ENERGY EFFICIENT SENSOR PLACEMENT FOR MONITORING STRUCTURAL HEALTH

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1. INTRODUCTION…(1/2)

- Structural health monitoring (SHM) – main application of wireless sensor network (WSN).
- SHM system - A type of system that gives information about any damages occurring in the structures like building, bridges etc.
- Damage- a significant change to the geometric properties of a structural system, such as changes captured frequencies and mode shapes.
- Mode shape- Each type of structure has a specific pattern of vibration at a specific frequency

INTRODUCTION...(2/2)

- Sensor placement is one of the fundamental problem in SHM

Senor Placement Method In WSN
- Random
- Uniform
- Grid/Tree
- Rectangular
- Circular,etc.

- In Civil engineering, sensors are placed at optimal location in order to achieve the best estimate of physical properties of a civil structure.

Optimal Sensor Placement Methods in SHM Applications
- Effective Independence (EFI) Method
- Kinetic Energy (KE) Method
- Genetic Algorithm, etc.

2. SENSOR PLACEMENT USING EFI METHOD(SPEM)

- It is used to optimize both sensor signal strength and the spatial independence of N targeted locations by optimizing determinant of Fisher Information Matrix

$$\Phi = \begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \phi_{1K} \\ \vdots & \vdots & \vdots & \vdots \\ \phi_{M1} & \phi_{M2} & \cdots & \phi_{MK} \end{bmatrix}_{M \times K}$$

Mode shape matrix is denoted as Φ. where each row indicates for mode shape measurement results from a particular sensor and here each M candidate locations have K type of mode shapes.

$$Q = \Phi^T . R^{-1} . \Phi$$

- Where Q is the FIM, determinant of FIM indicate placement quality of sensors. In SPEM, we need to maximize |Q|
- R is the covariance matrix of noise

$$E_j = diag(\Phi . Q^{-1} . \Phi^T)$$

E_j is the effective independence value of j^{th} location

CONTD…

Algorithm: SPEM

Let M is the number of candidate locations and N is the number of sensor nodes used for effective placement.

1. for i =1 : 1 : M-N
2. Compute E_i ;
3. Sort E_i ;
4. Remove last location (i.e., remove least E_i location From M location).
5. end

Output: N locations are selected from M total candidate location.

- There are M candidate locations
- Given N Sensors
- So we need to remove M-N locations out of M candidate locations using SPEM

3. OBJECTIVE OF THE PROPOSED WORK

Let |Q| is the determinant of fisher information matrix and each sensor nodes transmits its data to the base station in a shortest path. Let E_{max} is the maximum energy used by sensor in one round of data transmission

Objective

To maximize |Q| and minimize E_{max}, i.e., the sensor placement quality and the sensors lifetime by minimizing maximum energy consumed by one sensor. i.e., we need to maximize the function $|Q| / E_{max}$.

4. PROPOSED ALGORITHM

Let M is the number of feasible locations and N is the number of sensor nodes, where N<<M

1. Compute the N sensor node positions using Algorithm 1 (SPEM)
2. Compute the shortest path from all sensor nodes to sink where R_{max}, the maximum communication range given for sensor node.
3. Find the node, which is using maximum energy in one round
4. Sort sensor node positions according to effective independence value, and remove last location.
5. Place the removed sensor nodes in a position, so that traffic through the nodes which is using maximum energy will be reduced.
6. Find the function $|Q|/E_{max}$ of new placement. If this function is more than the previous one, then select it as new placement of sensors.
7. Continue from step 2, until we get good placement result.

5. SIMULATION RESULTS… (1/3)

- A total of 20 Sensor nodes are given (N=20) & 56 candidate location also there (M=56)
- We need to remove M-N locations, i.e. 36 positions out of 56 positions so that nodes are monitored effectively

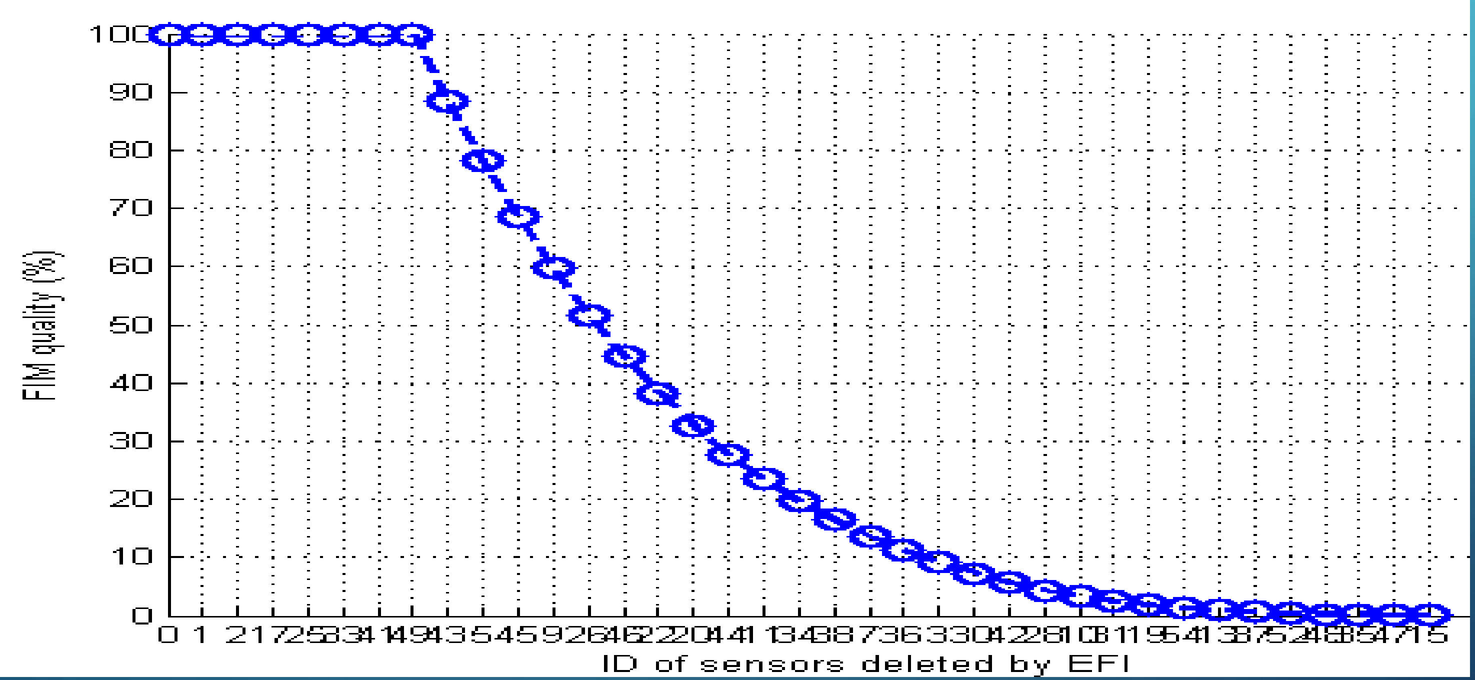
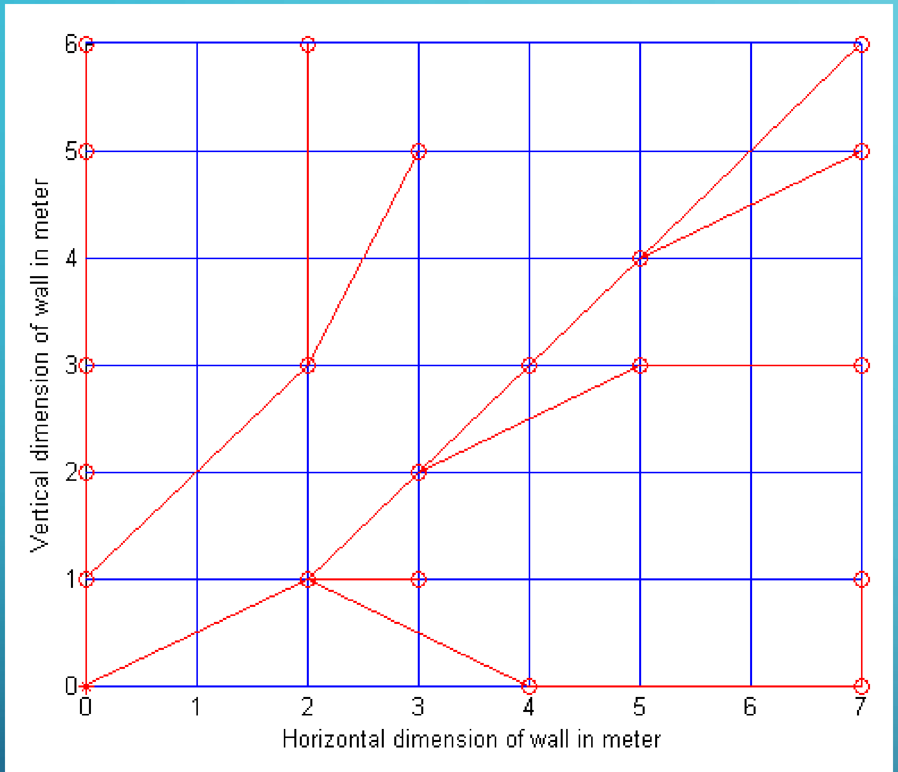
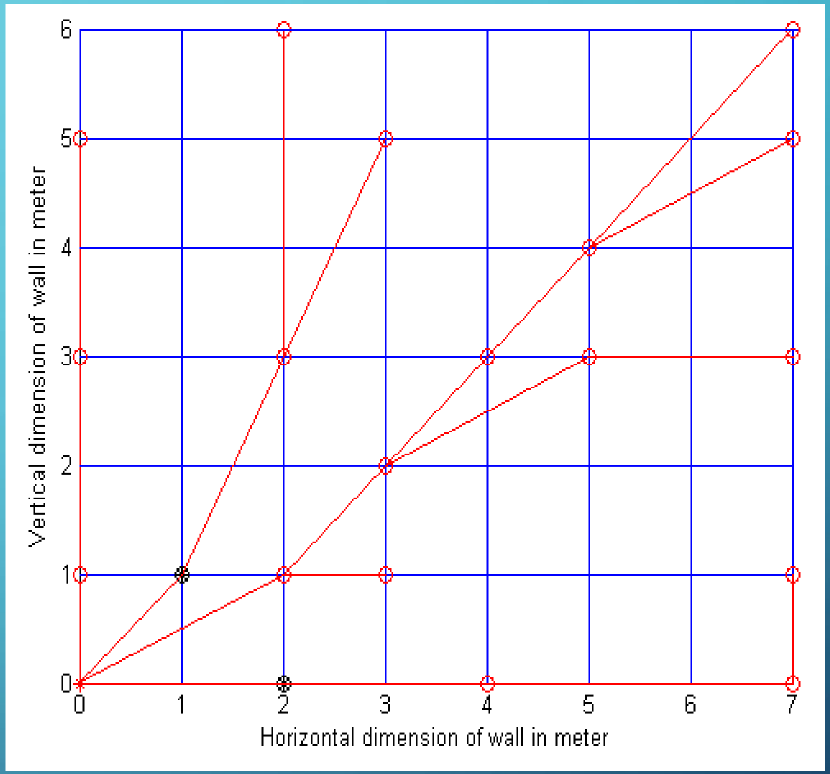


Figure 1. Sensors deleted based on the Placement quality by SPEM

SIMULATION RESULTS…(2/3)



(a) Sensor placement using SPEM



(b) Sensor placement using proposed one

Figure 2. Twenty sensor nodes are placed in a wall having 56 candidate locations and sink placed at (0, 0). Red line indicates the shortest path to sink for data transmission; (a) SPEM method is used for sensor placement; (b) sensor placed by proposed way and here two least effective sensor nodes placed at (0,6) & (0,2) are changed to (1, 1) & (2, 0) so that traffic through the nodes (0, 1) & (2, 1) will be reduced

SIMULATION RESULTS…(3/3)

Parameters used	Value
Number of sensor nodes, N	20
Number of candidate locations, M	56
Maximum communication range, Rmax	2m
Initial energy	0.5 J
Data packet length	4000 bits

Table 1. Simulation Parameters value

Parameters	SPEM	Proposed One
Emax	0.0051 J	0.0037 J
|Q|	63.0875	54.1972
|Q|/Emax	12370	14648
Number of round when first node died	99	134

Table 2. Simulation results

From the simulation results we can shows that the value the function |Q|/Emax considerably improved

6. CONCLUSION

- In this work, the sensor placement problem is discussed for structural health monitoring system not only from civil engineering structures point of view, but also from computer science efficiency.

- We placed sensor nodes by maximizing fisher information matrix and by minimizing the maximum energy consumed by sensor.

- Through the simulation, we demonstrated that the proposed algorithm improves the lifetime of wireless sensor network without much affecting sensor placement quality.

- As a future work, we can consider placement of relay nodes based on the traffic awareness so that it may decrease energy consumption without affecting sensor placement quality.

7. REFERENCES…(1/2)

1. Bhuiyan, M.Z.A.; Cao, J.; Wang, G.; Liu. X. Energy-Efficient and Fault-Tolerant Structural Health Monitoring in Wireless Sensor Networks. IEEE SRDS **2012**, 310-310.
2. Bhuiyan, M.Z.A.; Wang, G.; Cao, J.; Wu, J. Deploying Wireless Sensor Networks with Fault-Tolerance for Structural Health Monitoring. IEEE Transactions on Computers (TC) **2014**, 1-14.
3. Kammer, D.C. Sensor Placement for On-Orbit Modal Identification and Correlation of Large Space Structures. In Proceedings of the American Control Conference **1990**, 2984-2990.
4. Nie, P.; Jin, Z. Requirements, challenges and opportunities of wireless sensor networks in structural health monitoring. Proceedings of International Conference on Broadband Network & Multimedia Technology (IC-BNMT) **2010**, 1052-1057.
5. Li, D.S.; Li, H. N.; Fritzen, C.P. The connection between effective independence and modal kinetic energy methods for sensor placement. Journal of Sound and Vibration **2007**, 305, 945-955.
6. Ni, Y.Q.; Zhou, H.F.; Chan, K.C.; Ko, J.M. Modal Flexibility Analysis of Cable-Stayed Tin-Kau Bridge for Damage Identification. Computer-aided Civil and Infrastructure Eng **2008**, 23, 3, 223-236.
7. Ni, Y.Q.; Xia, Y.; Liao, W.Y.; Ko, J.M. Technology innovation in developing the structural health monitoring system for Guangzhou New TV Tower . Structural Control and Health Monitoring **2008**, 16, 1, 73-98.

REFERENCES…(2/2)

8. Spencer, B.F; Ruiz-Sandoval, M.; Kurata, N. Smart Sensing Technology: Opportunities and Challenges. Structural Control and Health Monitoring **2004**, 11, 4, 349-368.
9. Li, B.; Wang, D.; Ni, Y.Q. Demo: On the High Quality Sensor Placement for Structural Health Monitoring. IEEE INFOCOM **2009**, 1-2.
10. Li, B.; Wang, D.; Ni, Y.Q. High Quality Sensor Placement for SHM Systems: Refocusing on Application Demands. IEEE INFOCOM **2010**, 1-6.
11. Bhuiyan, M.Z.A.; Wang, G.; Cao, J.; Wu, J. Sensor Placement with Multiple Objectives for Structural Health Monitoring. ACM Transactions on Sensor Networks **2012**, 699-706.

Thank you for your attention!