Development of Immediate Earthquake Intensity Information Aggregation System Using Various Sensors And IP Multicast

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SUMMARY
This thesis focused on the server-less multicast transmission method which is able to get immediate seismic motion data from multiple terminals at the same time. A system was developed for immediate recording of seismic data, through use of multi-casting and notebook PC built-in sensors, to record high density seismic motion, the responses of individual buildings, and in-house damage. In addition to the possibility of constructing a seismic intensity network at low cost by using built-in acceleration sensors on existing notebook PCs, redundancy of the system is maintained at the time of an earthquake by use of the multicast transmission method. Further, there is the advantage of the system being able to operate with isolated external networks. Also, the usefulness of this system is shown through various experiments. In addition, expansion by use of depth sensors to improve understanding of in-house damage is also discussed.

Keywords: Real-time earthquake disaster prevention, Acceleration sensor, Depth sensor, IP multicast

1. INSTRUCTIONS

It is well known that assessing earthquake damage quickly and at an early stage contributes to early recovery and restoration, and the lessened impact of a second disaster. One method for assessing this damage quickly and at an early stage is through an instrumental seismic intensity scale, published by the Japanese Meteorological Agency. However, with the existing observation network, only a general idea of the damage in cities and district municipalities can be gained.

Studies are being conducted on cheap methods of gathering high-density seismic data to supplement the existing seismic network, such as the use of simple acceleration sensors to understand seismic motion (Griscom, D. T. (2007). Cochran, E.S. et al (2009).), and also the use of cameras to examine the conditions of surrounding areas as well as seismic motion (Van Den Einde L. et al (2008)). With these studies, the seismic data is recorded by sensors in general-purpose PCs, either internal sensors or ones that have been attached externally. This data is collected on the server, and used as source information to supplement the existing seismic observation network. A Client Server is used to gather the observational data of these past studies. Considering it from the standpoint of organisations that provide earthquake rescue and relief, this allows for an understanding of the whole picture of the affected areas, and the integrity of the sequentially-transmitted information can be checked easily.

However, with the client-server data gathering method, the more clients there are, the bigger and the server's load becomes, and due to congestion and interruption with the existing communication network, data gathering in the location of the disaster has become problematic. This has caused problems, such as the server crashing, and the whole system failing to operate. There are various ways by which this problem can be avoided, but the costs are high. To solve this problem at a low cost, it would be necessary to build a Client-Server system that does not require a server. In order to create this kind of server-less system, a new technique must be developed for distributed processing of earthquake data, equal analysis of the earthquakes and detection of mistakes from the existing server to the client server.

This study focused on the multi-cast transmission method, which is able to get immediate seismic motion data from multiple terminals at the same time without a server. In this study, a system was developed for immediate recording of seismic motion information, through use of multi-casting and notebook computers built-in sensors, to record high density seismic motion, the responses of individual buildings, and in-house damage.

2. THE IMMEDIATE SEISMIC INTENSITY INFORMATION AGGREGATION SYSTEM

2.1. Summary of the system

The immediate seismic intensity information aggregation system developed in this study used existing transmission networks and acceleration sensors that were built into general household/office PCs, constructing a high density sensor network. The seismic intensity information measured by the acceleration sensor with the multicast method is shared between multiple terminals, so it is possible to gain knowledge of high density seismic motion, building response and indoor damage directly after an earthquake has occurred. Through use of this system, it is possible to understand the seismic intensity dissemination of building response and three-dimensional (including height) seismic motion, instead of just superficial two-dimensional motion.

The main aim of this system is not to measure building response or get accurate measurements of seismic motion by replacing the existing earthquake observation network, but to gain a general understanding of serious in-house damage to buildings in which it was difficult to understand local damage with the original observation points, and buildings with varying natural periods.
It is assumed that the information gathered by this system can be utilized as rescue information for fire fighters, and information to support first response from disaster control headquarters in dealing with the disaster. However the information may also be useful for understanding the suffering caused by the disaster in the region, and for companies who own several buildings, so that they can easily get a grasp on the damage to buildings.

This system is mainly composed of application software and notebook PC built-in sensors, which process the acceleration sensors and distribute the seismic intensity information (Figure 1). The system also comprises PCs that do not have built-in sensors, but can read the information distributed from other terminals. The system can also be used with closed-circuit, wireless and ad-hoc transmission.

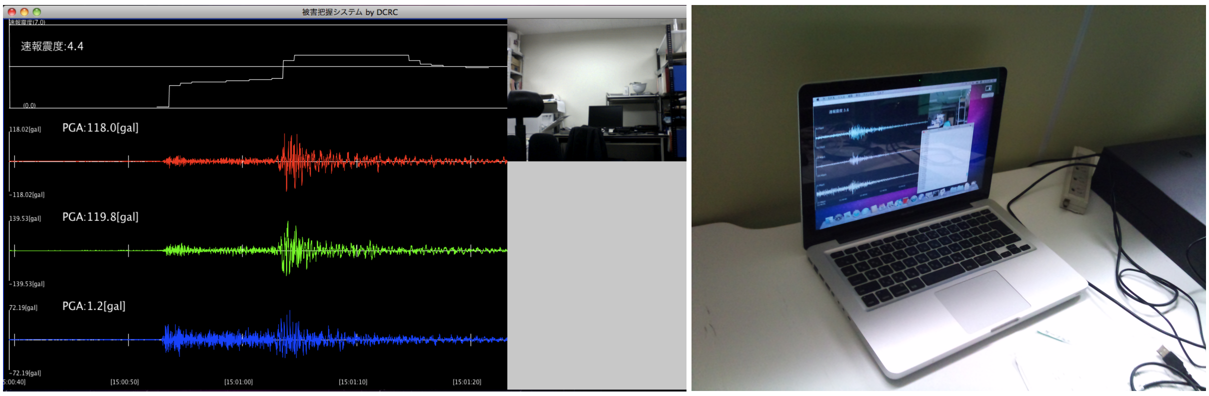

Figure 1. The immediate seismic intensity information aggregation system
Left: Screenshot of the system, Right: Notebook PC in operation

2.2. Main features of the system

・Seismic intensity information can be distributed simultaneously by multicast from the terminal that detected the vibration to other terminals. Also, the information distributed is not only gathered in one place on the server, it can be gathered at individual terminals, and can be displayed together with other seismic motion information on these terminals.

· It can be used in closed network environments which had problems with the information gathered by the server, due to the function which prevents misdetection of seismic motion.

· Using existing hypocenter information (USGS and AQUA(M. Matsumura (2006)), Early Earthquake Warning system (JMA)), the seismic motion information gathered by each terminal can be separated into tremors that are caused by earthquakes, and those that are not. For Early Earthquake Warning system, it is possible to distribute the hypocentre information using the multicast, and the information can be transmitted to terminals which the seismic motion has not yet reached.

· It is possible to establish a presence notification function, and identify geographical information gaps and information dissemination ranges.

· This system can generally be used with commercial notebook PCs with built-in sensors.

· The seismic intensity levels can be measured by the same method used by the Japanese Meteorological Agency.

· Using Google Earth, the seismic motion information gathered at each terminal can be presented three-dimensionally to show the vibration of the earth's surface and building response.

· Science educational materials can be used as simple equipment to measure vibrations.

· The system is open source, so that system modifications can be done proactively.

2.3. The system processing flow

As a prerequisite of this system, the positional information of the installation point must be recorded in the terminal in which the system is introduced. This is used for presenting the information gathered, and for determination of the seismic motion, which is described further on. When a terminal is moved to a different location, information on the new location must be recorded.

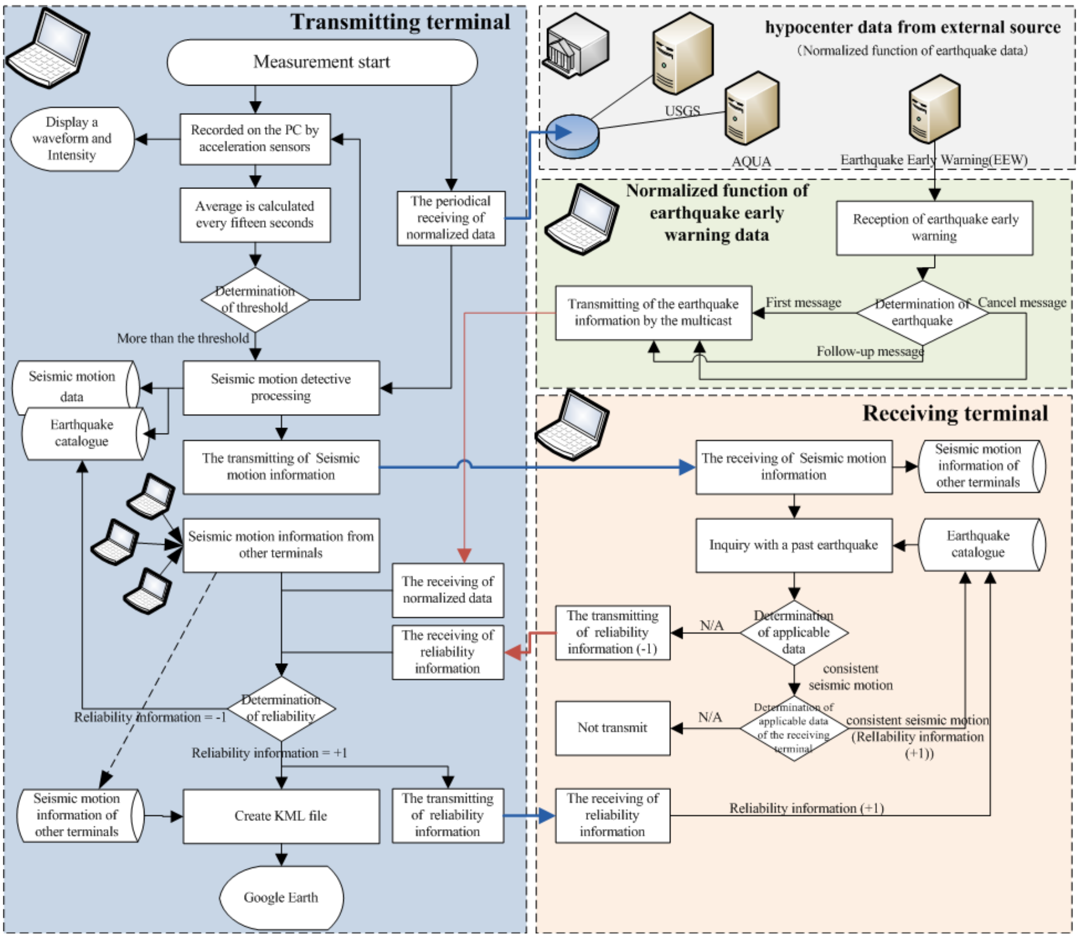

Figure 2. The system processing flow

The system processing flow is shown in Figure 2. First, the tremors are recorded on the transmitting PC by ordinary acceleration sensors and an average is calculated every fifteen seconds; this is the acceleration baseline. Next, if any acceleration results obtained exceed the fixed threshold (this can be established for each terminal), this data is recorded. In addition, seismic intensity levels matching the Japanese Meterological Agency's calculation methods are shown on the display screen once per second. At this point, processing is carried out the same way on vibrations that are not caused by earthquakes (excess impact due to lifting the PC, or the desk that the PC is on etc). In order to establish whether or not these vibrations are caused by earthquakes, hypocenter data is obtained from an external source (normalized function of earthquake data), or the information is transmitted by multicast to another PC (seismic motion misdetection prevention function).

The PC receiving the data determines whether relevant seismic motion has been detected and responds to the transmitting PC by multicast with reliability information as to whether or not it is an earthquake. The transmitting PC receives this type of reliability information from many other PCs, and then determines if there is an earthquake. This determination is transmitted by multicast to other PCs, and is recorded as earthquake information there. The time of the terminal is established in NTP, assuming that there is no gap of time which could influence the determination of the seismic motion of the same hypocenter using the time of occurrence of the maximum acceleration.

2.4. Seismic motion misdetection prevention function

When the levels of acceleration detected by the acceleration sensors exceed the fixed threshold, it is determined that there is an earthquake. However, there are instances when other factors may cause these levels to exceed the fixed threshold. Therefore, by exchanging information about the tremors between terminals with use of the multicast transmission method, a function is established to differentiate between earthquake tremors and non-earthquake tremors. Because of this function, it is possible that the system can be utilized in closed network environments, which had problems with the server method of information gathering.

Figure 3 shows the processing patterns of seismic motion information and reliability information; Table 1 shows the transmission processing patterns of seismic motion information and reliability information, and Table 2 shows the processing of reliability information of both the transmitting and receiving terminals. First, terminals that calculated acceleration which exceeded the fixed threshold follow pattern A (Table 1), as a whole, the individual ID of each terminal, the terminal location, seismic motion information and acceleration detection time etc are transmitted by multicast. With multicast transmission, the same information is sent to the transmitting terminal, so this information is ignored (Table 2, A1). Outside these transmitting terminals, the receiving terminals move to processing pattern B. The receiving terminals following the criterion of pattern B (Table 1), and only terminals that do not determine an earthquake transmit the reliability information (-1) by multicast. The reliability information is transmitted to all terminals, but goes to the necessary terminals first, and the other receiving terminals ignore this information (Table 2, B1, B2).

From the reliability information of the other receiving terminals with a response, and from the seismic motion information transmitted from other terminals, the first transmitting terminal determines whether or not there is an earthquake following pattern C criterion (Table 3), and transmits this information by multicast to all terminals (Table 1, C). This information is only recorded as earthquake information in the earthquake catalogue by the receiving terminals in cases when it has been determined that it is an earthquake (Table 2, C2).

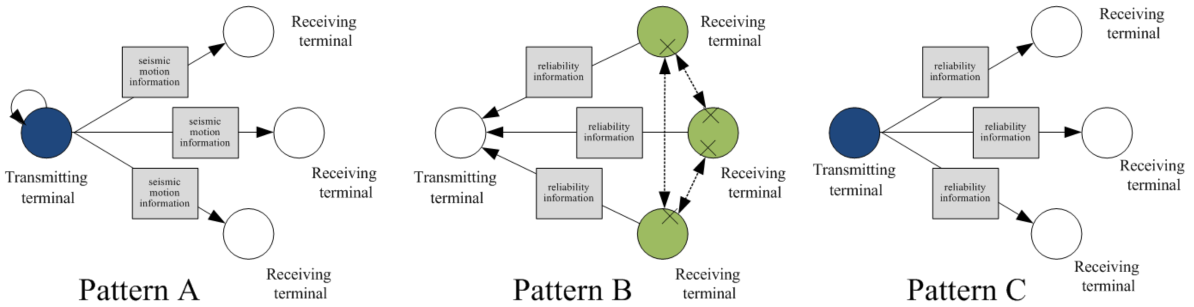

Figure 3. The processing patterns of seismic motion information and reliability information

Table 1. The transmission processing patterns of seismic motion information and reliability information

	Transmission	Destination	Processing & Transmission timing	Transmission details
Pattern A	Transmitting terminal	All terminals	At end of earthquake calculation	Terminal ID, terminal location information, seismic motion information, acceleration detection time, highest acceleration detection time.
Pattern B	Receiving terminal	Specific terminals	Receives seismic motion information from transmitting terminal, calculates transmission time of seismic motion information, from the distance between this terminal and the transmitting terminal, detects consistent seismic motion of this terminal from detection time of the transmitting terminal and transmission time of seismic motion information. In cases where no seismic motion data exists, -1 is transmitted as reliability information.	Terminal ID, terminal location information, ID of original responding terminal, reliability information (-1).
Pattern C	Receiving terminal	All terminals	Receives a set number of responses, adds up reliability received from reliability information of other receiving terminals with a response, and from earthquake information transmitted from other terminals, if reliability is positive, it is transmitted.	Reliability information (adds the information that there is an earthquake).

Table 2. The processing of reliability information of both the transmitting and receiving terminals

	Terminal	Processing after receipt
A1	Internal processing of transmitting terminal	The information which arrives at the terminal is that which has been transmitted by multicast, so this information is ignored.
A2	Internal processing of receiving terminal	In cases where consistent seismic motion is detected in this terminal, +1 for reliability is added to this terminal's earthquake catalogue. In cases where there is no consistent seismic motion, it moves to Table 1 Pattern B process.
B1	Internal processing of transmitting terminal	Updates the information of the earthquake catalogue of the transmitting terminal with reliability information transmitted from the receiving terminal (only transmitted from receiving terminal in the case of reliability being -1).
B2	Internal processing of receiving terminal	The same processing as A1
C1	Internal processing of transmitting terminal	The same processing as A1
C2	Internal processing of receiving terminal	Adds reliability information to earthquakes which are consistent in the earthquake catalogue. If it is not consistent, data is recorded temporarily (afterwards, when new data is obtained, this is recorded).

2.5. Normalized function of earthquake data

When an earthquake occurs, the seismic motion information is generally delivered sequentially from the terminals close to the hypocenter. However, in cases where the phenomenon of the tremors not reaching skyscrapers or basins etc after a certain amount of time, it is possible that there are irregularities in the transmission of the seismic motion information. Furthermore, in cases where there is aftershock, or the occurrence of an earthquake in another area at the same time, it is sometimes difficult to accurately determine which hypocenter the seismic motion information was transmitted, using only the time of the information. Therefore, a normalized function of earthquake data was established, as a means of distinguishing which hypocenter the transmitted seismic motion information is from. The normalized function is to connect data based on set conventions. The method of normalization is as follows: Information on the location of the hypocenter and time of occurrence, obtained from external machinery (hypocenter information from USGS or AQUA, or from Early Earthquake Warning system (JMA)) is used, and the arrival time of P waves and S waves is calculated from the distance between the hypocenter and the terminal. If this occurs in a set period of time during which vibrations were detected, it is determined that the vibrations were caused by an earthquake.

2.6. Presence notification function

With large-scale earthquakes, problematic congestion and interruption of transmission on the existing network occurs. The presence notification function uses the obstacle of transmission interruption to its advantage, to identify the area which the disaster has affected. This confirms a response to the information transmitted, identifies which terminals are operating, and determines that locations with no response are those where the disaster is most serious (Figure 4). In addition, since all terminals normally transmit presence notification information at the time of start-up and every hour, it can be used to identify individual terminals, or to confirm the presence of terminals etc.

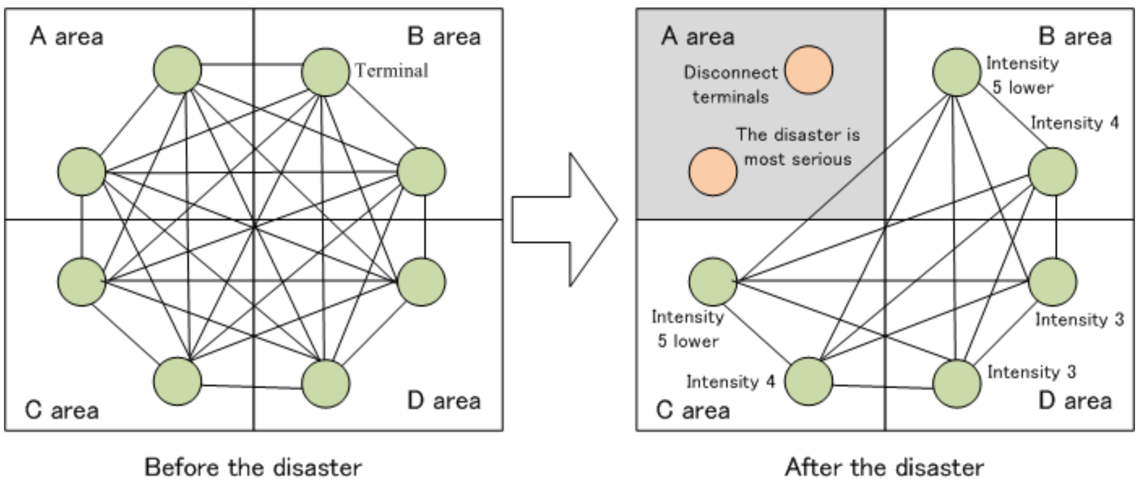

Figure 4. Conceptual diagram of presence notification function

2.7. Method to present the seismic intensity information gathered

Google Earth is used as a method to present the seismic intensity information gathered by each terminal. An example of the seismic intensity dissemination display is shown in Figure 5. With this system, when information is transmitted by multicast to another terminal, location information and trigger time information are also sent along with the seismic motion information. Height is included when presenting the data, which is converted based on the information about the location of the terminal, and the number of floors of buildings, in order to be able to show seismic intensity dissemination three-dimensionally.

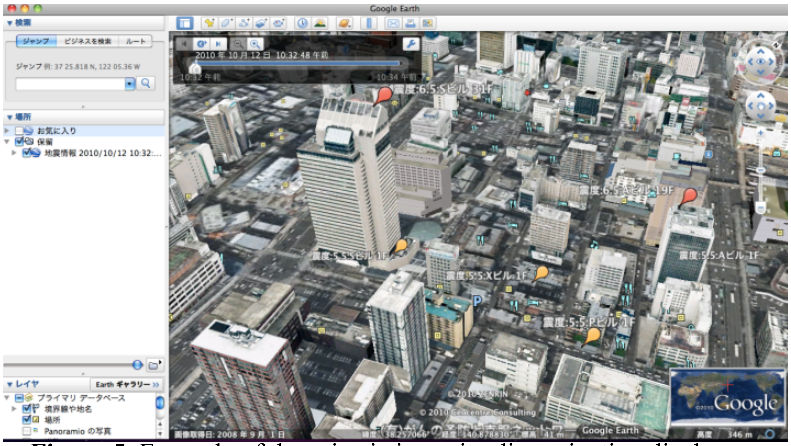

Figure 5. Example of the seismic intensity dissemination display

4. EXPERIMENTS

4.1. Experiment on vibrations of a notebook PC

For this experiment the vibrations of a PC in an unstable area were checked in order to establish the extent to which vibrations can be calculated in general use and in the same circumstances. To confirm the behaviour of seismic intensity, the experiment ran to the fixed scale of the NS wave acceleration wave pattern of the El Centro earthquake, adjusted from 3 on the seismic intensity scale to 6. The machinery used was that shown in Table 3 and a uniaxial earthquake shake table. Two types of board were used as platforms for the PCs to be placed on- aluminium and laminate.

The results recorded for each earthquake tremor are shown in Table 4. The results of this experiment were different depending on the shape and weight of the PC, but in cases where the PCs were not stable, they began slipping from 5 on the seismic intensity scale, and it is understood that this caused difficult in getting an accurate measurement of the input acceleration. However, up until 5 on the scale, it was possible to obtain accurate measurements. In cases where there was a larger acceleration than 5, this was thought to cause the PC to fall, so a rough determination could be made that this was more than a weak 6 on the seismic intensity scale. This information is sufficient to help disaster control first response and rescuers, get a general idea of the location of the disaster, which was the main aim of this thesis.

Table 3. Testing machines and reference acceleration meter

	Modele Type	Sampling rate
Lenovo Inc.	Thinkpad X61T	50Hz
Apple Inc.	MacBook MB466J/A	100Hz
KYOWA ELECTRONIC INSTRUMENTS CO., LTD.	AS-2GB	100Hz

Table 4. The results recorded for each earthquake tremor

		Intensity 3		Intensity 4		Intensity 5 lower		Intensity 5 upper		Intensity 6 lower		Intensity 6 upper	
		Inten-sity	PGA	Inten-sity	PGA	Inten-sity	PGA	Inten-sity	PGA	Inten-sity	PGA	Inten-sity	PGA
Acceleration meter（AS-2GB）		2.9	32	4.0	105	4.8	256	5.3	464	5.7	705	6.3	1389
Lenovo	Aluminium	3.0	35	4.1	118	4.9	291	5.4	521	5.7	504	6.1	669
	Laminate	3.1	35	4.1	117	4.9	281	5.4	379	5.6	430	5.9	472
	Fixed	3.1	35	4.1	110	4.9	290	5.4	496	5.8	750	6.4	1524
Apple	Aluminium	3.0	38	4.0	116	4.8	261	5.3	491	5.7	709	6.1	892
	Laminate	2.9	36	4.0	108	4.8	269	5.3	450	5.7	530	6.1	674
	Fixed	2.9	34	4.0	110	4.8	271	5.3	463	5.7	712	6.1	1426

4.2. Load experiment on multicast transmission

This experiment investigated to what extent transmission and reception from and to terminals was possible. Fifteen PCs were used in total six for seismic motion detection with built-in acceleration sensors, and nine that were not used for seismic motion detection, with no built-in sensors. These were constructed in a star network environment (Diagram 6). The method of this experiment was to cause vibration to the six PCs meant for detection of seismic motion at the same time, and to transmit the seismic motion information at the same time. The other PCs did not observe seismic motion, but were just used to respond with reliability information.

According to the results of the experiment, a problem occurred whereby some terminals could not receive information normally. The cause of this was that normal reception was not possible while the processing on the reception side was catching up. Based on this experiment, reception and transmission were modified to occur at the same time, and the transmission wait time was set at random from several ms to 5s at the most, to prevent reception from being concentrated. As a result, the seismic motion information was transmitted by multicast from the six motion-detecting PCs after the calculation of tremors, there was a response of reliability information at every terminal, and it was confirmed that accurate data was received by every terminal in around 20 seconds.

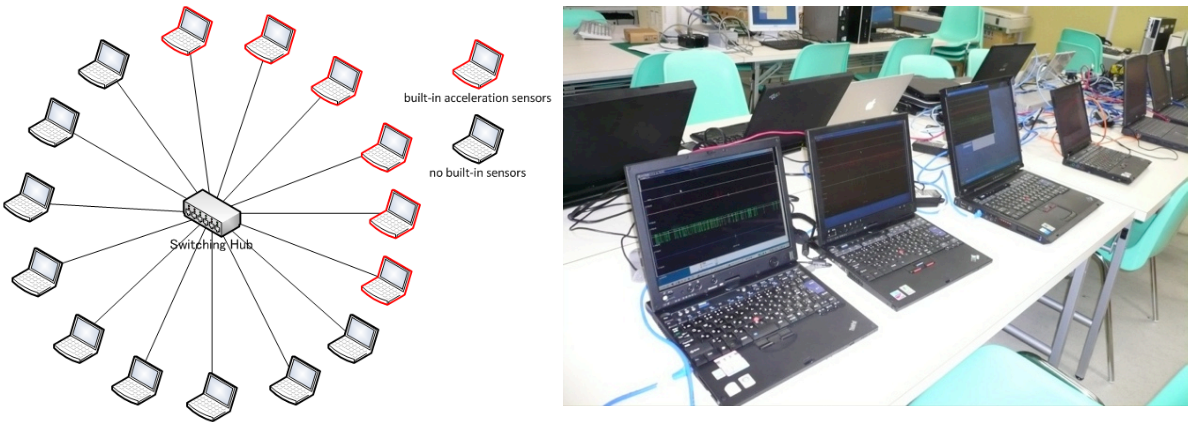

Figure 6. Load experiment of multicast transmission
Left: Network pattern diagram, Right: Experimental situation

4.3. Experiment on the seismic motion misdetection prevention function

An experiment on the seismic motion misdetection prevention function was also run alongside the abovementioned experiment. In this experiment, only five PCs with built-in acceleration sensors were used to detect seismic motion. The number of computers which received simultaneous vibrations was increased from one onwards, and it was confirmed that the seismic motion misdetection prevention function was operating accurately.

The results of this experiment are shown in Table 5. The results obtained matched the theory. Further, as the number of multicast transmissions increased, the time required for sharing of this information also increased. As a result of the transmission wait time being set at random from several ms to 5s at the most, there was an increase in time. The required time for sharing is not related to the increase in the number of transmissions.

Table 5. The results of experiment on the seismic motion misdetection prevention function

The number of the vibration terminals (Detective terminal)	1	2	3	4	5
The number of the terminals which do not vibrate	4	3	2	1	0
Judgment	Non-earthquake	Non-earthquake	Non-earthquake	Earthquake	Earthquake
The time required for sharing of this information	4.2sec	5.4sec	5.5sec	10.1sec	8.3sec
The number of multicast transmission	5	8	9	12	10
Breakdown of multicast transmission					
The number of the transmission from the vibration terminal	1	2	3	4	5
The number of the replies to terminal of the reliability information (Reply terminals × Detective terminals)	4 (4×1)	6 (3×2)	6 (2×3)	4 (1×4)	0 (0×5)
Reliability setting notice number from a detective terminal	0	0	0	4	5

5. EXPANDING FUNCTION OF IN-HOUSE DAMAGE

From the above, it is possible to gain an understanding of high density seismic motion, and the building response of specific buildings. However, this system is not sufficient for accurate understanding of in-house damage, or to confirm whether rescuers are needed. Therefore, as a way of expanding the function to make further understanding of in-house damage possible, a different processing method was tested. This was general observation using depth sensors, as a way of determining the fall and movement of household appliances, and the circumstances of the disaster. The Kinect sensors were used. The in-house depth is calculated by the sensor, edges of the furniture are sampled from the change in distance, and the furniture is tracked. At the time of an earthquake, the movement of the edges of this sampled furniture are determined, as are movement and falling of appliances. In addition, the same sensor can recognise human beings, so it is possible to detect whether or not there is somebody in the room. Figure 7 shows furniture tracking. Currently, accuracy is not sufficient, but further experiments will be conducted to improve this accuracy.

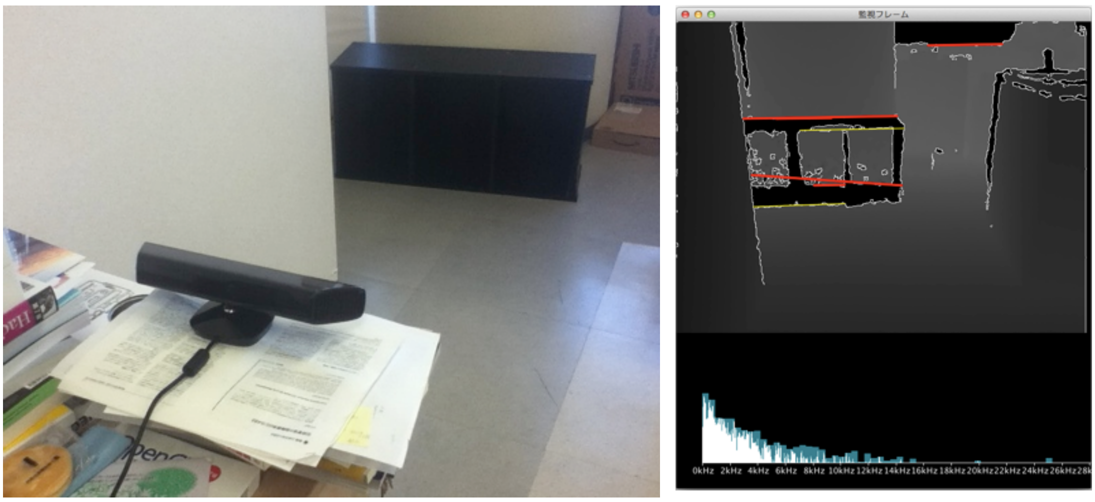

Figure 7. Expanding function of in-house damage
Left: Kinect sensor, Right: Furniture tracking

6. CONCLUDING REMARKS

This thesis focused on the server-less multicast transmission method which is able to get immediate seismic motion data from multiple terminals at the same time. A system was developed for immediate recording of seismic data, through use of multi-casting and notebook PC built-in sensors, to record high density seismic motion, the responses of individual buildings, and in-house damage. It is assumed that the information gathered by this system is mainly utilized as rescue information for fire fighters, and information to support first response from disaster control headquarters in dealing with the disaster. In addition to the possibility of constructing a seismic intensity network at low cost by using built-in acceleration sensors on existing notebook PCs, redundancy of the system is maintained at the time of an earthquake by use of the multicast transmission method. Further, there is the advantage of the system being able to operate with isolated external networks. In terms of the characteristics of this system, the following are all discussed: the development of an information misdetection processing method, through capitalisation of the special features of the multicasting, normalized function of data, and the presence notification function of all terminals. Also, the usefulness of this system is shown through various experiments. In addition, expansion by use of depth sensors to improve understanding of in-house damage is also discussed.

Hereafter, various vibration tests will be carried out. There are also plans to examine methods of excluding vibrations that are not caused by earthquakes, on independent PCs, as well as the processing method for data from large acceleration caused by falling.

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