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SEISMIC NETWORK IN KOREA : STRONG MOTION OBSERVATION FOR EARTHQUAKE ENGINEERING

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SUMMARY

Korea Integrated Seismic System (KISS) was developed and operated from 2002 for real-time data exchange among four earthquake-monitoring institutes: Korea Institute of Geoscience and Mineral Resources (KIGAM), Korea Meteorological Administration (KMA), Korea Electric Power Corporation (KEPCO) and Korea Institute of Nuclear Safety (KINS). In order to realize the real-time network, four institutes made a committee on 1997 and they evaluated and applied to their stations the Korea standard criteria of earthquake observation such as station naming, data format and communication protocol. Even though Korean peninsula might be classified as the weak to moderate seismic-activity region, more than one hundred digital stations including 3 borehole and 25 broadband stations, which have been constructed from 1997 to 2002 (recent five years), could be easily networked due to the standard criteria.

Accelerometers were installed at almost all the stations and the acceleration data have been retrieved real-time by KISS. The observed peak acceleration value can be used as the instrumental intensity of its local station site and the spatial distribution of local peak values shows roughly the severely damaged area. Real Time Intensity COlor Mapping (RTICOM) was developed to display the color contour of peak accelerations per second retrieved by KISS. RTICOM was designed as an independent database server to send not only visual images but also raw acceleration data though the internet request.

INTRODUCTION

Historically quite a few disastrous earthquakes had happened in the Korean peninsula; they destroyed cultivated facilities and killed up to 100 persons at once. Figure 1 shows the frequency of historical

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earthquakes chronically with MMI intensity. Seismic activity was very high between 15 to 18 centuries but it has recently decreased low enough to loose public attention.

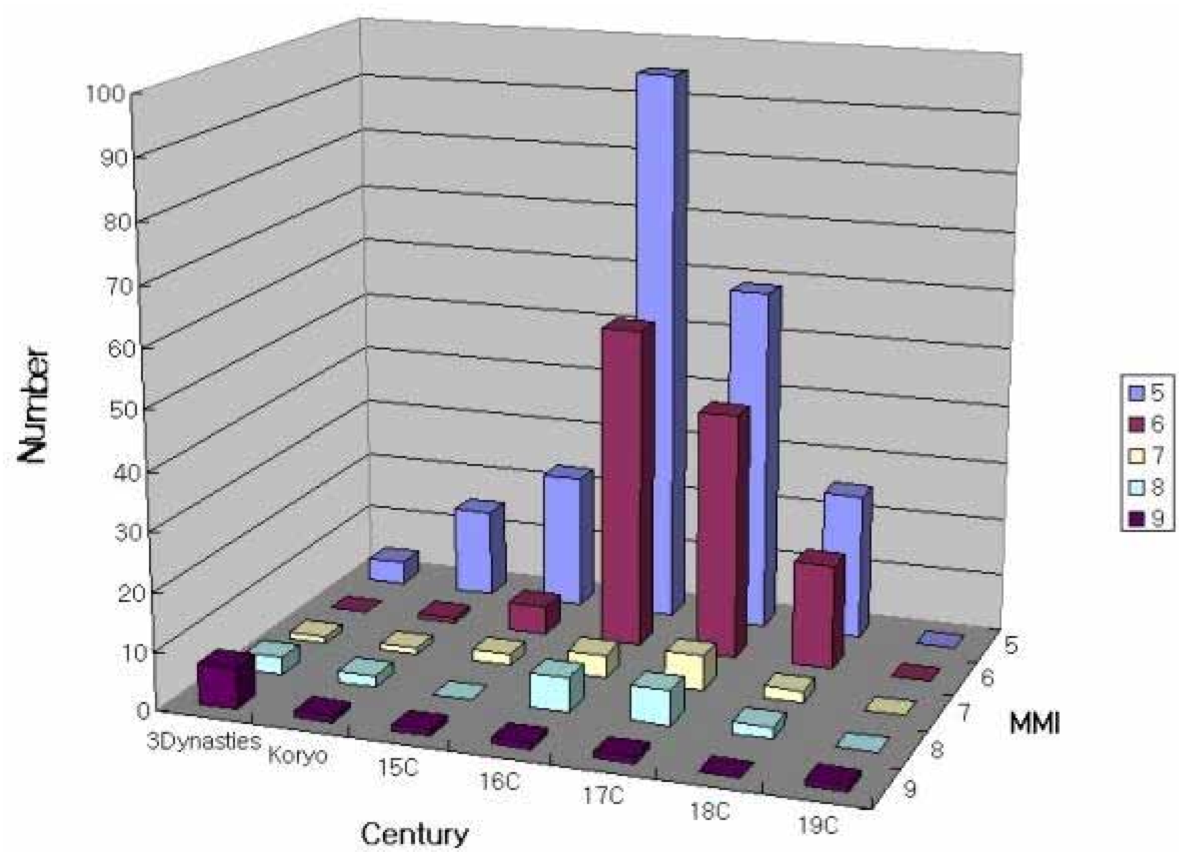


Figure 1. Frequency of historical earthquakes. Historical record of earthquakes was started from AD 2.

But the modernized observation and research of earthquake activity began with the construction of nuclear power plants in 1980's, for the earthquake resistant design is always the most concerned and critical issue on nuclear safety. As the only institute on the geological field in Korea, KIGAM was fully responsible for the evaluation of earthquake hazard in nuclear sites at that times.

The monitoring of local seismicity has been initiated from 1982 with 5 sets of mobile analog seismographs. Digital recording, even operated as mobile stations like as analog ones, was introduced on 1991 through Korea-Japan joint research project, so-called POSEIDON, at the Gyeongsang basin. Later on 1994, the first five permanent digital stations with 3 components were constructed at the vicinity of Wolsung nuclear power plant.

The Kobe earthquake on January 1995 gave a great shock to the Korean people since it occurred not at the plate boundary but inside the plate, which Korean peninsula belongs closely to. When the fear faded out, the Youngweol earthquake on December 1996 re-attracted nationwide attention since it was felt all over the country. But the Kyungju earthquake on May 1997 became a turning point on earthquake monitoring at Korea. After the epicenter of the earthquake, which was originally mis-located, was proved close to the Weolsung nuclear power plant, the status of national seismic monitoring was brought to light; only 12 analog seismic stations with only vertical component were under operation nation-widely by KMA and KIGAM has monitored the local seismicity with 12 digital stations. There were no strong-motion stations and even the digital stations could not record the full waveform due to low dynamic range. The prime Minister held the conference on countermeasure against earthquake monitoring and the followings were decided; KMA must exchange into digital seismic stations for rapid and precise reporting of earthquakes, KIGAM expand seismic stations for seismological research, and KEPCO and KINS also secure their own stations for the safety confirmation of nuclear power plants. The duty of KEPCO was done actually by its subsidiary company, Korea Electric Power Research Institute (KEPRI).

For the future integration, KIGAM proposed to set up the standard configuration of seismic stations in Korea. KMA, KEPRI and KINS accepted the suggestion and consequently the national seismic network could be realized in Korea. In this paper, the standard configuration was briefly introduced with the present distribution of stations. Then we explained how to network these organizations for sharing data by KISS (Korea Integrated Seismic System). Strong-motion observation is done not just for the study of structural behavior during ground shaking but for the rapid evaluation of damaged area and its severity. The latter can not be too emphasized in densely populated and industrial societies. Through the network of KISS, all the acceleration data can be shared simultaneously. If these data can be monitored in real time, we may mitigate the loss of life efficiently. Here, we showed how to visualize the distribution of the maximum horizontal acceleration as instrumental intensity in near real time.

STANDARD CONFIGURATION AND DISTRIBUTION OF SEISMIC STATIONS

When KIGAM constructed digital seismic stations at the first stage on 1994 for monitoring micro-seismic activity, the seismograph had some limited specification such as 3 channels with seismometer, 16bit A/D, only trigger method and serial communication. The dynamic range corresponding to 16bit A/D is just 94 dB, so the monitoring target, strong motion or micro-seismic activity, should be pre-determined by adjusting the gain level. Since the micro-seismicity was focused with a high gain, the strong motion resulted undesirably in the saturated waveform. Moreover, it did not cope with even the dynamic range of commonly used sensor, 120-130 dB.

Due to the rapid development of electrical engineering, 24bit A/D with delta-sigma digitization becomes popular and its dynamic range, 144 dB, is enough to realize the output of sensors. The sudden expansion of hard disk also allows to record the seismic waveform continuously. The data communication is very crucial to maintain the seismic network. The advent of TCP/IP protocol demands forcibly to change the fundamental concept of data communication between each station and data center. Moreover, earthquake engineering requires not velocity but also acceleration data of ground motion for earthquake-resistant design. Theses aspects were reflected throughly in the standard configuration, which is depicted in Figure 2.

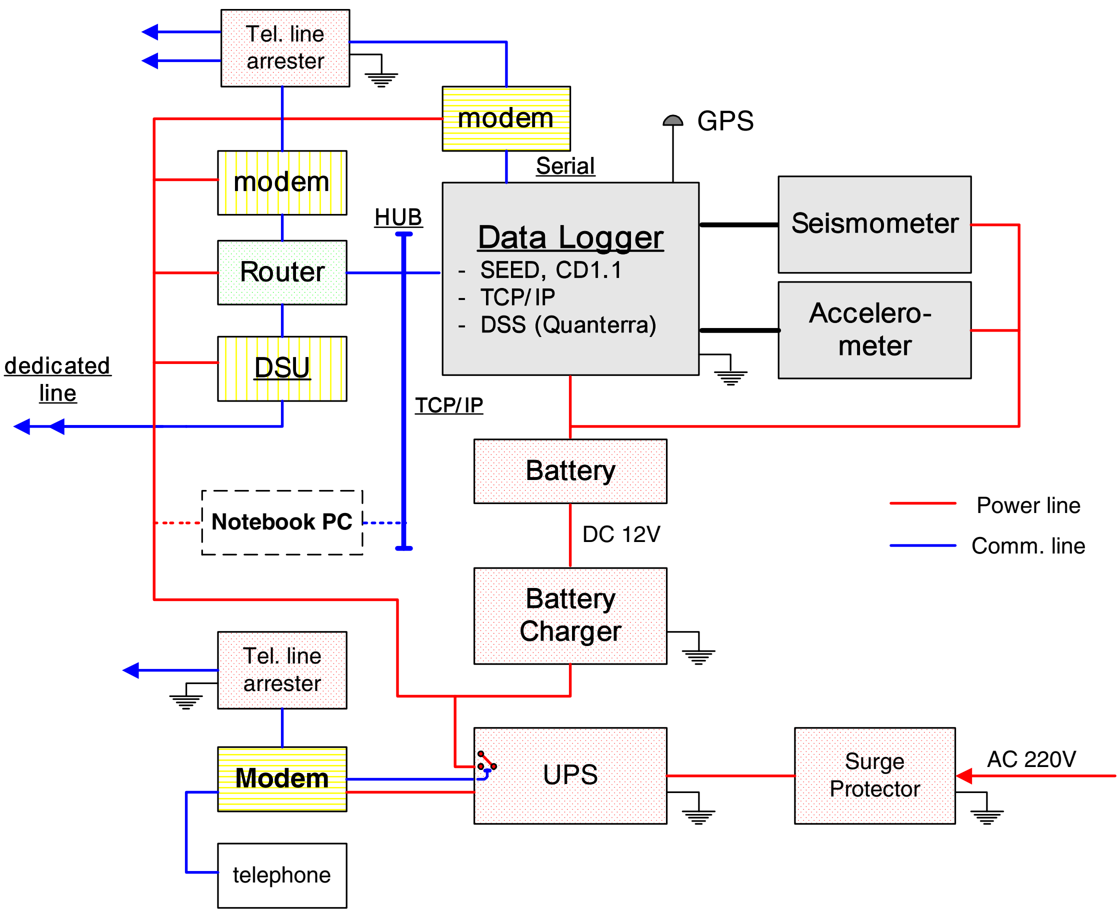


Figure 2. Standard configuration of seismic station in Korea

The standard specification of data logger is as fallows:

1) If allowable, it consists of two (electrically isolated) 24bit A/D boards for both seismometer and accelerometer in order to prevent unexpected internal looping.
2) It has an internal hard disk or equivalent memory. The disk can be easily expanded depending on the commercial availability. The disk memory should be right now partitioned into two parts, one for continuous recording and the other for triggered events.
3) For precise epicentral determination, the first arrival motion must be picked exactly. In order to do this, the phase information of seismometer remains intact after FIR filtering like as the recorder, Q4120 of Quanterra Co. with the minimum-phase filtering.
4) Both TCP/IP and serial communications are possible. For easy and flexible configuration, TCP/IP is used for continuous data retrieving but serial port is also used for brief and quick access.
5) DSS (Data Subscription Service) service is strongly recommended to be furnished internally for the rapid evaluation of damage. DSS is one of the internal functions of Quanterra data logger. Since it was designed without consideration of firewall, the service is not allowed to cross different organizations. Hence, DSS data should be exchanged through the pre-assigned network.
6) Even though the standard data format is SEED (Standard for the Exchange of Earthquake Data, developed for data exchange in U.S.A.), Mini-SEED (Data only SEED) is used popularly in practice. CD1.1 format is the standard one for exchanging data between IDC (International Data Center, the organization under CTBTO) and NDC (National Data Center) of participating nations. Since KIGAM

was authorized at UN as the NDC of Korea, so CD1.1 format must be used for exchanging data with other NDCs.

Figure 3 shows the distribution of all seismic stations in south Korea. Borehole digital array at Wonju, which consists of 26 radially deployed stations with the radius of 20Km, was constructed for nuclear test verification and KIGAM is fully in charge of so-called Wonju KSRS array as Korean NDC. KIGAM has two infrasound arrays for the discrimination of explosion and natural earthquake. Each infrasound array consists of 4 infrasound sensors on surface and 4 seismometers at the depth of 10m from the surface. KIGAM established the project of constructing 12 national borehole stations where disastrous earthquakes happened and main fault lines passed along. Until now, the construction of 4 broadband borehole stations was finished. KIGAM has also 8 broadband and 15 short-period (surface) stations.

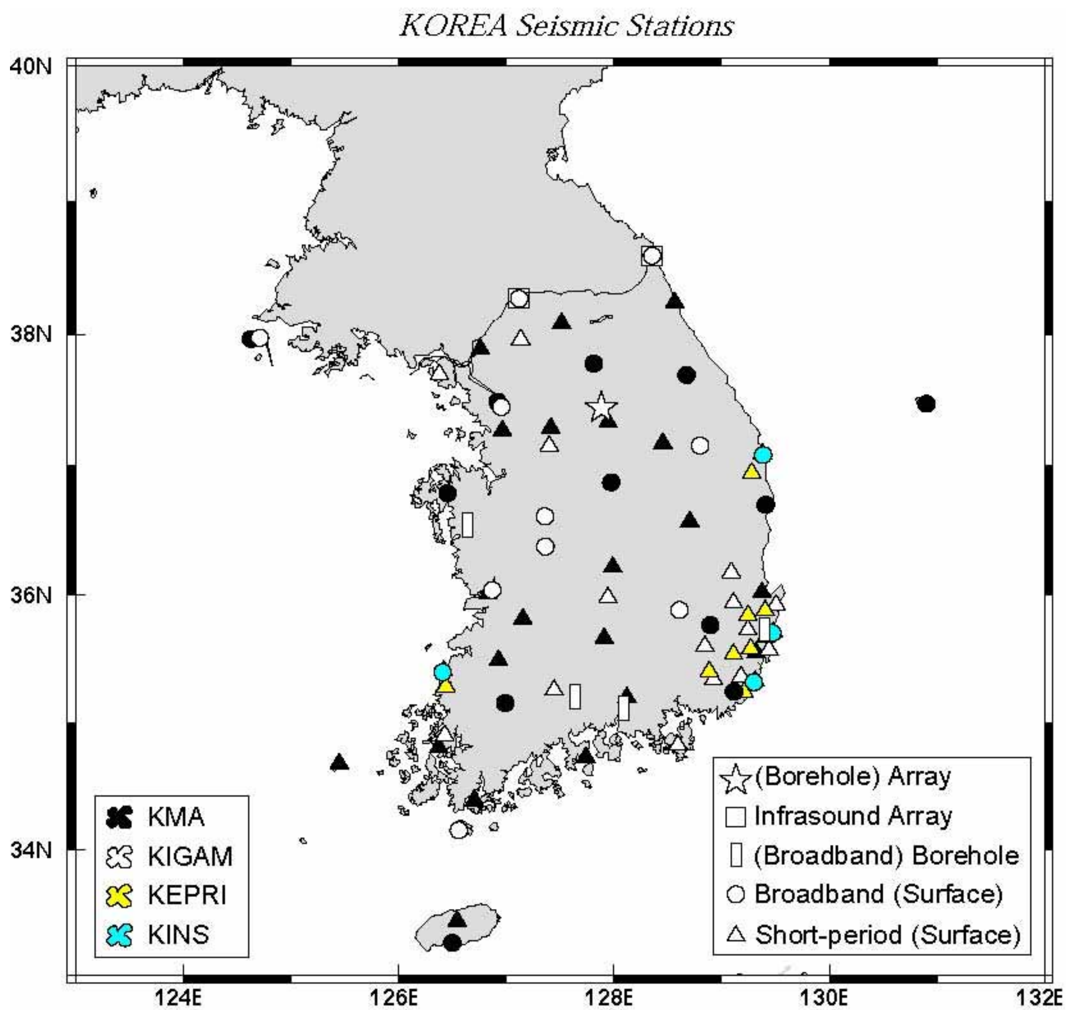


Figure 3. All kinds of seismic stations in Korea

KMA is officially responsible for announcing the location and magnitude of earthquake to the public, so KMA has nationwide seismic stations. At present KMA is operating 12 broadband and 21 short-period stations. KERPI has 13 short-period stations in and around 4 nuclear power plants. KINS has 4 broadband stations inside nuclear power plants.

Figure 4 shows the distribution of 106 strong-motion stations from which data can be retrieved in real time. Most of these stations belong to KMA and they are spatially uniformly distributed in order to evaluate un-biased instrumental intensity. For easy installation and maintenance, the data loggers of these strong-motion stations are all Quanterra's recorders such as Q4120, Q730 and Q330. Hence, DSS data as well as full waveform data can be acquired uniformly through network.

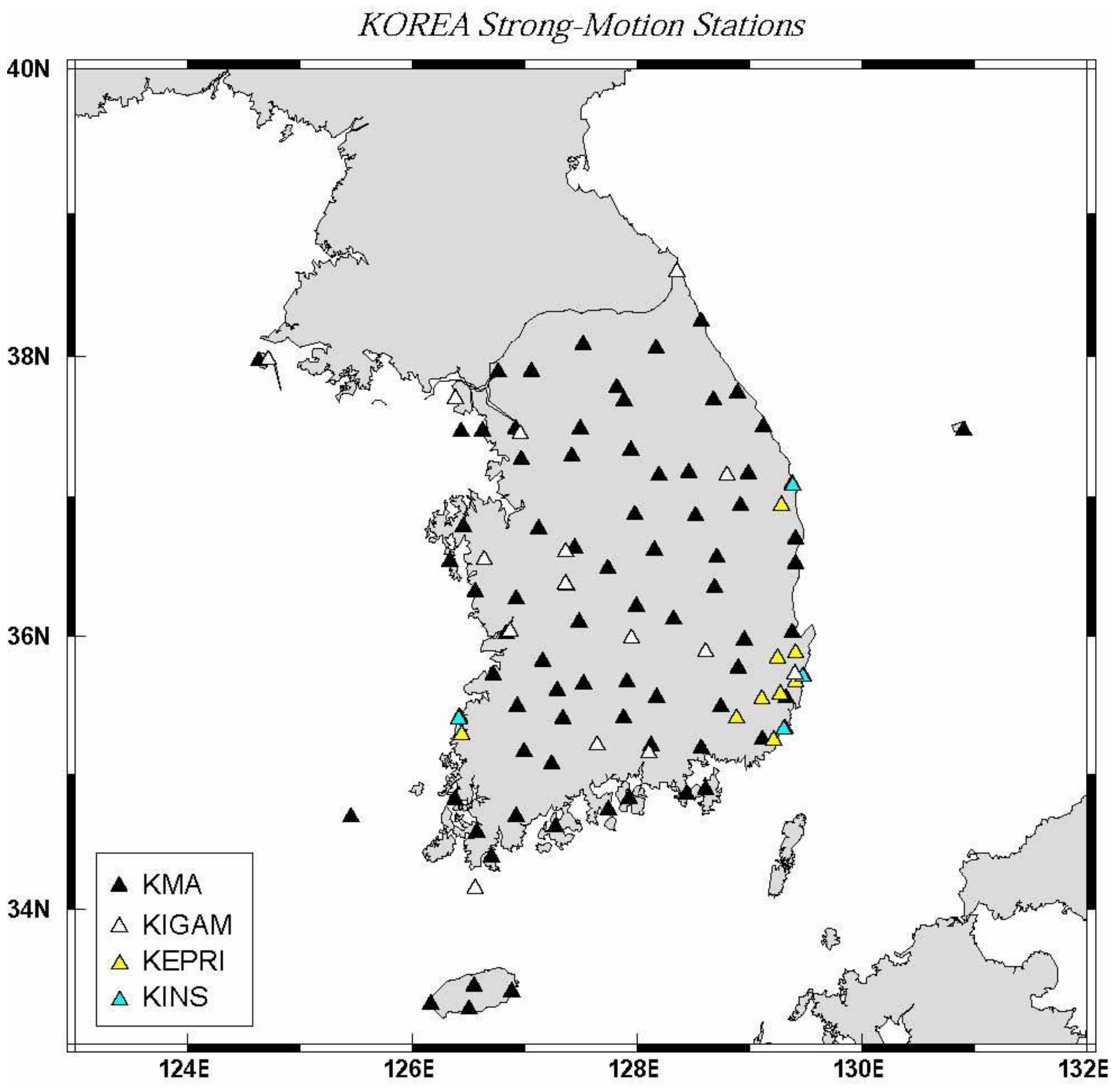


Figure 4. Strong-motion stations in Korea. From these stations, data can be retrieved in real time through national seismic networks, KISS

NATIONAL SEISMIC NETWORK: KISS

Korean peninsula is surrounded by prominent Tanlu fault in China and plate boundary in Japanese islands like as pocket, so tectonic stress dissipates severely along these geological weak boundaries and the seismic activity in Korea is inherently low to moderate. Hence every organization can not afford to construct seismic stations enough to fulfill even its own purpose. This limitation would be solved by national network through KISS (Korea Integrated Seismic System).

KISS (Korea Integrated Seismic System) was developed from the protocol of LISS (Live Internet Seismic Server) but their objectives are quite different. LISS is defined as an internet-based distribution mechanism allowing near-real-time data flow from seismic stations around the world to an essentially unlimited number of clients (http://www.liss.org/questions.htm). On the other hand KISS may be defined as an internet-based sharing mechanism allowing near-real-time data flow to automatic processing of pre-assigned limited organizations.

Figure 5 shows the schematic diagram of data flow through KISS. The data of Wonju KSRS station, which is one of IMS stations, is not shared but exclusively used by KIGAM. The data of Quanterra data loggers at KIGAM stations are retrieved by 'comserv' program and sent to comserv buffer, The data at comserv buffer in KIGAM are duplicated into KISS server. In KMA, the station data are retrieved into ORB buffer and these are also duplicated into KISS server. In another word, all kinds of near-real-time buffers in organizations are duplicated into the identical buffers inside KISS server. The buffers inside KISS are copied backward to other organizations almost simultaneously. Copied data are converted into the specific format of each organization and they are aligned together with its own data in front of automatic processing gate as shown in figure 5.

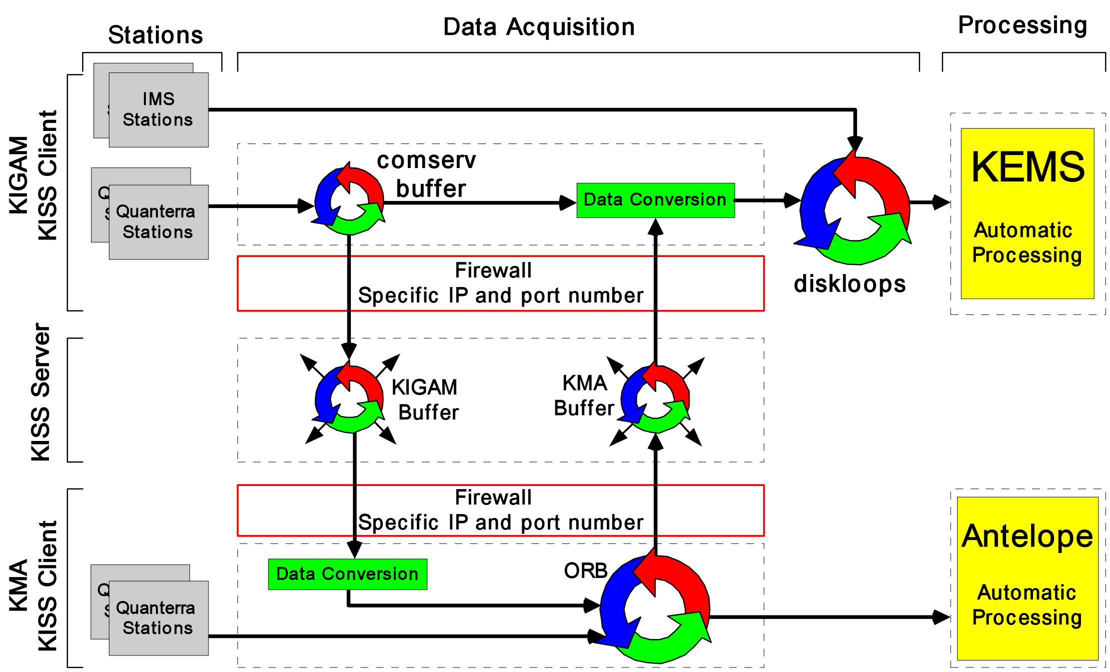


Figure 5. Data flow diagram through KISS

Figure 6 shows the organizations to participate in national network through KISS. Korea Water Resources Corporation (KOWACO) is responsible for the safety of dams and Korea Train Express (KTX) is for operating express train. Not only these two companies but Korea Gas Corporation (KOGAS) is willing to join in the national network.

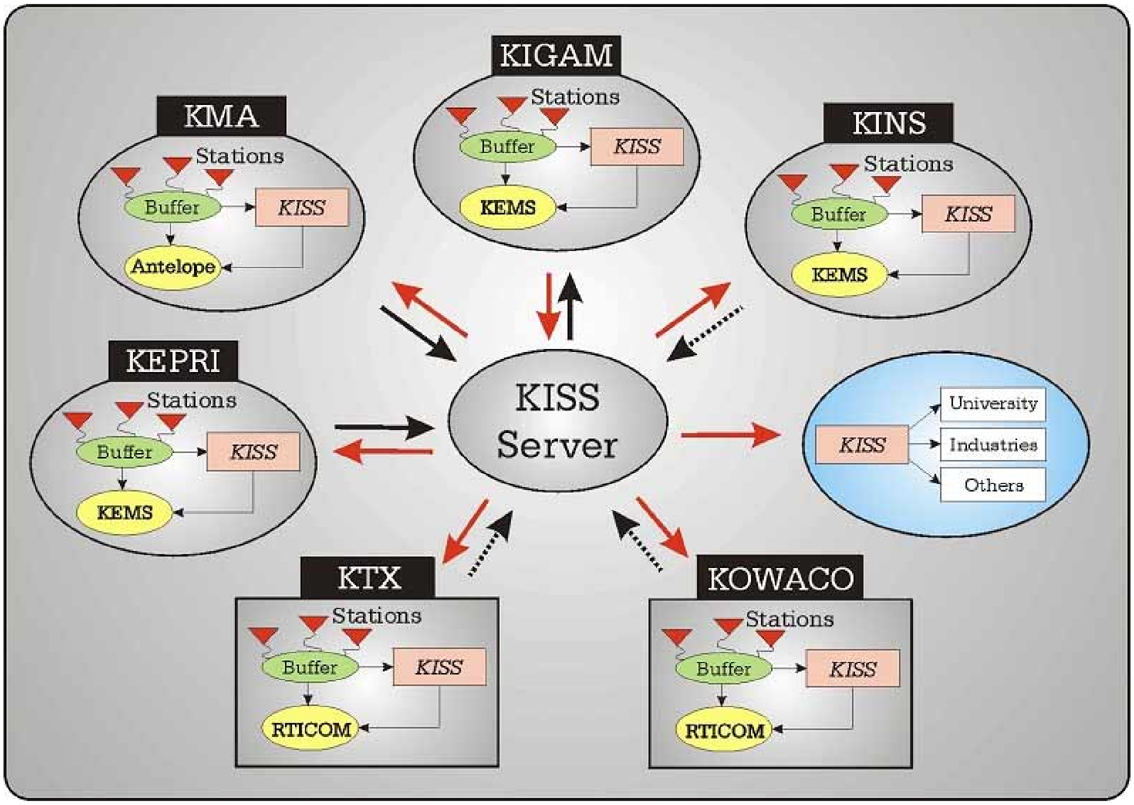


Figure 6. Korea national network through KISS.

VISUALIZATION OF INSTRUMENTAL INTENSITY: RTICOM

The intensity and pattern of damage are mainly dependent on the dominant frequency content of ground shaking as well as its absolute magnitude. The observed value by accelerometer in time domain (i.e. just conventional time series) is the sum of different frequency components of ground motion. Hence, if the damage ratio is estimated by the peak acceleration value without the consideration of frequency content, the estimation may be far from reality especially in the case of short-duration earthquakes. An one-story house is severely affected by ground motion if its dominant frequency is close to 10Hz. But tall buildings, long-span bridges and underground facilities have resonant frequencies much less than 10Hz. The measurable frequency band of most commercially available accelerometers is extended from 0.1Hz to 50Hz with negligible distortion. In order to delete the effect of frequency components greater than 10Hz, low-pass filtered acceleration data with 20 samples per second (sps) is used for instrumental damage evaluation in Korea.

Figure 7 shows the general waveform of acceleration data. One of DSS service of Quanterra data logger is to calculate the values of maximum, minimum and average (i.e. MMA) every one-second interval for each channel and to send these values immediately to requested users (subscription). These specific values are also retrieved and distributed to all enrolled organizations through KISS. Practically it takes 20-40 second to compress and make a packet of the full waveform data in order to send efficiently. But DSS data are sent at once every second without compression, so it can be used for rapid recognition and urgent warning.

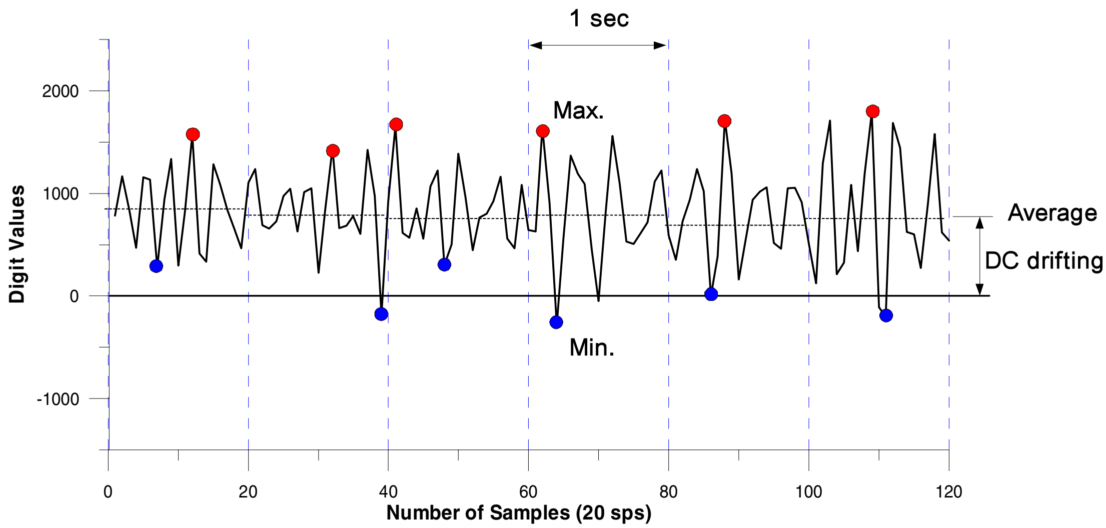


Figure 7. Schematic display of Min., Max. and DC drifting in acceleration data.

Processing DSS information

Ground shaking is sinusoidal wave, so no DC drifting should appear if there is not any permanent rupture or dislocation. But due to mechanical and/or electrical mis-adjustments as well as diurnal variation of temperature, DC drifting is inevitable. In order to get the true acceleration value, the effect of DC drifting should be removed. The background drifting, which is named as avg here, is usually calculated by averaging the sum of several one-second interval DC drifting values. Then the true absolute maximum acceleration value every second is obtained from the larger of abs|Max-avg| and abs|Min-avg|. Observed acceleration by 3-component accelerometer is composed of 3-dimensional vector components. Since facilities are generally very weak to shear wave, the absolute vector sum of two horizontal components is used to indicate instrumental intensity in Korea and it is defined as PGA (Peak Ground Acceleration). In summary, PGA is maximum absolute value of horizontal acceleration every one-second interval after removing DC drifting effect. This PGA is calculated for each station and synchronous PGA is grouped for visualization. The grouped data set can be sent through message queuing or shared memory.

Event detection by DSS information

Figure 8 shows schematic diagram of RTICOM, on which the data flow together with the procedure of event detection by DSS information is depicted. If earthquake happens, first the observed PGA at stations around the epicenter suddenly rises up. As a monitoring station is located farther away from the epicenter, the corresponding PGA will fade out. Hence whether earthquake happens or not can be detected by counting the number of stations where PGA values are greater than pre-assigned threshold within a certain time duration. The counting number and time duration are mainly determined by the spatial density of stations. Once an event is detected (i.e. KGDetect is activated in figure), the event is automatically announced through e-mail, mobile phone and warning alarm. Full waveform data are gathered in segment by the module, KGGetSegment for interactive data review.

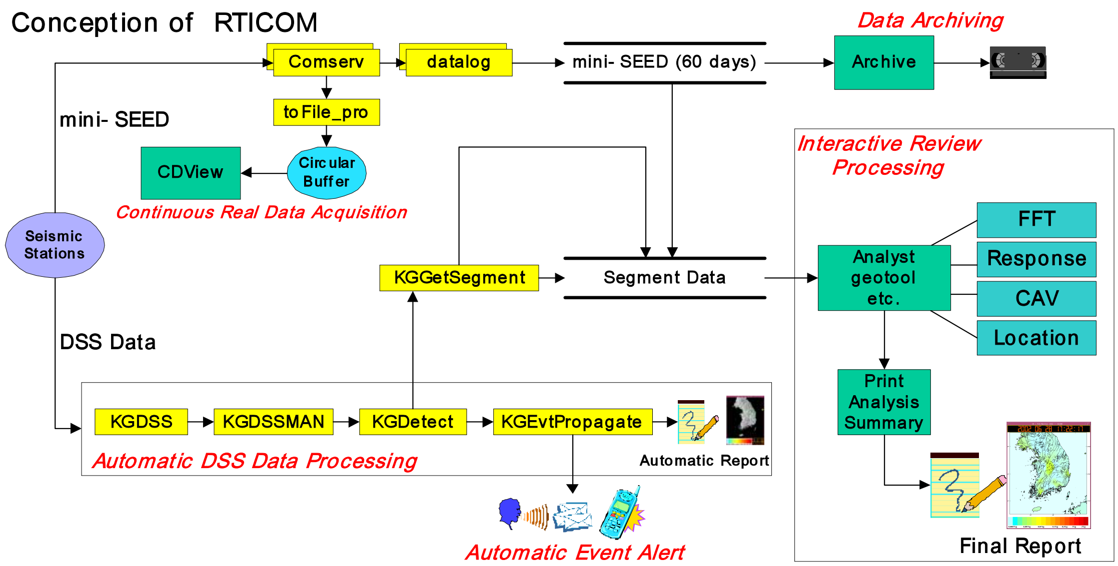
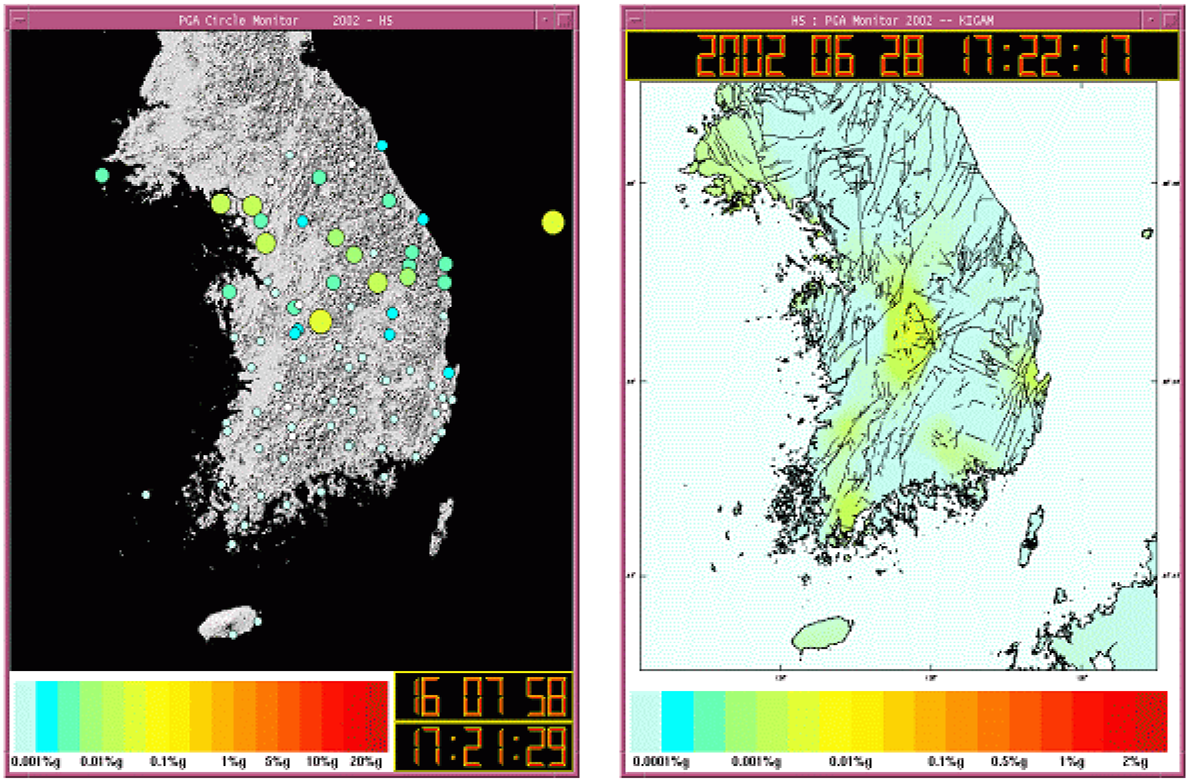


Figure 8. Data flow and procedure of event detection by DSS data.

Color imaging of DSS data

Station locations are not on the grid but they are irregularly spread out; somewhere densely and somewhere sparsely. Hence, irregularly distributed PGA values should be interpolated into grid values. Here, by using the library 'surface', one of GMT (Generic Mapping Tools, http://gmt.soest.hawaii.edu), the grid output, NetCDF (Network Common Data Form, http://www.unidata.ucar.packages/netcdf), is obtained. This grid file is one frame corresponding to each second. It is displayed on the screen by QT library of Trolltech company (http://www.trolltech.com) with given color code.

Figure 9 shows the snap shot of synchronous PGA values with color code below. The epicenter is located at northeastern China, so wave propagated from north to south. There are two un-desirable results; the background noise levels of stations show big difference and the output of interpolation is extended out into northern part where no data are available. The latter can be solved by defining the influence radius of interpolation. Even the background noise level varies with location but the discrepancy is less than 0.001g even for the worst site. This level is negligibly low enough to ignore for the evaluation of even small-to-medium sensible earthquakes.



(a) **(b)**

Figure 9. Visualization of peak ground acceleration (PGA) through RTICOM. (a) shows that PGA is calculated from two horizontal components for each station and displayed by radius size of circle as well as color code. (b) shows the snap shot of synchronous PGA values.

DISCUSSION

In Korea, all organizations or institutes could not secure seismic stations enough to satisfy their requirements and as the solution of this problem, KIGAM proposed to establish national network for sharing data. This proposal was widely accepted and prepared by the committee of four principal organizations which are obligated to observe seismic activity. The committee determined all items related to the monitoring such as the standard configuration of station and networking protocol. Due to these all efforts, totally more than 100 permanent strong-motion stations were constructed uniformly and KIGAM could succeed to develop the real-time network algorithm, KISS (Korea Integrated Seismic System). By virtue of KISS, the plan of national seismic network could be activated in Korea. To the countries of low to moderate seismicity like as Korea, we suggest to adapt this kind of national network as the solution of breaking out the limitation of available stations.

Through KISS, all acceleration data can be retrieved in real time irrespective of organizations or institutes. If imaging properly these instrumental intensity data in color code, both damage area and severity could be very quickly perceived. It was realized by RTICOM. The real-time visualization of strong-motion observation might play a crucial role to rapid emergency management and it could be one of important items in the earthquake hazard mitigation plan.