Time Synchronization System for Sensor Grid

KEN-ICHIRO ISHIKAWA*, AKIRA MITA**

ABSTRACT:

Health monitoring is a key technology for structures. In this paper, we introduce Sensor grid. Sensor grid is an intelligent sensor node network for permanent health monitoring. The network is wired network consists of commercial network equipments. We implemented time synchronization system in Sensor grid. In the result, Jitter of sensors which are 190m away is within 10μs.

1. INTRODUCTION

Health monitoring is a key technology for structures. The importance of this technology is increasing more than ever. For health monitoring of gigantic structures, a large amount of sensors are required to get vast amount of information. Recently many researches in the health monitoring research forcus wireless sensor networks. However, we still think that wired communication is very important for the monitoring system. The wired communication is faster than wireless communication and it moves robust in noisy condition. In addition, it can achieve permanent power supply which is needed for permanent structural health monitoring. However, conventional analog sensors require a lot of cables. Therefore it is difficult to apply existing wire-based structural health monitoring system for the system involving thousands of sensors.

Sensor grid is a sensor system suited for large sensor networks. It has smart sensors. Each sensor has a processor and a digital network port. The smart sensor measures data and the measured data can also be processed and transmitted. It uses TCP/IP protocol and enhances 100BASE-TX network for communications. Sensor grid can reduce cables and it can achieve fine time synchronization. In previous works, one or a few central computer managed all the data from all the sensors. But in Sensor grid, the sensors can filter their own data. The central computer manages only filtered data. Thus the communication traffic decreases. Since processors are becoming cheaper, a sensor having a processor built in becomes realistic. Sensor grid uses unused lines in the category 5 cable for fine time synchronization. By using those lines, jitter among the

*Reserch Fellow, National Research Institute for Earth Science and Disaster Prevention, shinzan @mtb.biglobe.ne.jp
**Professor, Keio Univgersity, mita@sd.keio.ac.jp

joined sensors could be 10μs or less.

The smart sensor has time source individually, thus the timing jitter is inevitable. Time synchronization consumes bandwidth for data communication used by usual communication. It is interfered by data transmission. Sensor grid overcomes it by transmitting coded timing signal through 2 paired lines in the category 5 cable. The timing signal contains time, command and the sensor's ID. The time synchronization of Sensor grid was evaluated by computer simulations and also by a real system which was implemented for SUZAKU-V with Virtex-2P (FPGA with a built-in CPU). The FPGA in the SUZAKU-V manages the synchronization signals and sensor data conversion. The built-in CPU in the SUZAKU-V stores the sensor data in the memory, selects the nontrivial data, transforms them to the XML format and then transmits them. Sensor grid can be a key tool for the health monitoring for a gigantic structure.

2. SENSOR GRID ARCHITECTURE

Sensor grid is a health monitoring system for gigantic structures. It has scalability. It can manage large number of sensors. Sensor grid proposed have consists of cells of one hub, one mother sensor node and child sensor nodes. The topology of cells is a tree structure. There is one root cell in Sensor grid which connects to a host computer (Fig.1).

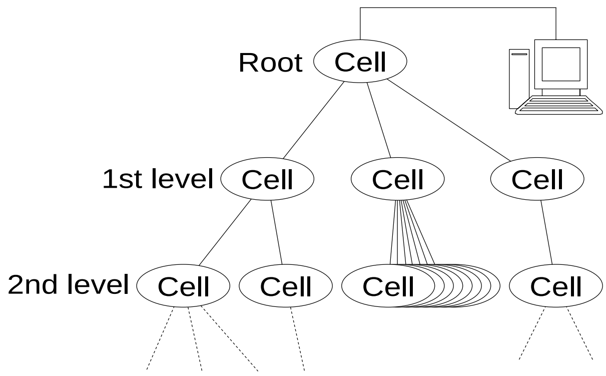

Figure. 1 The cell structure

A network of Sensor grid can be wired or wireless. Usually wired network is used in Sensor grid, because Sensor grid should work over more then 10 years because most structures will be used for more than 10 years. Most nodes in Sensor grid need permanent power supply, in which wired connections seem to be necessary. In addition, wired power supply enables us to use power consumption processor. Thus applying wired connections between sensors is reasonable. In this paper, only wired network is introduced.

The cell can connect to computers through the Ethernet. The hub has ports so that it can be connected to an upper level cell, a mother sensor node or child sensor nodes. Ports at child sensor nodes can connect to not only child sensor nodes but also lower level cells (Fig.2). Network without hubs needs as many cables as the sensor nodes because each sensor has to connect to the host computer directly. But network in Sensor grid transmitting data via hubs needs only one cable to connect an upper level cell with lower level cells.

In Sensor Grid, sensors and computers can communicate with each other by TCP/IP or UDP/IP. It can use full bandwidth for data transmission because time synchronization can be done by un-used data lines. Because modified hubs for time synchronization in Sensor grid do not stop the communication, ordinary networks can be merged into a large Sensor grid.

A sensor node may have several different sensors. Sensed data by the sensors will be converted to digital data by A/D converters. The digital data can then be evaluated and filtered by processor in the sensor node. The filtered data will be stored in the DRAM memory or flash memory. When the filtered data are important, they are transmitted to the upper level cell. This process is made recursively. Finally, host computer can obtain the essence of the measured data. Unimportant data will be stored in the sensor node and they will be erased after a certain time or when the storage becomes full. Operator can access the stored data by connected computer anytime. This structure reduces network congestion.

Time synchronization is very important when intelligent sensors are used. Because those sensors have individual clocks, sensed data is meaningless when time synchronization is not done. A synchronization signal is generated at the root cell. Then it propagates to the lower level cells. When connection between the root cell and lower cells becomes off line, the mother sensor node in cells will generates its own synchronization signal and then it propagates to the lower level cells.

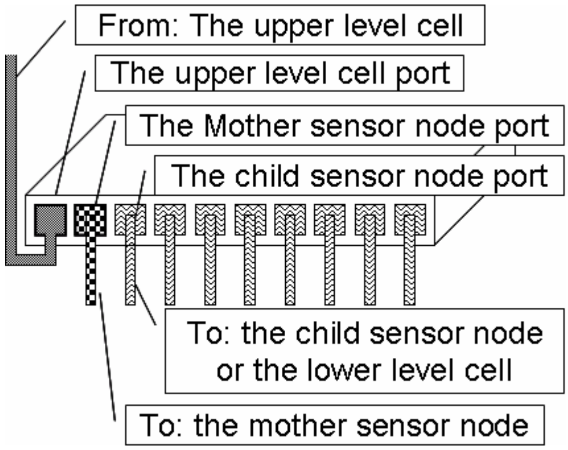

Figure.2 The hub

3. EXISTING SYSTEMS

IDSN (Intelligent Distributed Sensor Network)[1] is a wired sensor network. Each sensor in IDSN has a processor. The processor is used mainly for measured data adjustment. The adjustment consists of calibration and prediction. The calibration can be done by sensor benchmark value. The sensor benchmark value is the transition regulation of substance, for example, from liquid phase into a solid one. The prediction is done by making mathematical model and measuring its influence factors during its exploitation. Sensor grid and ISDN have sensors with a processor in the wired network. But usages of the processor and the network are different.

WINS (Wireless Integrated Network Sensors)[2] is wireless sensor network. The sensor node in WINS has a sensor, a processor and a wireless LAN port. Those sensor nodes can communicate with each other by Internet protocol. The sensors can establish multi-hop network. WINS and Sensor grid have a similar concept. The main difference between Sensor grid and WINS is that Sensor grid adopts wired network but WINS adopts wireless network. The difference comes from that Sensor grid focuses on permanent power supply and stable communication but WINS focuses on high availability. Sensor grid is used for different situations unlike WINS.

4. TIME SYNCHRONIZATION IMPLEMENTATION

Sensor grid in this implementation uses wired network by 100BASE-TX. The functions of Sensor grid in this implementation are time synchronization and A/D conversion.

Each node in Sensor grid in this implementation has a sensor board and a main board. The sensor board has a 16 bit A/D converter. The main board is SUZAKU-V. SUZAKU-V contains VirtexII-Pro, 32MBytes SDRAM and 8MBytes flash RAM.

For timing synchronization, Sensor grid in this implementation uses 2 pairs of no-used lines (4-5 pair line and 7-8 pair line) in the category 5 cable. Modified hubs are used for timing synchronization. The hubs can be modified to be able to connect to usual network. Synchronization signals will be transmitted in RS-485 manner. A mother node could take 32 child sensor nodes. The transmission process is listed below (Fig.3).

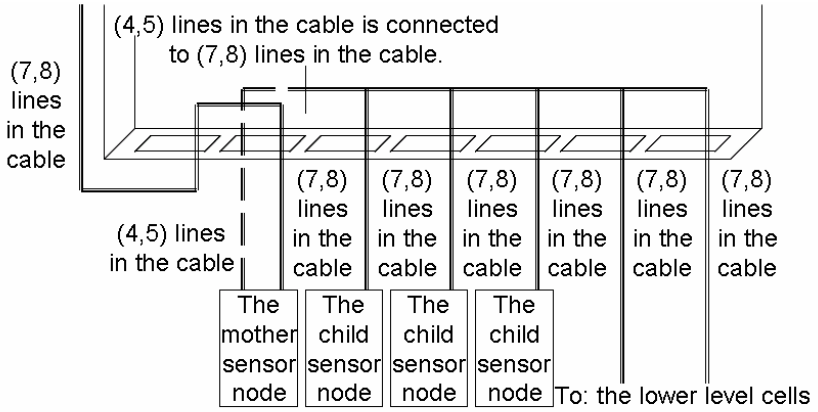

Figure.3 The connection

1. The synchronization signals are transmitted from a 7-8 pair line on a child sensor node port of an upper level cell to a 7-8 pair line on a synchronization port of a lower level cell.
2. The 7-8 pair line on the synchronization port is connected to a 7-8 pair line on a mother sensor node port.
3. The 7-8 pair line on the mother sensor node port in the hub is connected to a 7-8 pair line on a mother sensor node.
4. The mother sensor node is synchronized by using the received synchronization signals.
5. The mother sensor node generates new synchronization signals.
6. The new synchronization signals were transmitted from a 4-5 pair line on the mother sensor node.
7. The 4-5 pair line of the mother sensor node is connected to a 4-5 pair line of the mother sensor node port in the hub.
8. The 4-5 pair line on the mother sensor node port in the hub is connected to a 7-8 pair line of a child sensor node ports in the hub.
9. The 7-8 pair line on the child sensor node port in the hub is connected to a 7-8 pair line on a child sensor node and a 7-8 pair line on a synchronization port in a lower level cell.
10. The child sensor node is synchronized by the using received new synchronization signals.

As it shows, the synchronization signals are different between the mother sensor node and the child sensor nodes in the same cell. Thus there are timing jitters between them.

Base frequency of the synchronization signals is 10KHz. Higher frequency makes time synchronization more accurate. But higher frequency also results in some problems in high frequency waves. In this implementation conservative frequency is used.

The synchronization signals can encode the modified Manchester encoding (Fig.4). It starts with high level kept 3/2 cycles. After that, encoded time, sender ID and orders are followed. The synchronization signals starts within 10ms and it needs 6.7ms for being sent completely, so measurement starts up to 16.7ms after the sensor nodes being connected to the network.

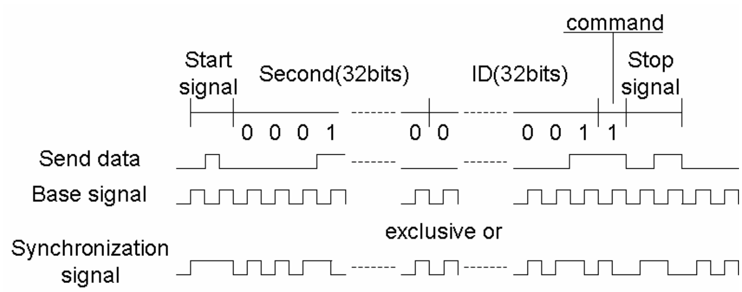

Figure.4 sending signal

5. EVALUATION

5.1. Simulation

The time synchronization was evaluated by Verilog simulation. It didn't consider wire delay and RS-485 chip delays. There were 5 sensor nodes estimated (Fig. 5). Node-1 is a mother sensor node in root cell. Node-2 is a mother sensor node in 1st level cell. Node-3 is a mother sensor node in 2nd level cell. Node-4 and node-5 are child sensor nodes in the 2nd level cell. The sensor nodes which have 5 types of cycle time (Table 1) are evaluated. The recognition correctness of the synchronization signals and the jitter of 1 KHz signals were carefully evaluated.

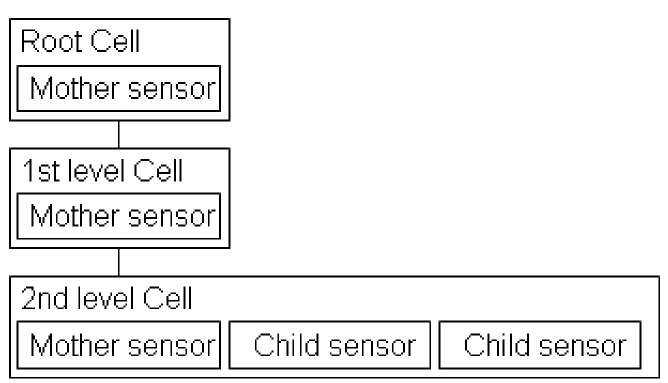

Figure 5: evaluation structure

Table 1: Cycle time

	Node-1	Node-2	Node-3	Node-4	Node-5
Type-A	146ns	150ns	154ns	146ns	154ns
Type-B	154ns	150ns	148ns	146ns	154ns
Type-C	148ns	150ns	152ns	148ns	152ns
Type-D	152ns	150ns	148ns	148ns	152ns
Type-E	150ns	150ns	150ns	150ns	150ns

5.2. Jitter evaluations in the real experiment

Time synchronization in 5 sensor nodes was evaluated in the real experiment. Jitter is evaluated by the output of an A/D converter where the input signal is from the same source with the same voltage. Cell structure is same as the one shown in Fig. 5. Three cases were tested. In case-1 and in case-2, the root cell and the 1st level cell, also the 1st level cell and the 2nd level cell, were connected by a 90m category 5 cable respectively. In case-3, the root cell and the 1st level cell, also the 1st level cell and the 2nd level cell, were connected by a 1m category 5 cable respectively. In the whole case, hubs and sensor nodes were connected by 5m category 5 cables. Thus the longest distance between sensor nodes was 190m. Case-1 and Case-2 had same network structure, but sensors were located in the different ports. Same sensors were located in the same ports in case-2 and in case-3. The synchronization signals were converted to RS-485 format by the MAX3488 chip and were transmitted through the hubs and the category 5 cables.

6. RESULTS

6.1. Simulation

It was confirmed that the sensor nodes were synchronized correctly (Fig.6). Waves in upper area in Fig. 6 are 1 KHz rhythmic waves. Downer area is time data. ID and order were recognized correctly. All sensor nodes were synchronized 27ms later after it had started. Jitters of each cycle time type were shown in Table 2. The results of type-E showed jitters were 0 when cycle time of sensor nodes was the same. The results of type-A, B, C and D show jitter was up to about 10μs. When cycle time of the mother sensor node in the root cell was longer, jitter was longer. And when cycle time of the mother sensor node in the root cell was shorter, jitter was shorter. When this circuit is implemented on the Virtex-2Pro, the number of occupied slice flip flops is 190 of 2816, the number of occupied input LUTs is 318 of 2816, and the number of occupied slices is 231 of 1408.

Table 2: Jitter in simulation (average, max)(μs)

	Node-1	Node-2	Node-3	Node-4	Node-5
Type-A	0.00,0.00	0.13,0.13	0.26,0.27	0.25,0.26	0.39,0.40
Type-B	0.00,0.00	1.47,2.68	3.68,6.69	6.50,10.69	3.68,6.56
Type-C	0.00,0.00	0.13,0.13	0.26,0.27	0.25,0.27	0.39,0.41
Type-D	0.00,0.00	0.74,1.34	2.22,4.02	2.21,3.89	3.62,6.02
Type-E	0.00,0.00	0.00,0.00	0.00,0.00	0.00,0.00	0.00,0.00

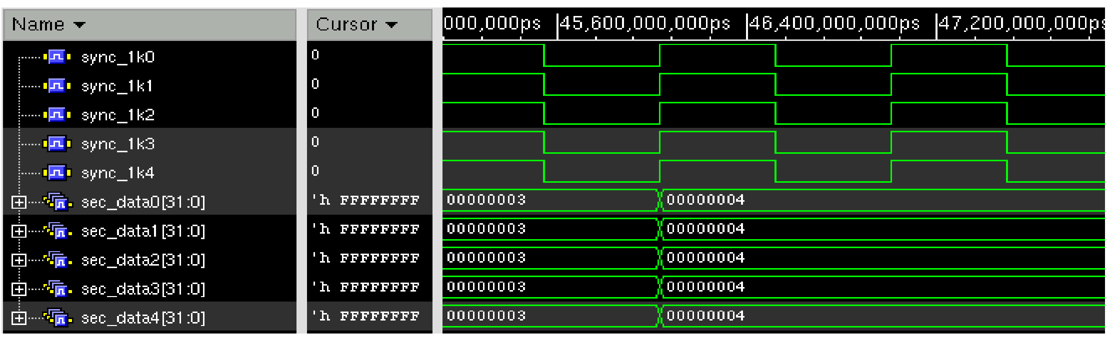

Figure 6 Time synchronization in the simuation

6.2. Jitter evaluation in the real experiment

It could be confirmed that the sensor nodes could be synchronized correctly. ID and orders in synchronized signals were recognized correctly. All sensor nodes were synchronized up to 27ms later after it had started. Jitter is showed in Table-3, 4, 5. Results of 10000 points were captured and evaluated. All points were divided into 10 groups and the values in the tables are mean values of each group. Maximum jitter is -8.17μs (occurred in case-2). Jitters were decided by some complex factors, such as network structure, the combinations of a mother node and child nodes and so on. Category 5 cable length did not affect in these cases. The synchronization did not interfere in TCP/IP and UDP/IP communication.

The results show that sensor nodes in Sensor grid in these implements can be synchronized very well in gigantic structures.

Table 3: Jitter in real(case-1)(μs)

	Node-1	Node-2	Node-3	Node-4	Node-5
Jitter	0	1.12±1.66	-4.12±1.71	-5.09±1.71	-1.58±1.46

Table 4: Jitter in real(case-2)(μs)

	Node-1	Node-2	Node-3	Node-4	Node-5
Jitter	0	0.65±1.91	-2.84±2.64	-5.66±1.92	-2.30±2.00

Table 5: Jitter in real(case-3)(μs)

	Node-1	Node-2	Node-3	Node-4	Node-5
Jitter	0	1.14±1.88	-2.81±2.90	-5.54±1.63	-2.09±1.60

7. CONCLUSION

The time synchronization technique designed for Sensor grid is suggested. It uses modified commercial category 5 cables and modified commercial hubs. Its communication will not be affected while time synchronization was being done. It was evaluated in the real experiment. To show that the maximum jitter is -8.17μs. The time synchronization technique for Sensor grid proposed here is feasible for large sensor networks.

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