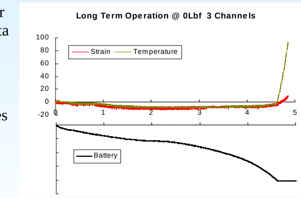


System reproducibility and Stability

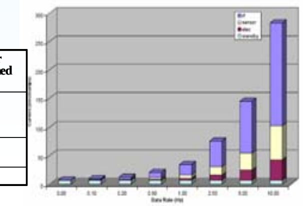


System reproducibility and Stability

- Experiments show that under continuous streaming the data transmission can take place only for about 4.5 hours
- Experiments show that RF signal transmission consumes most of the battery power
- Power consumption can be decreased by sensible use of microcontroller and radio sleep modes



Operational Mode	Power Consumed (mW)
Continuous transmission of sensed data from node to the base station	45
Logging and processing consumes	5.0
Sleep mode	0.02



CONCLUSIONS

A 916 MHz ASK Pulse code and a ZigBee 2.4 GHz 802.15.5 standard wireless nodes were evaluated for potential integration into an aircraft environment for structural health monitoring applications. Advantages and limitations are identified. The 2.4 GHZ system is identified to be least sensitive to environmental noise, possesses increased operational range, provides limited operation, due to the 4 to 5 hours limited operational life span of the 3.7V lithium ion internal rechargeable battery. Furthermore, a framework of ZigBee^{TM} based wireless sensor network is proposed and a feasibility study is carried out employing the PICDEM Z development kit with built-in temperature sensor.

FUTURE WORK

Further R&D needs to continue to address some high priority areas concerning the security of the data, the power requirement, and the WSN integration within an aircraft environment without impacting operational, maintenance and certification requirements. The effectiveness of the use of RFID as the backbone of a WSN is the subject of our future work as well.

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