IVHM System Integration Network Performance Analysis using Different Middleware Technologies and Network Structure

Rajkumar Choudhary
Researcher, IVHM Centre
Cranfield University
Cranfield, Bedford, UK
e-mail: r.choudhary@cranfield.ac.uk

Suresh Perinpanayagam
Lecturer at Cranfield University
Cranfield University
Cranfield, Bedford, UK
e-mail:s.perinpanayagam@cranfield.ac.uk

Eugene Butans
Senior Research Fellow, SATM
Cranfield University
Cranfield, Bedford, UK
e-mail: eugene.butans@cranfield.ac.uk

Abstract*—According to Aircraft Crashes Record Office (ACRO), total number of accidents occurred from 1999-2013 were 2556 in worldwide, were primarily due to loss-of-control in flight, controlled flight into terrain, and system/component failure. These accidents caused big capital loss for aircraft industry and 18987 deaths. Aircraft manufacturers are investing a huge amount of money to minimize these accidents by implementing new technologies, e.g., IVHM (Integrated Vehicle Health Management) in legacy and new generation aircraft. In aircraft industry, maintenance costs represent the third largest expense item after labor and fuel costs for both regional and national carriers with maintenance costs commonly comprising 15-18% of the operational expenses. By implementing IVHM technologies not only the maintenance costs can be reduced, also the fatality rate can be minimized. IVHM can provide more specific scheduled maintenance, onboard diagnostics and prognostics services. The aim of this paper is to investigate, about finding network architecture suitable for IVHM integration in vehicles (e.g., aircraft) that should be able to support interoperability between multiple vendors' IVHM components and insertion of new IVHM capabilities using simulation and optimization technique. To develop IVHM network architecture, essential data such as bandwidth, data rate, throughput, latency and performance in communication network will be collected using various enabling technologies (i.e., middleware) and OSA-CBM (Open System Architecture for Condition Based Monitoring) data model. Using simulation tools, e.g., OPNET (Optimized Network Engineering Tools), these sample data will be tested at large scale environment (e.g., aircraft or train). After simulation, multi-objective optimization will be used in trade-off analysis that aims to find cost effective and fully functional IVHM network architecture.

Keywords-Distributed systems; IVHM; systems integration; architecture; OSA-CBM; middleware

I. INTRODUCTION

According to Boeing, an airplane has an average economic life of about 27.2 years. [1] This life span can be further divided into three categories: airplane useful life, airplane economic life, and airplane service life. In maintenance and service, the aviation industry invest enormous amount of money, to keep the aircraft operationally available throughout in-service period of its life cycle. The IVHM emerges as an advanced diagnostics and prognostics techniques provider. IVHM technologies can impact in both acquisition cost and maintenance cost throughout the life cycle of aircraft by efficiently identifying and predicting failures to enable the effective planning of maintenance tasks [2].

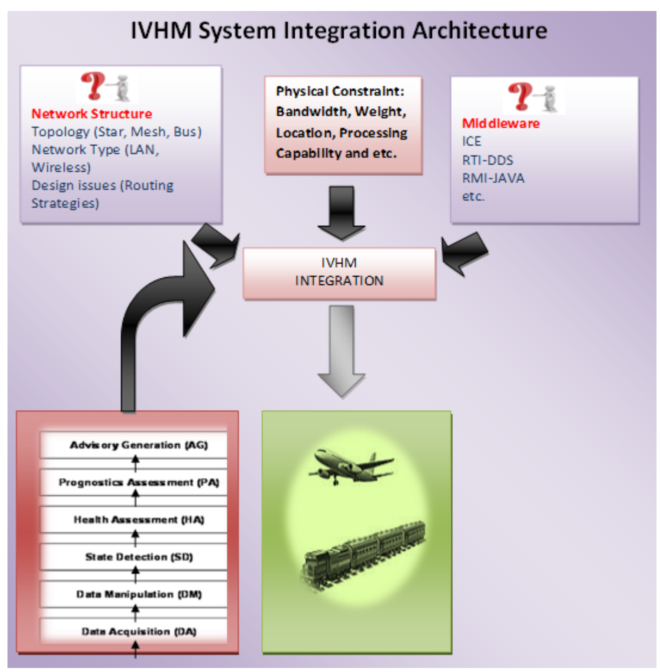

Figure 1. IVHM System Integration Architecture

This research is focused on Designing and Development of a Large-Scale IVHM Network Architecture using Multi-Objective Simulation Optimization. The architecture should be flexible and extensible that can directly support the implementation of upcoming

 ISBN: 978-1-61208-398-8

technologies of IVHM and various IVHM cooperate partners. Extensive research has been conducted by Boeing, Thales and other system integrators for system integration of IVHM. Most of the work has been done for development of individual subsystem and integration of IVHM on the aircraft. An adaptable architecture is required which can support interoperability between multiple vendors' IVHM components and insertion of new IVHM capabilities [2]. In the past, there have been very limited studies done on different approaches in integration of IVHM components. Aircraft industry is looking for scalable, flexible, economical and reliable network architecture for IVHM technologies integration in aircraft. Planning the reliability issues is necessary such as reliability of communication networks and reliability of Network costs. The penalties issue needs to be considered which may exceed the profits from the providing IVHM integration services. How to integrate this IVHM architecture in an efficient and cost-effective way to maximize the overall product rate is a challenge to the IVHM industry [3]. IVHM systems include sensors, processing units and software, which comes from multiple suppliers having different configurations. Several IVHM based projects are in progress for different technologies using various programming languages and contrary platforms by different organizations, for example: Integrated Intelligent Flight Deck (IIFD) Project and Aircraft Aging and Durability (AAD) Project. IVHM technologies can be developed following the OSA-CBM data model as a common standard. OSA-CBM (Open Source Architecture for Condition Based Monitoring) is developed by MIMOSA, which is based on ISO standards (i.e., ISO13374-1, ISO13374-2 and ISO13374-3).

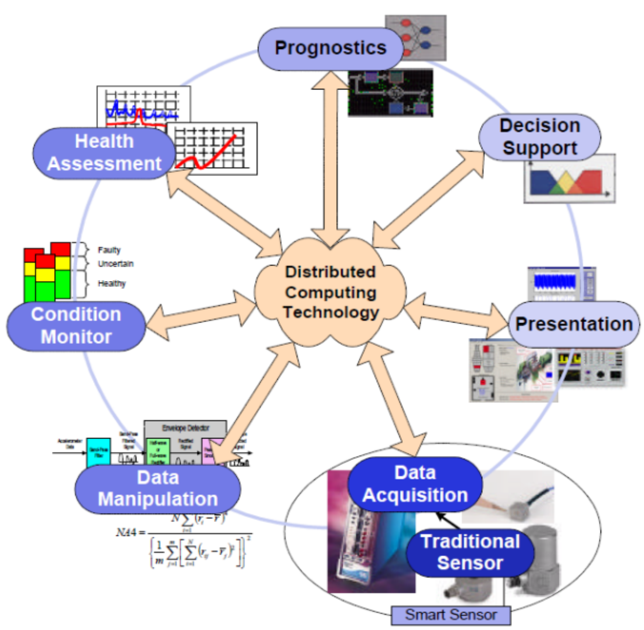

Figure 2. OSA-CBM Model developed by MIMOSA (Machinery Information Management Open Systems Alliance) [4]

As shown in Figure 2, OSA-CBM model consists of seven layers, which are Data Acquisition (DA), Data Manipulation (DM), State Detection (SD), Health Assessment (HA), Prognostics Assessment (PA), Advisory Generation (AG) and human interface layer.

All OSA-CBM based IVHM systems follow the same pattern. Various sensors are used to collect data in DA layer, which is later transformed into a suitable format in DM layer, and this data is then analyzed using knowledge discovery algorithms. The data from lower layers is used to know the current state of component in SD layer. In HA layer, the current health of the component is analyzed based on data collected from previous layers. The RUL (Remaining Useful Life) of subsystem and prognostics details are saved and can be assessed in PA layer. Later this data is required to be shared across maintenance departments to take appropriate actions such as arrangement of spare parts if problem in any component has been detected. The AG layer sends information to relevant department to take appropriate actions if any fault detected. Lastly, human interface layer provides information to access data in OSA-CBM model. The IVHM practitioners are facing difficulties with determining the best method for interconnecting the system's components via communication networks. There is a need to tackle many issues for building large network architecture such as bandwidth saturation events (Point in which all available bandwidth is used up), broadcast impact on CPU processing, unpredictable reachability, address collision, unused duplicate circuits, non-optimal routing, limited network management, isolated configuration control and support a multi-protocol environment [5].

The addition of IVHM capabilities shall be further explained in Section II. The network architecture requirements related to IVHM technology insertion and an open systems approach to systems integration are covered in Section III. Section IV covers the modeling to evaluate the network performance of different IVHM implementations. The result of experiments is discussed in Section V. Lastly, the conclusion is covered in Section VI.

II. INSERSION OF IVHM CAPABILITIES

A typical IVHM system involves many different components that vary in bandwidth demand. IVHM system needs to be able to support multiple types of interconnection networks for hardware and software components that are dramatically different in their routing capabilities. Study of information exchange between the different subsystems and the system level is highly recommended for insertion of IVHM capabilities, which is essential for communication issues, synchronization, and input/output functionality [6]. The IVHM network architecture must provide a methodology for adding future network technologies without affecting existing IVHM components and interoperability across existing interconnection networks. The IVHM is facing difficulty with determining the best

 ISBN: 978-1-61208-398-8

way for interconnecting its components via communication networks. There is a need to tackle many issues for building large network architecture such as bandwidth saturation events, broadcast impact on CPU processing, unpredictable reachability, address collision, unused duplicate circuits, non-optimal routing, limited network management, isolated configuration control and support a multi-protocol environment [5]. The physical constraints of IVHM architecture are Acquisition of high fidelity data, cost of certification, limited communication Bandwidth, limited local processing, post flight test maturation, size, weight and power [7]. In order to overcome these constraints the IVHM architecture should incorporate various features such as Health ready subsystems (e.g., generator (IDG (Integrated Drive Generators)), open system (e.g., OSACBM), hierarchical-and-Distributed, partitioning of flight and Enabling technologies (e.g., Chafing protection system) [8]. An IVHM system is more than just a set of IVHM technologies. The technologies must work together in a realistic environment and must provide significant safety improvements to justify the development, integration, and costs associated with these technologies [6].

III. ARCHITECTURE REQUIREMENTS

A. *Available middleware technogies for implementation of IVHM Systems*

Middleware-enabling technologies are now used for distributed real-time and embedded (DRE) systems that control communication among devices in physical, chemical, biological, or defense industries [8]. Middleware that can satisfy stringent quality of service (QoS) requirements, such as predictability, latency, efficiency, scalability, dependability and security, can be used for development of IVHM network architecture.

TABLE I ENABLING TECHNOLOGIES –MIDDLEWARE [9]

Distributed Data Model	Middleware	OSA-CBM		Mapping Language	Protocol	Data Bus	Standard
		Interface	Data Model				
Client/Server	CORBA (TAO/JacORB)	Yes	Valuetype (from CORBA ver.2.3)	IDL	UDP (TAO), TCP	Ethernet, AFDX	OMG's CORBA
	ICE	Yes	class	Slice	UDP, TCP	Ethernet, AFDX	Proprietary
Publish/Subscribe	IceStrom	Yes	class	Slice	UDP, TCP	Ethernet, AFDX	Proprietary
Data Distribution service	RTI DDS	No	valuetype (Proprietary Extension)	IDL, XML	UDP, TCP	Ethernet	OMG's DDS-DCPS
	OpenSplice	RMI Extension	valuetype (DLRL)	IDL	UDP, TCP	Ethernet	OMG's DDS-DCPS /DLRL

Acronyms: AFDX –Avionic Full-Duplex Switched Ethernet, DCPS –Data Centric Publish/Subscribe, DDS –Data Distribution Service, RMI –Remote Method Invocation, TAO –C++ Implementation of CORBA, TCP –Transmission Control Protocol, DLRL –Data Local Reconstruction Layer, IDL –Interface Definition Language, JacORB–Java Implementation of CORBA, OMG –Object Management Group, UDP –User Datagram Protocol, XML –extensible Markup Language

In Table 1, a detailed comparison of important distributed computing object middleware technologies, which include ICE, IceStrom, RTI DDS, OpenSplice and CORBA on the basis of mapping language, protocol, data bus, standard, and OSA-CBM framework support, has been done [9].

IVHM subsystems can be implemented using any of these distributed data models: Client/Server, Publish/Subscribe and Data Distribution service. Different middleware supports different Distributed Data Model, e.g., ICE middleware supports Client/Server. All middleware use some kind of mapping language which provides interoperability. TCP and UDP are the most common protocols. CORBA, ICE and IceStorm can work on both Ethernet and AFDX data bus whereas RTI DDS and OpenSplice support only Ethernet.

Client/Server model utilize OSA-CBM interfaces and supports the required data flow characteristics (i.e., trigger by state changes or push all). It has an advantage of simplicity but the disadvantage is its direct connection between IVHM subsystems (i.e., tightly coupled).

Publish/Subscribe model uses Publish/Subscribe server as a global data space which manages data subscriptions and responsible for data delivery. It is loosely coupled as there is no direct connection between IVHM components. It has some disadvantages such as single point of failure and data latency (i.e., Data takes longer to deliver).

Data Distribution service combines various Publish/Subscribe server. Localized Publish/Subscribe server carries out data delivery. The service named dynamic discovery is used to find out IVHM components and what data are available for them. Removing or upgrading a subsystem will not affect other subsystems.

B. *OSA-CBM and its interfaces to implement IVHM systems*

The OSA-CBM specification is a standard architecture for moving information in a condition-based maintenance system. A more in depth look reveals a way to reduce costs, improve interoperability, increase competition, incorporate design changes, and further cooperation in the realm of condition-based maintenance [10]. Open system IVHM architecture can be built using OSA-CBM standard. OSA-CBM focuses on IVHM functionality and associated data models. Most OSA-CBM works are from Boeing, GE Aviation and ARL. Research need to be done on how OSA-CBM can be implemented or how IVHM architecture can be designed to compliant with OSA-CBM. An example of communication between two IVHM components using RMI-Java middleware and OSA-CBM data model is shown in Figure 3.

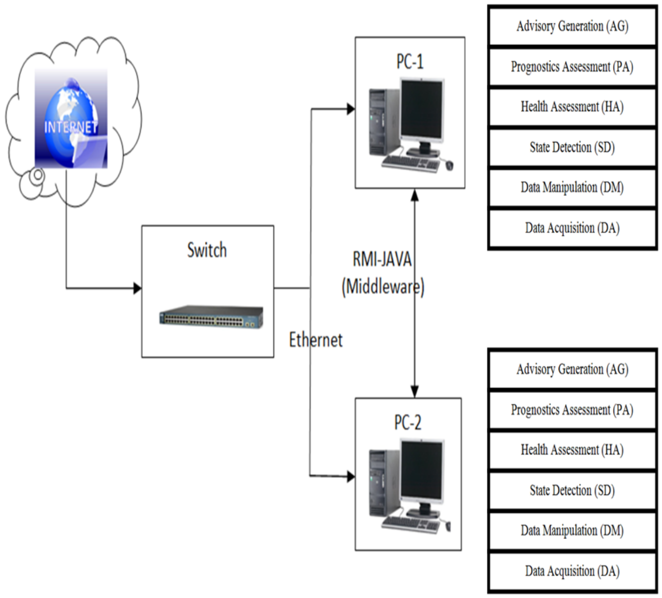

Figure 3. Communication between two IVHM Components using RMI-Java middleware and OSA-CBM data model

IV. MODELLING AND EXPERIMENTS

A. *RMI-Java Latency performance test:*

Hardware and software used for experiment:

PC1 CONFIGURATION : Intel Pentium CPU 2127U @ 1.90GHz, RAM – 4 GB, Windows 8.1 – 64bit Operating system

PC2 CONFIGURATION : Intel Pentium CPU 2127U @ 1.90GHz, RAM – 4 GB, Windows 8.1 – 64bit Operating system

Software used : Netbeans IDE 8.0.1
Java version : JDK 1.7
Middleware : RMI-Java
Data Model used : OSA-CBM
Overhead included from : OSA-CBM, RMI-Java Middleware and etc.

For experimental setup, two PCs (Personal Computers) are used to create a Client/Server model. Server acts as a service provider, and a client that acts as a service receiver. OSA-CBM is implemented in both as a common data model.

TABLE II RMI-JAVA LATENCY TEST

Data Transfer Size (bytes)	Latency per Data Transfer (milliseconds)
8	0.01969
16	0.03328
32	0.06769
64	0.12925
128	0.25379
256	0.51476
512	1.06714
1024	2.0008
2048	4.1136
4096	8.8302
8192	17.458

In Table II, the intention is to find the performance of RMI-Java using OSA-CBM data model by increasing the size of data.

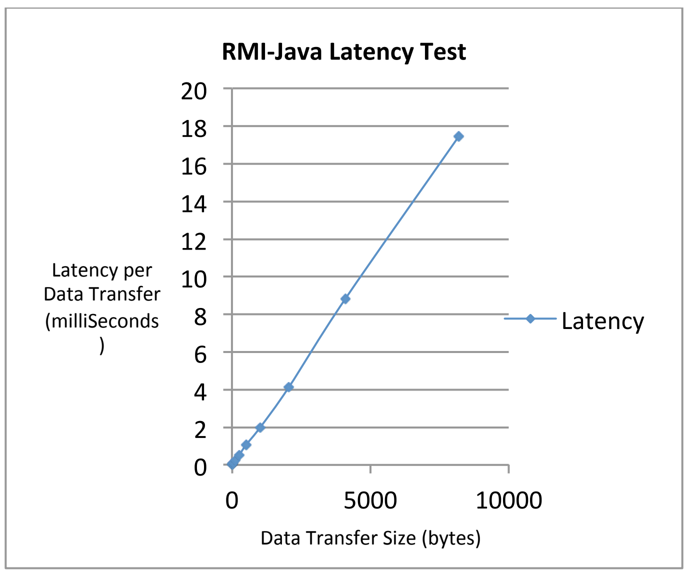

Figure 4. RMI-JAVA Latency test

Figure 4 illustrates the performance test of RMI-Java, based on latency and data size.

B. *RMI-Java Throughput performance test:*

Throughput (Kbit/second) = (Latency per data transfer (ms)/1000) *(data transfer size (bytes)/1000) * 8

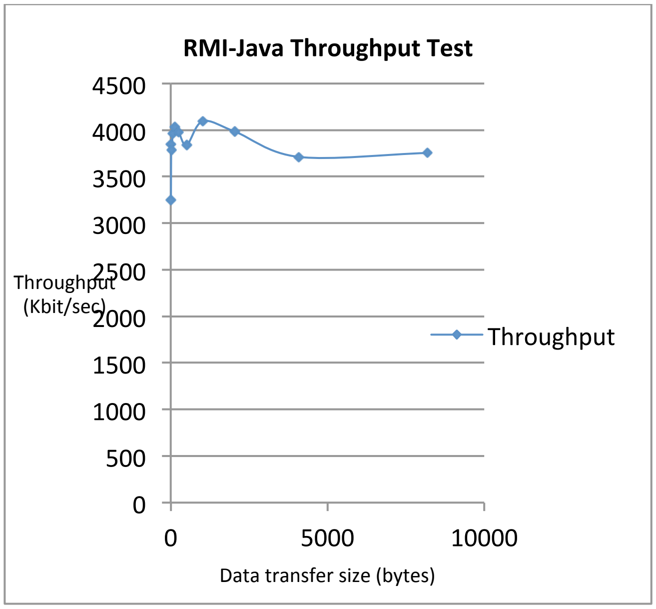

Figure 5. RMI-JAVA Throughput test

In this section, the throughput is calculated using values from Table II and the result is shown in Figure 5.

V. RESULTS AND DISCUSSION

As the work in progress, the result shows the performance of one middleware which is RMI-JAVA. RMI-JAVA shows low and predictable latency that scales linearly with message size. The performance test on ICE, RTI-DDS will also need to be done. The result aims to find the best system integration network architecture for IVHM. IVHM brings more sophisticated condition based maintenance system and problems at the same time, to synchronize with existing components and adapt with upcoming upgrades of the components. And, the components belong from different vendors with different configurations. After comparing several different enabling technologies (e.g., RTI-DDS middleware, ICE, CORBA and IceStrom), different mode of networks (e.g., LAN, WAN and wireless), different distributed data mechanism (e.g., Client/Server, Publish/Subscribe and Data Distribution service), different protocols (e.g., UDP and TCP/IP) and different network topologies (e.g., Star. Mesh and Ad-Hoc), this project will focus on implementing IVHM technologies on aircraft (vehicle) using best open system distributed communication system.

VI. SUMMARY AND FUTURE WORK

In summary, this project is about simulating IVHM Architecture and optimizing related parameters to find out a suitable way of system integration. The literature review can be generalized in six respects which are Aerospace operation and maintenance, IVHM, System integration, Network embedded, modeling and simulation at large scale platform (vehicle) network and simulation optimization. The research problem is to find out a suitable IVHM System integration strategy and how the strategy influence the QOS and cost to the IVHM systems which will be used in the IVHM implementation in vehicles(e.g., aircraft). Main data of the model, such as type of Data and network requirements of the related IVHM subsystems will be collected in the later months. Data characteristics (e.g., Bandwidth requirement, data speed and data security) will be collected using OSA-CBM model with different middleware technologies (e.g., ICE and RTI-DDS). An automated design environment will be created which can be used to find best possible network for IVHM integration.

REFERENCES

[1] Helen Jiang. (2013, Mar.) aircraft_economic_life_whitepaper.pdf. [Online], Accessed: [2014,Dec] http://www.boeing.com/assets/pdf/commercial/aircraft_economic_life_whitepaper.pdf

[2] T. Sreenuch, "PnP IVHM Architecture IVHM Seminar," , Cranfield University, Cranfield, 2010.

[3] Kirby Keller, T Dave Wiegand, Kevin Swearingen, Chris Reisig, Alan Gillis, MikeVandernoot, , "An architecture to implement Integrated Vehicle Health Management systems," *IEEE*, vol. 1, pp. 2-6, 2001.

[4] MIMOSA. MIMOSA. [Online], Accessed: [2015,Jan] http://www.mimosa.org/?q=node/350

[5] JeffryS.Yaplee and Robert 0.Denney "Building a Large Network at the Boeing Company," *IEEE*, vol. 1, pp. 20-22, 1988.

[6] Principal Investigator: Ashok N. Srivastava, Ph.D. Project Scientist: Robert W. Mah, Ph.D. Project Manager: Claudia Meyer, (2009) National Aeronautics and Space Administration. [Online], Accessed: [2015,Jan] http://www.aeronautics.nasa.gov/nra_pdf/ivhm_tech_plan_c1.pdf;

[7] Kirby Keller, Jim Peck, Kevin Swearingen, and Dan Gilbertson, "Architecture for Affordable Health Management," *AIAA*, vol. 1, pp. 1-3, 2010.

[8] Nanbor Wang. Douglas C. Schmidt, and. Aniruddha Gokhale (2014, Aug.) QoS4DRE.pdf. [Online], Accessed: [2014,Dec] http://www.cs.wustl.edu/~schmidt/PDF/QoS4DRE.pdf

[9] T. Sreenuch, "PnP IVHM Architecture," in *IVHM Seminar*, Cranfield University Cranfield, 2012, p. 10.

[10] MIMOSA. [Online], Accessed: [2015.Jan] http://www.mimosa.org/?q=resources/specs/osa-cbm-330

[11] OptTek Systems Inc. [Online], Accessed: [2015,Jan] http://www.opttek.com/OptQuest

[12] Jacob H. Christensen ,David B. Anderson, Bryan D. Hansen "Scalable Network Approach for the Space Plug-and-play Architecture," *IEEE*, vol. 6, 2012.

[13] Mostafa Fazeli, "Assessment of throughput under opnet modeler simulation tools in mobile ad hoc networks(MANETs)," *IEEE*, 2011.

[14] T. Sreenuch, A. Tsourdos I.K Jennions, "Distributed embedded condition monitoring systems based on OSA-CBM standard," *CSI*, pp. 238-246, 2012.

[15] Sumair Khan, "Performance Comparison of ICE, HORB, CORBA and Dot," *International Journal of Computer Applications*, vol. 3, 2010.

[16] Kalyan Perumalla, Alfred Park, Hao Wu, Mostafa H. Ammar Richard M. Fujimoto. Large-Scale Network Simulation: How Big? How Fast? [Online], Accessed: [2014,Dec]

 ISBN: 978-1-61208-398-8

http://www.cs.mcgill.ca/~carl/largescalenetsim.pdf

[17] Shahrul Kamaruddin Rosmaini Ahmad, "An overview of time-based and condition-based maintenance in industrial application, Pages 135–149," in *Computers & Industrial Engineering*.: Computers & Industrial Engineering, August 2012, vol. 63. [Online], Accessed: [2015,Jan]. http://www.sciencedirect.com/science/article/pii/S0360835212000484

[18] Richard E. Schantz and Douglas C. Schmidt, "Middleware for Distributed Systems," vol. 1, no. 1. [Online], Accessed: [2014,Dec] https://www.dre.vanderbilt.edu/~schmidt/PDF/middleware-encyclopedia.pdf

[19] T Sreenuch, "IVHM CONOPS," in *IVHM Seminar*, Cranfield University Cranfield, 2012.

[20] Grant A. Gordon, Honeywell Laboratories Dimitry Gorinevsky, "Design of Integrated SHM System for," vol. 1, no. 1, 2005.