Application of Remote Sensing and Information & Communication Technologies for Disaster Response

by

Akihiro Sanada [1] and Takaaki Kusakabe [2]

ABSTRACT

At natural disasters, damage detection & urgent response is key issue to save lives, reduce damage influence and recover properly. This paper presents possibility and effectiveness to apply remote sensing and information & communication technologies to emergency response, mainly collection of information about facility damage and dissemination of information about disaster operation among field staffs and headquarter-level. The results indicate that 1) about 2m spatial resolution is required to detect damaged facilities by high-resolution satellite, 2)it is possible to detect facility damage by LIDAR. It is also recognized that introduction of palmtop for emergency response increases the efficiency of communication and information shearing between field-level and headquarter-level.

KEYWORDS: Communication, Damage Detection, High-resolution Satellite, LIDAR, Palmtop

1. INTRODUCTION

The bigger natural disaster becomes, the more rapid response should be executed. In reality, it is more difficult to collect, process, analyze and disseminate information including facility damage information at major disasters. At severe natural disaster, personnel in charge of emergency response and administrating infrastructure likely suffer from disaster damages. It causes shortage of staffs. Under such situations, remote sensing and information & communication technologies can support staffs in fields and headquarters. An example how such technologies can support emergency response is shown in Fig-1. Remote sensing technologies lead to rapid damage detection. Gathering, Processing and providing information real-time electronically can save the number of staff for communication about disaster operation.

This paper thus reports on studies 1) to apply high-resolution satellite and LIDAR for detection of facility damage and 2) to introduce palmtop for field staffs to send and acquire information to/from headquarters.

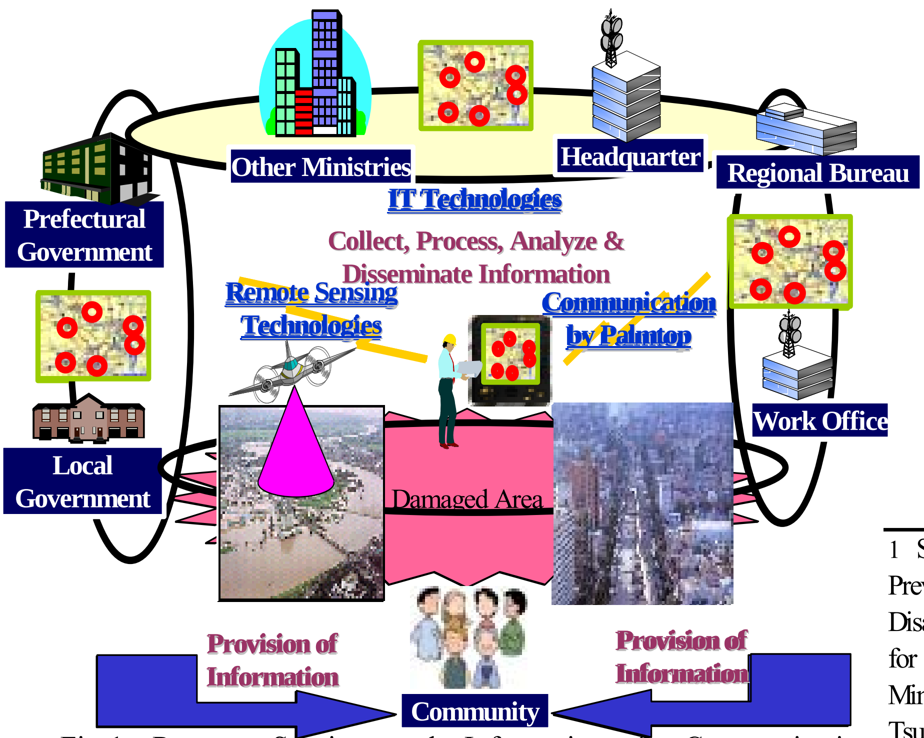


Fig-1 Remote Sensing and Information & Communication Technologies that can support disaster management

1 Senior Researcher, Earthquake Disaster Prevention Division, Research Center for Disaster Risk Management, National Institute for Land and InfrastructureManagement, Ministry of Land Infrastructure Transport, Tsukuba-shi, Ibaraki-ken 305-0804 Japan

2 Head, ditto

Table-1 Target Remote Sensing

Platform	Sensor
Artificial Satellite Stratspheric Platform Aircraft Helicopter UAV (Unmanned Air Vehicle)	Optical Sensor SAR (Synthetic Aperture Radar) LIDAR (Light Detection and Ranging)

2. DAMAGE DETECTION BY REMOTE SENSING

In 1995 Hyogo-ken Nanbu Earthquake, a lot of road facilities collapsed due to strong ground motion. Nevertheless, residents used cars for their evacuation. In result, very serious traffic congestion occurred. Personnel in charge of facility inspection always use vehicles to investigate their facilities. Naturally they were involved in traffic jam. This was one of reasons why damage detection was delayed at the earthquake. On the other hand, several high-resolution satellites are now operated. One of characteristics of remote sensing is that it can acquire data of wide ground surface at the same time. At a serious natural disaster, damaged area is widely spread. Therefore, it is suitable to recognize the distribution of damaged facilities by remote sensing shown in Table-1. In this study, high-resolution satellite and airborne LIDAR are picked up from this table.

2.2 High-resolution satellite

The possibility to capture facility damage by images from optical sensors is discussed. Images are set with five different spatial resolutions. And by means of 1) watching raw images by staffs themselves and 2) applying image processing, relations between spatial resolution and visibility are investigated. In addition, applicability of image processing to various kinds of damage type is studied.

2.2.1 Sample images

Images are made by scanning aerial photos of damaged facilities, which are chosen from the 1995 Hyogo-ken Nanbu Earthquake as shown below;

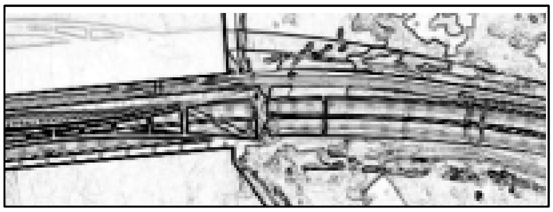
1) Kobe-Hamate Bypass, National Highway #2 (Fig-2)

Girder shifted 1.5m in transverse direction to bridge axis.

Fig-2 Shifted Girder at Kobe-Hamate Bypass (Simulated Image with 1m resolution)

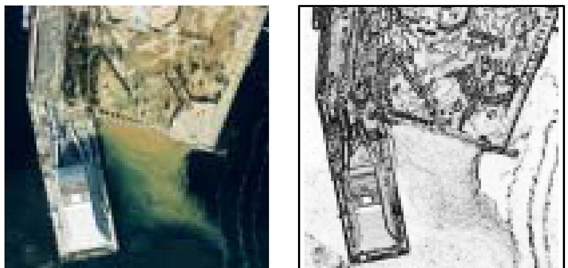
Fig-3 Subsidence at the Daikai Station (Simulated Image with 1m resolution)

(a) Simulated Raw Image with 1m resolution



(b) Result of Edge-enhancement

Fig-4 Approach Bridge that fell down at Nishinomiya Port Bridge



(a)Simulated Raw Image with 1m resolution

(b)Result of Supervised Classification

Fig-5 Damaged bulkhead, outflowing sand and liquefaction at the Naka Tottei

Table-2 Possibility to extract Damaged Facilities

Facility	Damage	20cm Resolution		50cm Resolution		1m Resolution		2m Resolution		10m Resolution	
		Color Image	Monochrome Image	Color Image	Monochrome Image	Color Image	Monochrome Image	Color Image	Monochrome Image	Color Image	Monochrome Image
Kobe-Hamate Bypass	Shifted Girder	○	○	○	○	○	○	×	×	×	×
Daikai Station	Subsidence	○	○	○	○	△	×	×	×	×	×
Approach Bridge	Collapsed Bridge	○	○	○	○	○	○	○	○	×	×
Naka tottei	Liquefaction	○	○	○	○	○	○	○	○	×	×
	Outflowing Sand	○	○	○	○	○	○	○	○	○	×
	Collapsed Bulkhead	○	○	○	○	○	○	○	○	×	×

○:Easy to extract △:Possible to extract ×:Impossible to extract

2) Daikai Station of Kobe Rapid Transit Line (Fig-3)

The center pillars in Daikai station, which was located in underground, collapsed. This resulted in subsidence at the surface, National highway #28, for 90m long and 28m wide. Depth is maximum 2.5m.

3) Approach bridge of Nishinomiya Port Bridge, at Bay Shore Route of Hanshin Expressway (Fig-4(a))

Approach bridge, 52m span and 6 lanes, fell down about 25m.

4)NakaTottei Pier in Kobe Port (Fig-5(a))

Bulkhead was damaged for 190m long and sand were outflowing. Additionally, liquefaction occurred in Nakatottei area.

2.2.2 Possibility to detect damage by watching raw images

In this experiment, civil engineers who have no information about locations of damaged facilities check the images. And it is judged whether they can find damaged facilities or not. Each image is size of 30cm×20cm and covers a spatial area of several hundreds meter around including damage facilities. How clearly damages are found is classified into three categories as following;

1) It is easy to extract damages from images.
2) It is possible to extract them.
3) It is impossible to extract them.

Most influenced factor in extraction is spatial resolution of images. Therefore, 5 different resolutions,i.e.10m, 2m, 1m, 0.5m and 0.2m, were examined in this experiment. The result is shown on Table-2.

1) Resolution 0.2m to 0.5m

In the case of Daikai Station, it is possible to detect cracks but difficult to understand caving down. Except subsidence at the Daikai Station, it is easy to find out damages of facilities.

2) Resolution 1m to 2m

It becomes difficult to detect girder shift at Kobe-Hamate Bypass and subsidence in Daikai Station.

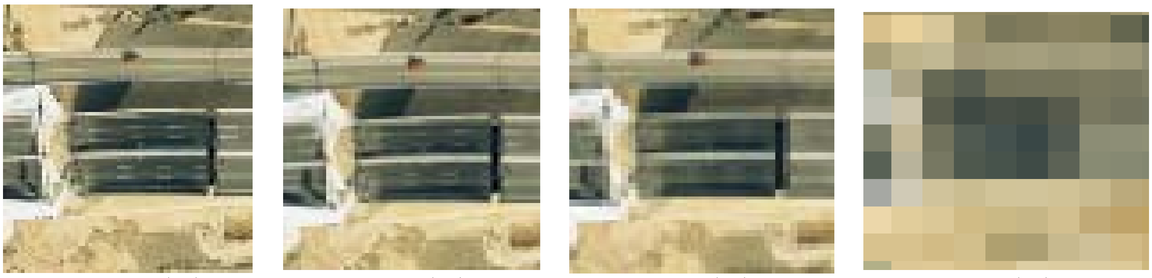
3) Resolution 10m

There is no damage that can be detected easily except outflowing sands in Nakatottei Pier.

Thus, it is understood that the minimum of 2m resolution is required to detect facilities damages, even though widely spread damages like liquefaction and land slide can be extracted from 10m resolution images.

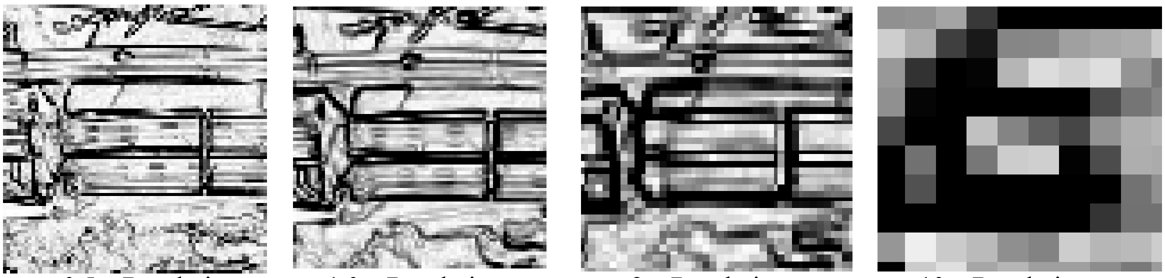
2.2.3 Application of image processing

In this experiment, two kinds of image processing, which are edge-enhancement and supervised classification, are applied to the two images: approach bridge of Nishinomiya Port Bridge and Nakatottei Pier. After image processing, possibility to extract damages from the images is estimated on each resolution. Fig –4(b) shows the result of application of edge-enhancement. This indicates that enhanced edges at road side and road center becomes discontinuous in the collapsed parts. In other parts, enhanced edge is continuous and looks clear. Fig-6 shows the result of applying edge-enhancement in 5 different resolutions. It is possible to detect collapsed part in the case of 2m or better resolution images, but impossible in the case of 10m resolution. In addition, results on the application of edge-enhancement to Nakatottei Pier indicate that edge-enhancement is suitable to detect damages of line-shaped facilities and difficult to detect damages which spread widely (Fig-5(b)). Widely spread damage should be detected by classification. In this study, supervised classification is applied. The result is shown in Fig-7. In classification, as training data, three sample pixels inside the liquefaction and outflowing area are chosen and pixels which has similar color with training data are judged as damaged area. The result indicates



0.5m Resolution 1.0m Resolution 2m Resolution 10m Resolution

(a) Raw Images



0.5m Resolution 1.0m Resolution 2m Resolution 10m Resolution

(b) Images processed by edge-enhancement

Fig-6 Approach Bridge of Nishinomiya Port Bridge

0.5m Resolution 2m Resolution 10m Resolution

(a) Raw Images

0.5m Resolution 2m Resolution 10m Resolution

(b) Images processed by supervised classification

Fig-7 Naka Tottei Pier in Kobe Port

that the image of 2m or better resolution is good to specify the spread of liquefaction area.

Thus, suitable matching between damage type and image processing exists. In addition, same as extraction by human, in information extraction by computer, 2m or better resolution is necessary.

Table-3 Specification of Measurement by LIDAR

Laser repitition rate	15000Hz
Scan frecuency	25.2times/sec
Scan angle	8°
Swath width	136.4m
Horizontal accuracy	0.3m,1σ
Vertical accuracy	0.15m,1σ
Operating altitude	975m
Ground speed	185km/hr(51m/sec)

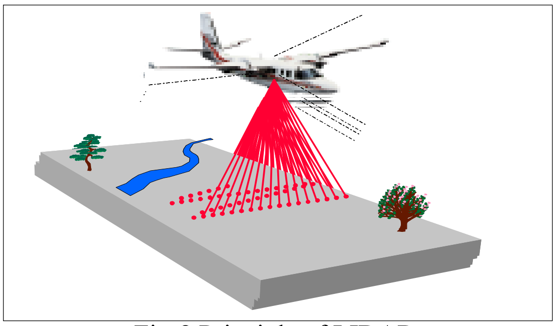
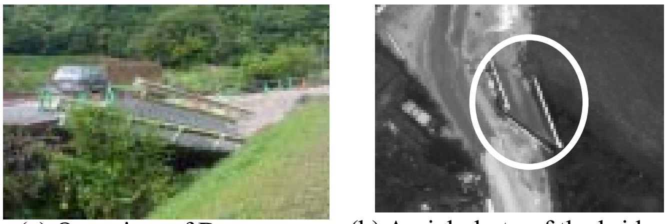


Fig-8 Principle of LIDAR

Fig-9 Damaged Quaywall in Sakai Port



(a) Overview of Damage (b) Aerial photo of the bridge

Fig-10 Collapsed Bridge in Saihaku-cho

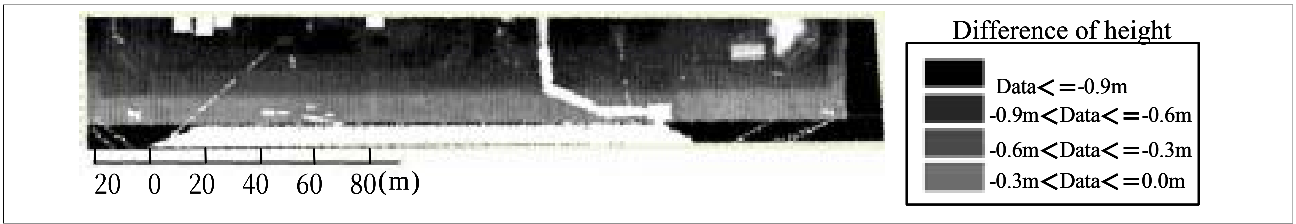


Fig-11 Level difference from the average height of face line of the quaywall

Fig-12 Settlement of one cross section across the face line in the damaged quaywall

2.3 LIDAR

Using LIDAR makes it easier to get ground elevation data. Because a lot of kinds of damage due to earthquakes are expressed by changing elevation represents , it is examined to capture damages based on LIDAR data in this study. Specification of measurement is in Table-3.

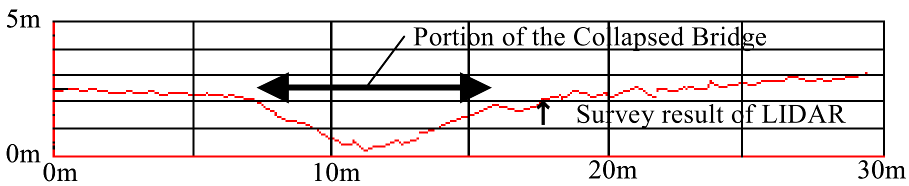


Fig-13 Survey result on the collapsed bridge

The principle of LIDAR is shown in Fig-8. Using the time taken for beams of light to return to the sensor after firing to the ground, elevation is calculated.

2.3.1 Target damaged facilities

In this study, damaged facilities at the 2000

Tottori-ken Seibu Earthquake, in Oct. 2000 were measured by means of LIDAR. Target damages are shown below.

1) –13m Quaywall in Sakai Port

Cracks and settlement occurred behind caisson along the face line. Difference in level was 60cm(Fig-9).

2) One span bridge in Saihaku-cho

The bridge,7m long and 4m wide, fell down because of damage in abutment(Fig-10).

2.3.3 Result of measurement

Fig-11 is the map of level difference from average height of face line of quaywall. White areas in Fig-11 are ship coming alongside the quaywall and the unloador shown in Fig-9. At the approximately 10m inside from the face line, color changes in Fig-11. This indicates that damage in quaywall can be captured by LIDAR. Fig-12 shows settlement of one cross section across the face line of the quaywall. The solid line is the survey result of LIDAR and broken line is the result of ground measurement. In points of the location and width of inclination, and the volume of height-difference, result measured by LIDAR is in good agreement with ground measurement.

Fig-13 shows the survey result of LIDAR on the collapsed bridge. Because elevation at pre-earthquake in this bridge is not obtained, precise comparison is difficult. However, LIDAR data in the portion of collapsed bridge decline. It indicates that LIDAR can capture a damaged bridge.

Based on these two examples, elevation data captured by LIDAR may have provided a useful indication of existence of damaged facilities.

3. EFFICIENT INFORMATION SHEARING by IT(INFORMATION TECHNOLOGIES)

At disaster risk management, various kinds of information are sheared among related entities. Personnel in charge of sending and receiving information to/from other division likely make mistakes such as forgetting to provide data. Even inside one division, it becomes difficult to revise data and shear them at sever disasters. Headquarter always enforces lower level to gather and send information immediately. This increases confusion of lower level organization at disaster response.

Introduction of information & Communication technologies to disaster risk management is studied to improve these serious situations. In this paper, application of palmtop devices for staffs in fields is reported.

3.1 Present Difficulties

3.1.1 Staffs in fields

1) They always bring paper-based maintenance data to fields during inspections of facilities. This data is bulky, heavy, big and inconvenient.
2) They mainly use cell phone in communication with headquarter. In serious disaster, normal communication system is overloaded and easily becomes unavailable.
3) Most of information is only from field staffs to headquarter. In result, field inspectors can recognize only what they watch by themselves.

3.1.2 Staffs in Headquarter

1) They want to know road closure due to disaster immediately. In reality, it takes long time to inspect facilities to make it clear where road is closed. Because progress of field inspection cannot be informed to them for long time, staffs in office cannot judge situations of each portions in road network whether no road closures are reported in result of inspection or road closures are not reported because staffs can not reach them.
2) In the case of closure, additionally, they want to know the reason why the part is closed, difficulty level of recovery and time to re-open.
   Sometimes oral reports are difficult for staffs in office to recognize situations.
3) Information is sent from various sources and it is difficult to make them in time line. In result, they cannot understand what are latest situations.
4) Information on supplies and equipments for restoration and recovery is now conveyed by telephone. It is difficult to send them orally.

3.2 Application of palmtop

Fig-14 Palmtop and other devices used in the experiment

To solve these problems listed in 3.1, application of palmtop is studied. Based on preset problem, first, functions with which palmtop should be equipped are discussed.

3.2.1 Functions of palmtop for headquarters

1) Function of recording time and date
Data that are input to palmtop should have the attribute of time and date. It becomes easy to make data in time line. Accessing to the newest data is easily executed.
2) Function to deal with images
Not only text data but also image data can be sent to headquarters. Personnel in headquarters can easily recognize situation including damages in fields. Judging damage level objectively is difficult. However, by sending images, field staffs do not need to judge damage level and personnel in headquarter can judge it by their own criteria.
3) Function of GPS
Locations in which field staffs are working are recorded in real-time. This data is sent to headquarters. In result, headquarters can know at any time where they are. They also can know which facility is already inspected.

3.2.2 Functions of palmtop for field staffs

1) Function of indicating seismic ground motion level.
Data observed by seismographs are announced on palmtop. Staffs can easily recognize distribution of ground motion and size of an earthquake.
2) Function of indicating estimated damage
Before/during field inspection, staffs can refer to estimated facilities damage.
3) Function to deal with images
Situation in field can easily and precisely reported to headquarter.
4) Memory Function
Facility management data can be stocked in palmtop and provided for field inspectors through palmtop. They do not need to bring paper-based data. In addition, in reporting facility damage, such data is attached to the report. Headquarters can realize damaged facility detail easily.

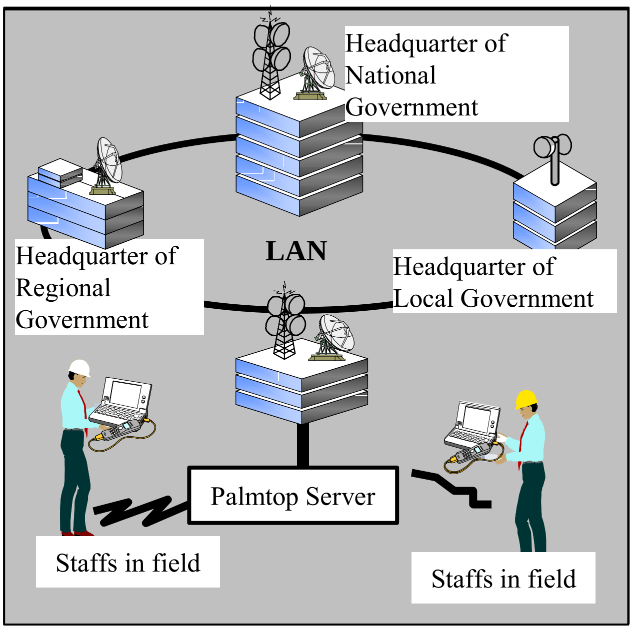


Fig-15 Structure of network in this experiment

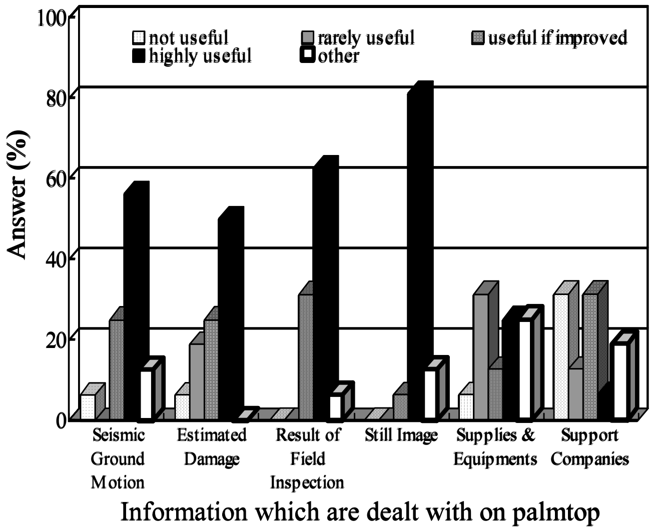


Fig-16 Usefulness of each information

3.3 Field experiment

Based on the discussion in 3.2, these new functions are equipped in palmtop and the availability and efficiency of those functions are checked by the field experiment. The palmtop and related devices used for this experiment are shown in Fig-14.

3.3.1 Scenario

In the field experiment, under the assumption of earthquake occurrence, personnel in charge of maintenance facilities execute field inspection. During the inspection, they report their result and facility damage condition to headquarters using palmtop. At the same time, field inspectors get several kinds of information from other field inspectors, headquarter and facility management database. Personnel working for headquarters acquired the facilities damage level through palmtop by text data and still images.

3.3.2 Information that are dealt with on palmtop

(1) Seismic ground motion

(2) Estimated damage

Estimated damages are gotten from SATURN[1](Seismic Assessment Tool for Urgent Response and Notification).

(3)Information about support companies

Locations of support companies' offices are shown on the map in palmtop by icon. Companies' attributes (name of company, telephone number, contact person's name) are on palmtop when the icon is clicked.

(4) Information concerning supplies and equipments for recovery

Locations of storages of supplies and equipments for recovery are shown on the map in palmtop. And list of stocked supplies and equipments come out on the screen of palmtop when the icons are clicked.

(5) Function to read and send digital camera shots

In addition to these data, by networking palmtop server and servers of local (municipal), regional (prefectural), and national headquarters, information shearing can be done among not only headquarters but also staffs in fields. Fig-15 indicates the structure of networking in this experiment.

3.3.3 Result of field experiment

After the experiment, opinions of participants are obtained through questionnaires to evaluate the effect of palmtop.

The usefulness of each data in 3.3.2 is shown in Fig-16. This result indicates that information about 1) seismic ground motion, 2) estimated damage, 3) report of field inspection results to headquarter through palmtop, 4) report of situations in field with images, 5) acquiring information from headquarter and other staffs in fields is efficient for field staffs. On the other hand, it is understood that information about 1) supplies and equipments for recovery and 2) support companies are not effective. Participants as field staffs in the experiment have opinions that it is difficult to input data by pen and voice input or selection from pull-down menu are useful.

Participants as staffs in headquarters have opinions that information shearing using network means incorrect data and uncertain data are also sheared in an instant. Once such data are conveyed, it is more difficult to modify them. Therefore, in such cases, data should be transferred with the attribute of level of precision (i.e. uncertain data/certain data).

At the introduction of palmtop to disaster response, it is pointed out by the experiment that palmtop for only disaster response use is not good from the point of cost performance. Functions for disaster risk management and usual facility management should be in one palmtop. In the field of road management, palmtop for roadway patrol has been already introduced. Therefore, in this study, it is now ongoing to add functions for disaster response to the palmtop for roadway patrol.

4. CONCLUSIONS

Detection of damaged facilities due to earthquake by high-resolution satellite and LIDAR was demonstrated. In the case of high-resolution satellite, 2m or better resolution is needed. And palmtop demonstrated its potential for improving field staffs' activities at disaster response. More works such as standardization of data format are necessary by utilizing other information & communication technologies in order to realize smooth and efficient disaster management.

5. REFERENCES

1. Sugita, H. and Hamada, T. : Development of Real-time Earthquake Damage Estimation System for Road Facilities, *Proc. 7th U.S.-Japan Workshop on Earthquake Disaster Prevention for Lifeline System*, 1997.