AC 2010-2417: WORK IN PROGRESS: TEACHING WIRELESS SENSOR NETWORKS THROUGH LABORATORY EXPERIMENTS

Paul Cotae, University of the District of Columbia

Dr. Paul Cotae, Associate Professor of Electrical and Computer Engineering has more than 25 years of experience in the communication field (research and education). He received a Dipl. Ing. and a M.S. degrees in communication and electronic engineering in 1980 from the Technical University of Iassy and a Ph.D. degree in telecommunications from "Politechnica" University of Bucharest, Romania in 1991, and a Master in Applied Mathematics in 1998 from the University of Colorado at Boulder. From 1994 to 1998 he spent four years at the University of Colorado at Colorado Springs and the University of Colorado at Boulder as a Fulbright Scholar and Visiting Associate Professor doing research and teaching in ECE department and APPM department. He served also as a consultant to Navsys Corp., Colorado Springs, in 1997. From 2002 to 2008 he was with the Department of Electrical and Computer engineering at the University of Texas at San Antonio (UTSA). From 1984 to 2001, he was with the Department of Electrical Engineering, Technical University of Iassy, where he conducted research and teaching in the area of digital communications as a Full Professor at the same department. Since 2008, he has been with the University of the District of Columbia as an Associate Professor. His current research interests include multiple access, modulation and coding, mobile communications, and digital communication systems. He has authored or coauthored more than 100 papers in these areas and four books. Dr. Cotae serves as an Associate Editor for IEEE Communication Letters, EURASIP Journal on Signal Processing, Elsevier International Journal of Computers and Electrical Engineering (JCEE), and he has been on the Technical Program Committee and Session chair of the IEEE Conferences GLOBECOM (2003-2009), VTC Spring 2005, 2006 and ICC 2005-2009. He is a Senior Member of IEEE, member of ASEE, member of HKN (Eta Kappa Nu) and SIAM. He is cited in Who's Who in American Education, Who's Who in America, and in Who's Who in the World. He has been nominated two times for the best teacher award (2005 and 2006) in the College of Engineering at UTSA. He is the IEEE Director and IEEE ComSoc chair Whasington DC Section. He is Faculty Fellow for ONR-ASEE Summer Faculty Research Program.

Esther Ososanya, University of the District of Columbia

Dr. Esther T. Ososanya is a professor of Electrical and Computer Engineering at the University of the District of Columbia. During her career, Dr. Ososanya has worked for private industry as a circuit development engineer and as a software engineer, in addition to her academic activities. She received her education in the United Kingdom, where she achieved her Ph.D. in Electrical Engineering from the University of Bradford in 1985. She was also a Visiting Professor at Michigan Technological University for five years, and an Associate professor at Tennessee Technological University for 7 years prior to arriving at the University of the District of Columbia in the Fall of 2001. Dr. Ososanya is interested in new applications for VLSI, MEMS, parallel processing, and pipeline architecture. In recent years, she has worked with colleagues to apply these technologies to such environmental problems as watershed monitoring and management, Biosensors, and Sustainable Energy applications.

Lily Kemathe , University of the District of Columbia

Lily Kemathe is a senior student in the Senior Design Class of the Spring of 2010 at the University of the District of Columbia

Suresh Regmi, University of the District of Columbia

Suresh Regni is a senior student in the Digital Communication Class and the Senior Design Class of the Spring of 2010 at the University of the District of Columbia

Kamden Patrice Kouam, The University of the District of Columbia

Kouam Kamden Patrice is a student in the Digital Communication Class and in the Senior Design Class of the Spring of 2010 at the University of the District of Columbia

Work in Progress: Teaching Wireless Sensor Network Communication through Laboratory Experiments

Abstract

Wireless communications is becoming a transparent technology with which incoming college students most certainly have vast firsthand experience as users. Wireless Sensors Network Communications often proves to be a quite challenging subject to teach because many students appear to find the subject too technical. In this paper, we present some undergoing capstone design projects and laboratory experiments to provide the students of wireless communication and networking with a hands-on experience. The motivation of this approach is twofold. First, the projects pertain to the area of wireless sensor networks where rapid technological changes in wireless sensing devices have changed the types of work electrical and computer-engineering students are likely to do in their careers. Second, student groups come up with their own project applications and problem statements for which to design a system.

1. Introduction

The academic field is undergoing significant changes correspondent to the revolutionary advances in technology. Nowadays, more students have full time jobs or family obligations, which negatively affect on the frequency of student visits to the classes or labs. One of the enormous opportunities modern technologies provide lies in the effective use of computers and the Internet as potent educational tools. In the last few years, many universities have successfully used Internet based distance learning technologies.

This article discusses the possibility of teaching wireless sensor network communication through laboratory experiments. We focus on the following experiments: optimum placement of sensors in wireless sensor networks [3], [19], [21], sensor placement for effective diagnosis of multiple faults [5],[7],[8],[10], and continuous health monitoring using wearable biosensors [4]. For each project we presents the related work, how the proposed project is different, the requested equipment within the undergoing experiment and the anticipated results. We also focus the major educational activities [1], and provide the list of hands-on projects to be developed. We anticipate that the full project will be completed in the next 18 months.

2. Laboratory experiments

2.1 Optimum Placement of Sensors in Wireless Sensor Networks

Energy efficient system design in wireless sensor networks has become the top priority in order to provide the maximum possible lifetime of a given network [3]. Many communication, power management, and data dissemination protocols have been specifically designed for Wireless Sensor Networks where energy awareness is an essential design issue. Wireless communications between sensors requires more energy than the sensing and computational part of each node. As the distance between nodes grows, the power needed to transmit has to increase to overcome attenuation in the medium and achieving sensitivity of the receiver. The transmission range of the radio on a sensor is limited [4]. Even at the highest power setting, attenuation of the signal is so great that only a short distance (sometimes 9 meters) from the node and the receiver, sensitivity is such that the receiver is receiving only noise [2].

In **Fig. 1** a) we performed an experiment where we deployed randomly a number of sensors on a given surface. Based on the developed algorithms, the optimum placement of sensors (for measuring i.e. the temperatures) is obtained and is represented in **Fig. 1** b). This figure is the enlargement of the picture shown on the laptop.

Related work: Sensor nodes that route data from other sensors not only have to transmit data but other nodes as well. Computation of the correlation and entropy of received data with the data gathered at routing nodes uses more energy and length of transmission is greater at these nodes [9],[11].

How ours is different: Given the sensing locations, the fundamental problem is to determine the optimal locations of nodes together with optimal energy provided to them so that the network is alive during the desired lifetime with minimum energy consumed [3,4].

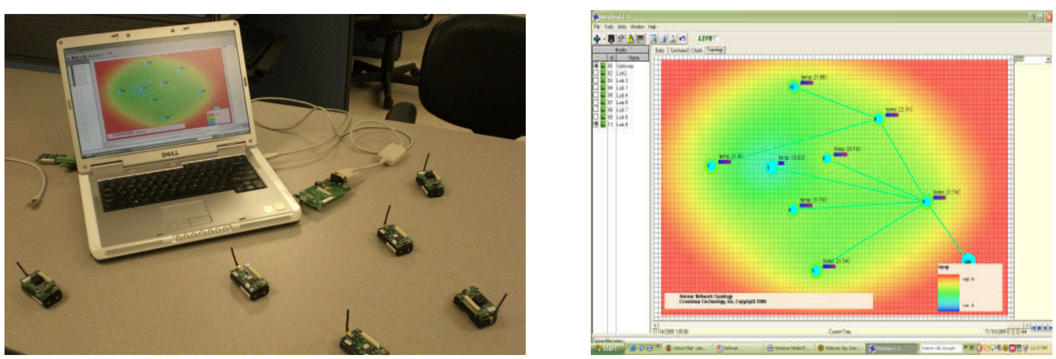

Figure 1: a) Random placement b) Optimal placement

Requested equipment within the proposed experiment: This laboratory experiment project focuses on the optimal placement of the nodes. The optimal power setting of the transmitter is such that the Receiver Signal Strength (RSS) at the receiver is greater than the sensitivity at the receiver while the bit error rate (BER) is able to remain in a given range during the desired lifetime of the network. This research laboratory project also deals with the optimal base station(s) placement (with its unlimited power supply) situated centrally in such a way as to reduce the power consumed by nodes during communication of sensors data.

Results: The software package for the optimal placement of the nodes that can be delivered with the Received Signal Strength Indicator (RSSI) at the receiver and energy consumption at the transmitter. The deliverable software is interoperable and can be set at the lowest power necessary to overcome attenuation in the medium and sensitivity in the receiver.

2.2 Sensor Placement for Effective Diagnosis of Multiple Faults

In engineering practice, measured data are always inaccurate because of the existence of parameter variation or noise. In such cases, questions arise naturally, i.e., are the conventional studies on the determination locations insensitive to parameter variation or noise during system identification, or damage detection. This project thrust aims to develop a sensor placement methodology for effective fault diagnosis [12],[13],[15],[18]. The proposed framework will be built on the effective independence and sensor computational algorithms that start with all feasible sensor locations and reach the desired number of locations by eliminating those having the least contributions to the fixture faults. The least squares method will be used to identify fixture faults from measurement data [17]. The proposed project enables the effective identification of multiple fixture faults even in the presence of moderate measurement noise. The diagnosis of fixture failure in real automotive parts demonstrates the use of the proposed methodology [14],[16],[20].

Experimental plan: The implementation procedure for determining the optimal placement of sensors consists of the following steps:

1) First generate a random matrix. Algorithms to generate such matrices are given in Matlab;
2) Generate a data matrix of the designated pattern vectors;
3) Find the Fisher Information matrix associated to this matrix;
4) Calculate the determinant for the Gram matrix for each sensor using our method. This is done by deleting the rows and columns of matrix corresponding to the sensor reading with lowest interference, thus providing effective independence for the chosen sensor location
5) Remove the sensor which has least determinant from the data matrix by obtaining the matrix,
6) Add the next column from the matrix of data in order to update the Gram matrix with a new sensor. This procedure is repeated until an optimum matrix is obtained with all optimum sensor location sets. A preliminary example is given in Fig. 2a) together with collected experimental results in Fig. 2b).

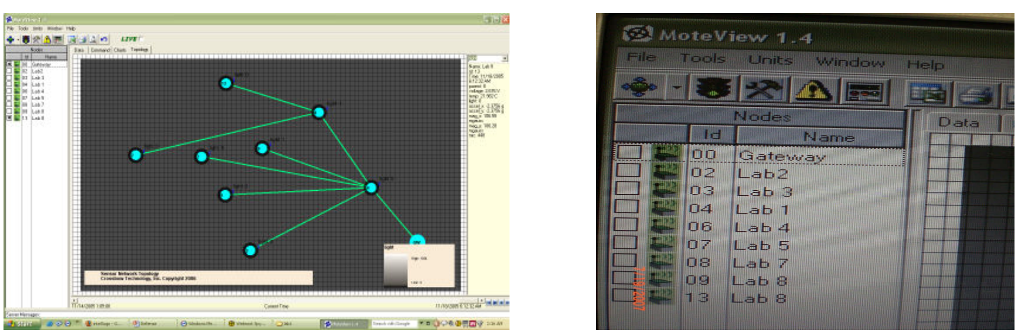

Figure 2: a) Effective identification of multiple fixture faults b) Experimental results

Related work elsewhere: Significant research has recently been conducted in the diagnosis of fixture faults. Each pattern is defined such that it represents a certain displacement mode of the part. The corresponding designated patterns are calculated by projecting the actual measurement data on to the designated patterns. The designated patterns must be mutually orthogonal which accounts for most of the variability in the data, which can then be identified. A relation between the designated patterns and each case of single and multiple fixture faults is determined in the afterward. Fixture faults may be diagnosed using the pattern –fault relationship.

How ours is different: We propose a methodology for optimal placement of sensors to be used in the diagnosis of multiple fixture faults in compliant parts using the Gram matrix approach [13]. In addition, a methodology for the diagnosis of multiple fixture faults considering compliant parts is presented and it is illustrated in **Fig 3**. The diagnosis methodology uses the least squares approach to estimate the fixture fault vector from measurement data. It also uses finite element analysis to fully consider the compliance of the part to find the diagnostic vectors, termed “designated patterns.” The diagnosis of fixture failures in real automotive parts demonstrates the use of the proposed methodology [20].

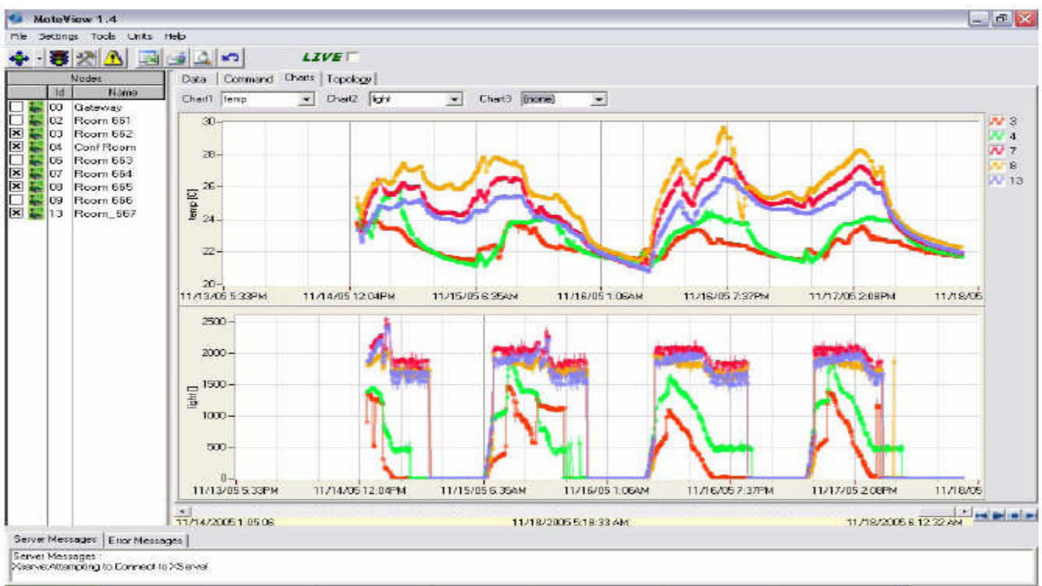

Figure 3: Screenshot of the database in Chart View

2.3 Continuous Health Monitoring Using Wearable Biosensors

For hospital inpatients that require continuous health monitoring, current biosensor technology typically tethers patients in a tangle of cables, whereas wearable sensors could increase inpatient comfort and may even reduce the risk of tripping and falling, a perennial problem for hospital patients who are ill, medicated, and in an unfamiliar setting. On a daily basis, wearable sensors could detect a missed dose of medication by sensing untreated elevated blood pressure and could trigger an automated reminder for the patient to take the medication. In this project we focus on miniaturized, telemetric, photoplethysmograph (PPG) sensors for long-term, continuous monitoring. The Crossbow MIB510 sensor board uses base stations and other motes for sending the required information. An example of environment programming [22],[23] is shown in **Fig. 4.**

The recognized signals are sent to the nearby computer where the required simulation is done. The results obtained are launched in real-time for the patient monitoring. The distances between the ring sensor and the host computer are increased in due intervals and the results are tabulated. The Ring Sensor is further developed for other medical applications such as detection of Arthritis and Kidney Diagnosis.

Related work elsewhere: Currently wearable physiologic parameters make up the "vital signs" that are the most important information in emergency medical situations; wearable biosensors might enable a wireless monitoring system for large numbers of at-risk subjects. This same approach may also have utility in monitoring the waiting room of today's overcrowded emergency departments.

How ours is different: The whole sensor system will run continually using a small battery. Several ways to deal with these problems are:

i) secure the photo detector at a location along the finger skin such that the dc component may be influenced less by the finger motion,

ii) attenuate the influence of uncorrelated ambient light as well as reducing power consumption,

iii) increase the amplitude of the ac component so that the signal-to noise ratio may increase,

iv) measure the finger motion with another sensor.

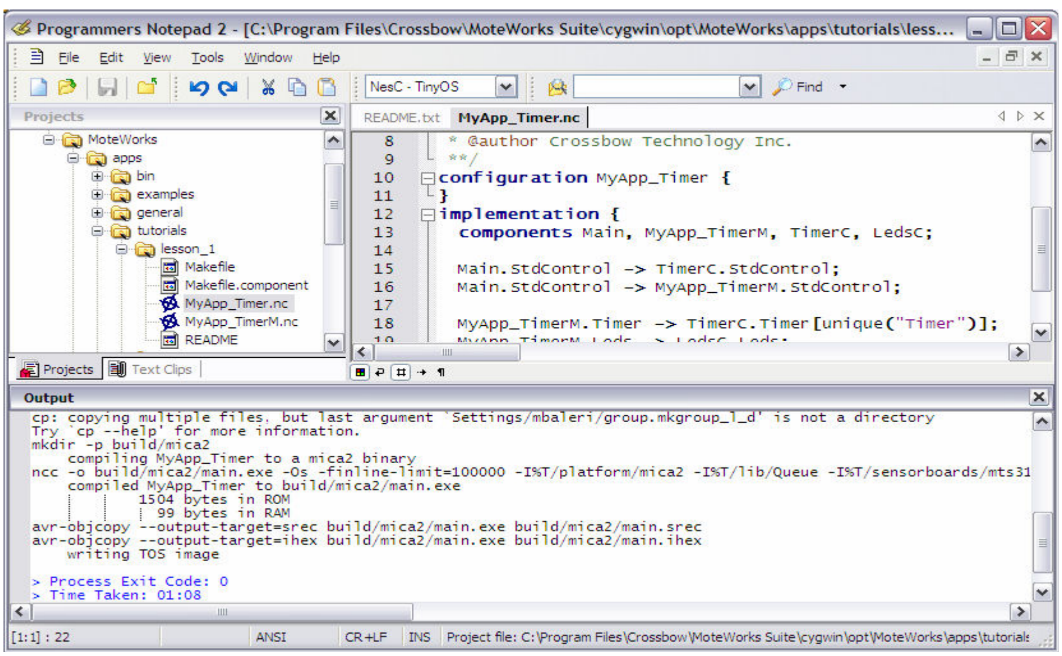

Figure 4: Screen Shot of Programmers Notepad

.

Requested equipment within the proposed project: The proposed lab research will develop a new type of sensor, called a "ring sensor," which is attached to a finger base for monitoring beat-to-beat pulsation; the data is sent to a host computer via a radio-frequency transmitter. Two major design issues are addressed: minimizing motion artifact and the other minimizing the consumption of battery power. An efficient double ring design is developed to lower the influence of external force, acceleration, and ambient light, and to hold the sensor gently and securely on the skin, so that the circulation in the finger may not be obstructed. A prototype ring sensor will be designed and tested. The efficient ring sensor design for continuous monitoring of a patient using the MIB510 serial interface sensor board is the main proposed deliverable for the project. The MIB510 allows for the aggregation of sensor network data on a PC. Any MICAz node is used as a base station for the MIB510 sensor board [22]. For all these projects completion chart is presented in Table I.

Table I Milestones

No.	Task name	Time (months) taken for completion
1.	Initial Start up (Collection of articles and Purchasing the sensors)	1
2.	Planning the experimental setup	1
3.	Initialization of the Motes and working of the sensors	1-2
4.	Combining the sensors with MATLAB for Simulation	1
5.	Simulation of the whole system	1
6.	Application based Real-time launching of the sensors	1-2
7.	Taking real life examples for the operation of the ring sensors over increased distances	1-2
8.	Implementing the sensors for other medical applications (like Arthritis, Kidney Diagnosis)	1
9.	Writing the report for the entire experiment	1-2
10.	Reviewing and editing the final report	1

3 Educational Activities

The following summarizes the educational goals for the teaching wireless sensor network communication through laboratory experiments project:

3.1 Development of student networks and peer support programs: We will implement a "hands-on computing design database" and widely disseminate them as educational units for broadening student participation in computing and wireless sensor networks. It will help to increase the involvement of minority and other underrepresented students. The concept is a systematic approach to collect peer expertise for dissemination among other students.

3.2 Involvement in research projects from students and their preparation for advanced graduate studies and/or successful careers in electrical engineering. We will implement the concept of hands-on design modules' collection. The dissemination of the project database will expose available research expertise in computing as many projects will originate from various research teams. At the same time, a system of rewarding for best submitted hands-on designs will drive students to join research groups and prepare competitive submissions. The formalized approach of design reporting and documentation can be used for knowledge transfer between student generations and will support vertically integrated research teams. Research effort is facilitated through peer-to-peer and faculty-to-student contacts. In addition, the proposed concept will motivate faculty to encourage student participation for better motivation and additional financial (award) support.

3.3 Development of a portal for dissemination of hands-on projects and associated documentation: We will connect the design portal with the "Senior Design" website and will be jointly maintained using Electrical and Computer Engineering (ECE) Department resources. The hands-on electrical engineering and computing design modules will be aggregated topically for easier access.

3.4 Integration of the proposed effort with ongoing retention, recruitment, and outreach programs at the ECE Department of the University of __. Our project in teaching wireless sensor network communication through laboratory experiments will be integrated in ongoing efforts of applying best practices in peer-to-peer tutoring and joint mentorship programs. Proposed hands-on design modules are very suitable for tutoring. The project will contribute in recruiting minority students from local high schools and community colleges as our database, demonstrations and dissemination will improve university research visibility. Thus the proposed project activities and dissemination of results is in line with the aggressive ongoing outreach programs.

4. Examples of hands-on projects

- Implement an illustrative compression kit for PC (Matlab [24], Labview [25]) and wireless devices.
- Implement two-way software radios for various signaling sources.
- Implement simple sensor-server link using Crossbow kits [22].
- Implement algorithms for ring sensors using Arch Rock Primer Pack/IP development software [23].
- Development of mathematical algorithms for reducing the determinamt of the Gram matrix.
- Deliverable software for Effective Diagnosis of Multiple Faults.

5 Conclusions

Collaboration among STEM disciplines is needed for meaningful education in wireless sensor networks. This paper focuses on the technological aspects of wireless sensors networks focusing on optimum placement of sensors in wireless sensor networks, sensor placement for effective diagnosis of multiple faults, and continuous health monitoring using wearable biosensors. We discuss some challenges that were encountered and how were overcome. The novel aspect of our work was the high level of involvement at all technical levels by undergraduate students. Future undergraduate research areas are explored with suggestions how wireless sensor networks topics can infuse knowledge into undergraduate education.

Bibliography

[1] Paul Cotae, Ester Ososanya, Wagdy Mahmoud, Lavita Witherspoon, Damaine Sweeney, Nirmal Sharma Chapagai, "Design and Application of a distributed and Scalable Underwater Wireless Sensor Acoustic Networks" 2009 Annual ASEE Global Colloquium on Engineering Education, Budapest Hungary, Oct. 12-15, 2009.

[2] Paul Cotae, Fatou Diop Mbengue, " On the Power Efficient Resource Allocation for the Overloaded Multipath CDMA Systems", 2009 IEEE Sarnoff Symposium, Princeton, NJ, pp.1- 6, March 2009.

[3] Paul Cotae, Sireesha Yalamanchili, C.L. Philip Chen, Arturo Ayon, "Optimization of sensor locations and sensitivity analysis for engine health monitoring using minimum interference algorithms", EURASIP Journal on Advances in Signal Processing, vol. 2008, Article ID 280346, 9 pages, doi:10.1155/2008/280346, Jan. 2008.

[4] E. Serpedin, H. Li, A. Dogandzic, H. Dai and Paul Cotae, "Distributed Signal Processing Techniques for Wireless Sensor Networks"(editorial), EURASIP Journal on Advances in Signal Processing, vol. 2008, Article ID 540176, 2 pages, doi:10.1155/2008/540176, Jan. 2008.

[5] A. Khan, D. Ceglarek, J. Shi, J. Ni and C.T. Woo, "Sensor optimization for fault diagnosis in single fixture systems: a methodology,'' Journal of Manuf. Sci. Eng., vol. 121, pp. 109–117, 1999.

[6] D. Ceglarek and J. Shi, "Dimensional variation reduction for automotive body assembly", Manuf. Rev., vol. 8, pp. 139–154, June 1995.

[7] D. Ceglarek and J. Shi, "Fixture failure diagnosis for auto body assembly using pattern recognition", Transaction of ASME, Journal of Eng. Ind.., vol. 118, pp. 55–66, 1996.

[8] D. Apley and J. Shi, "Diagnosis of multiple fixture faults in panel assembly, "Journal of Manuf. Sci. Eng., vol. 120, pp. 793–801, 1998.

[9] D. Djurdjanovic and J. Ni, "Stream of variation based analysis and synthesis of measurement schemes in multi-station machining systems", Proc. of the 2001 ASME international Mechanical Engineering Congress and Exposition, New York, NY, 2001

[10] D. Kammer, "Optimal sensor placement for modal identification using system realization methods", J. of Guid. Control and Dyn., vol. 19, pp. 272–731, 1996.

[11] G. C. Franchi, and D. Gallieni, "Genetic-algorithm-based procedure for pretest analysis", AIAA J., vol. 33-71, pp.1362–1364, 1994.

[12] J. S. Hu and M. S. Wu, "Identifying root causes of variation in automobile body assembly using principal component analysis", Transactions of the NAMRI, vol. 20, pp. 311–316, June 1992.

[13] L. Yao, A. W. Sethares, and C. D. Kammer, "Sensor placement for on-orbit modal identification via genetic algorithm", AIAA J., vol. 31, pp. 1922–1927, 1993.

[14] L. W. Poston, and H. R. Tolson, "Maximizing the determinant of the information matrix with the effective independence method", Journal of Guid. Control. and Dyn. J., vol.15, pp.1513–1514, 1992.

[15] M. Chang and C. D. Gossard, "Computational method for diagnosis of variation-related assembly problems", Int. Prod. Res. J., vol. 36, pp. 2985–2995, 1998.

[16] Q. Rong, D. Ceglarek and J. Shi, "Dimensional fault diagnosis for compliant beam structure assemblies,"

Manuf. Sci. Eng. J., vol. 122, pp. 773–780, 2000.
[17] Q. Rong, D. Ceglarek and J. Shi, "Adjusted least squares approach for diagnosis of ill-conditioned compliant assemblies," Manuf. Sci. Eng. J., vol. 123, pp. 453–461, 2001.
[18] W. Cai, J. S.Hu, and X. J. Yuan, "Deformable sheet metal fixturing: principles, algorithms and simulations," Transaction of ASME, Journal of Manuf. Sci. Eng., vol. 118, pp. 318–324, 1996.
[19] Y. Ding, P. Kim, D. Ceglarek and J. Jin, ''Optimal sensor distribution for variation diagnosis for multi-station assembly processes,'' IEEE Trans. Rob. Autom., vol. 19, pp. 543–556, 2003.
[20] Y. Wan and R. S. Nagarkar, ''Locator and sensor placement for automated coordinate checking fixtures,'' Transaction of ASME, Journal of. Manuf. Sci. Eng. J., vol. 121, pp. 709–719, 1999.
[21] Y. Y. Li and L. H. Yam, ''Sensitivity analyses of sensor locations for vibration control and damage detection of thin-plate systems", Sound and Vibration J., vol. 240, pp. 623-636, 2001.
[22] http://www.xbow.com/
[23] http://www.archrock.com/
[24] http://www.mathworks.com/
[25] http://www.ni.com/