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A digital social network for rapid collection of earthquake disaster information

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Abstract. Acquiring disaster information quickly after an earthquake is crucial for disaster and emergency rescue management. This study examines a digital social network – an earthquake disaster information reporting network – for rapid collection of earthquake disaster information. Based on the network, the disaster information rapid collection method is expounded in this paper. The structure and components of the reporting network are introduced. Then the work principles of the reporting network are discussed, in which the rapid collection of disaster information is realised by using Global System for Mobile Communications (GSM) messages to report the disaster information and Geographic information system (GIS) to analyse and extract useful disaster information. This study introduces some key technologies for the work principles, including the methods of mass sending and receiving of SMS for disaster management, the reporting network grouping management method, brief disaster information codes, and the GIS modelling of the reporting network. Finally, a city earthquake disaster information quick reporting system is developed and with the support of this system the reporting network obtained good results in a real earthquake and earthquake drills. This method is a semi-real time disaster information collection method which extends current SMS based method and meets the need of small and some moderate earthquakes.

1 Introduction

Earthquakes, an inevitable natural disaster for human beings, are a serious threat to human security and come first among all disasters in terms of casualties and economic loss (Ma et al., 2010). For example, the Wenchuan earthquake caused losses of RMB 8451 million and the death of about 87 000 people (Sun and Zhang, 2012). Within three days after an earthquake is a vital period for earthquake rescue and often named as “72-hour golden rescue period” (China Earthquake Administration, 2010). The survival rate could be sharply decreased after this period. The rapid and dynamic collection of earthquake disaster information after an earthquake, especially within three days is a key in earthquake emergencies (Nie et al., 2002) and it is also the foundation of all the relief work. The size of the earthquake disaster can be evaluated from the disaster information. In other words, the disaster information from several minutes to several days is much more important than other periods, which is also named as semi-real time period to emergency response period (Yamada et al., 2004).

In China, quick and dynamic collection of earthquake disaster information has been given a high position with the use of technology and applications. In the Chinese government file, “The Program for the Development of National Earthquake Science and Technology (2007–2020)” (http://www.cea.gov.cn/), quick acquisition and evaluation of earthquake disaster information are listed as a priority development project. However, collection of the disaster information is a task which has wide aspects and a large workload and it has exposed many shortages in the practice of earthquake emergency response and rescue (Xu et al., 2010a).

There are many studies on the collection of earthquake disaster information worldwide. In these studies, the photogrammetry and remote sensing based method is the most widely discussed one. The first use of this method can be dated back to 1906 in the San Francisco earthquake (Liu et al., 2004). With the rapid development of remote sensing technology, by now it has already been applied in several real earthquakes, for example, the Niigata earthquake in Japan, the Chi-Chi earthquake in Taiwan, and the Wenchuan earthquake in China (Li and Tao, 2009).

Many studies concerning this method have also been done. For example, Hajime et al. (2002) studied the spectral characteristics of damaged and undamaged buildings in the Kobe earthquake. This method is expected to be used for early damage assessment in earthquakes. Ronald et al. (2008) provide an overview of how remote sensing technologies have or could be used in the management of natural disasters. In general, studies of this method vary from the disaster evaluation model (Tsai et al., 2008), extraction of damaged building information (Wang et al., 2004), and other related key models to the application of different remote sensing platforms such as SAR (Liao and Shen, 2009) and the hyperspectral platform (Faulring et al., 2011). But this method also needs to be further investigated with regard to several aspects, such as the speed and accuracy of the disaster information evaluation. For example, in the 2008 Wenchun earthquake in China, the first image of the disaster area was obtained three days after the occurrence of the earthquake (China Earthquake Administration, 2010). Moreover, the method does not cater for small earthquakes: if an earthquake does not cause bad building damage, then it is difficult to evaluate the disaster information.

The Internet based earthquake disaster information collection method is also a very important method and has been widely used. The "Did You Feel It?" system is such a typical system that has been developed by USGS (http://earthquake.usgs.gov/research/dyfi/). It collects disaster information from the public via the Internet. The main aim of this system is to collect people's experiences of earthquakes and to compile a map of the shaking. The British Geological Survey (BGS) also use the Internet to develop the "BGS E-Mail Earthquake Questionnaire" system to obtain earthquake disaster data from the public (http://www.earthquakes.bgs.ac.uk/questionnaire/EqQuestIntro.html). However, these methods are not a semi-real time disaster information acquiring method. Hisada et al. (2008) also put forward an earthquake damage information quick collection method, which suggests the collaboration between a local government and residents. This study is a useful attempt in semi-real time disaster information collection.

As a newly emerging and rapidly developing method, the SMS based method has led to wide interest and studies. Actually the mobile phone has already been widely used in collecting information at local, regional, and continental scales to help answer diverse questions in the geosciences and environmental sciences (Graham et al., 2011). In earthquake engineering field, Corbane et al. (2012) explore the relationship between the spatial patterns of SMS messages and building damage, which provides direct support for search and rescue teams. In China, a 12 322 platform has been developed by the China Earthquake Administration and used to collect earthquake disaster information. In this platform, voicemail and short messages are also used by calling the number "12 322". However, several issues related to these methods should be considered, such as how to use SMS effectively to send disaster information quickly, how to extract useful disaster information quickly, and how to determine whether the source of the disaster information is reliable.

This paper will study a social network based earthquake disaster information rapid collection method by using Geographic information system (GIS) and Global System for Mobile Communications (GSM) technology and try to solve the above problems. The social network is composed of earthquake disaster information rapid reporters. So the social network can also be called an earthquake disaster information rapid reporting network.

2 Forming an earthquake disaster information reporting network

2.1 Components of the reporting network

First we want to introduce the components of the earthquake disaster information reporting network. The social network comes from sociological theory and it typically refers to the network relationship between persons (Newman, 2004). With the development of Internet and wireless communications, social networks have been shown to be communities formed through MSN, mobile telephones, and so on (Flake et al., 2002). People are the theme of the social network, and the various connections between people constitute the relationships, which include static relationships and dynamic context transformation based relationships, which are caused by the action of interaction and activities. A digital social network or community is a digitalized representation of a social network. It has produced many applications in daily life and work, such as Facebook and RenRen. It also produces a good application effect in many professional fields. Just like the earthquake field, Haubrock et al. (2007) have tried to establish a concept for a community-based map creation process in the context of earthquake intensity estimation.

In China, such a social network has been established for collecting earthquake disaster information, and its digital representation can be called an earthquake disaster information reporting network.

The reporting network construction requirements include the following:

1. The reporting network should be constructed in accordance with the country level, provincial level, and city level.

2. Each town or street is the smallest component of the whole disaster information reporting network, and in each town (street) there must be at least one earthquake disaster information reporter.

3. In order to guarantee the reliability of the reported disaster information, the reporter should be a formal local government employee. The reporter can be occupied part-time by a town (street) technology assistant or a civil affair assistant. In areas with appropriate conditions, the reporter should try to be occupied part-time as a member of the earthquake knowledge dissemination network or earthquake macro-phenomenon observation network.

2.2 Structure of the reporting network

The structure of the reporting network is hierarchical as extracted from the construction requirements (Fig. 1). The uppermost level is the country level, while the city level is crucial for the whole network, as it is the basis for the collection of earthquake disaster information. The provincial level bureau just needs to confirm and check the disaster information reported from the city level.

Since the city level reporting network is the foundation, we should know its detailed structure. The structure of the city level reporting network can be depicted as in the right of Fig. 1. The network is composed of two kinds of nodes (edge nodes and central nodes) and their connections. An edge node is a disaster information reporter who is responsible for collecting disaster information and sending it to the central node, while the central node is the city earthquake bureau. After the earthquake, the city earthquake bureau will send an instruction to the reporters ordering them to collect earthquake disaster information. After receiving the disaster information reported from the edge nodes, the central node will extract useful disaster information and report to the provincial earthquake bureau. The city earthquake bureau is also responsible for the regular training of the disaster information reporters.

So the edge node is a person who actually collects disaster information on the spot. Taking Changzhou city of Jiangsu Province as an example, the earthquake disaster information reporter positions are occupied by members of the street or town civil affairs information staff who cover the whole city. They act as disaster information reporters as a part-time job. The Changzhou earthquake disaster information reporting network includes 1048 information members in total. However, in Nanjing the disaster reporters work part-time for the county or street administration as technology assistants. There are only 147 members of Nanjing earthquake disaster information reporting network.

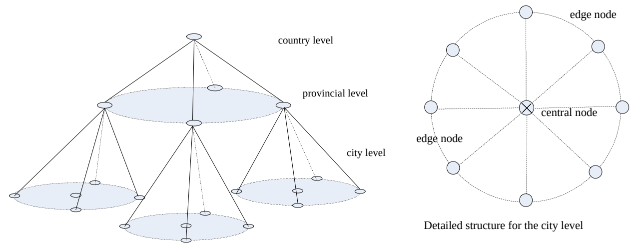

Fig. 1. Hierarchical structure of the reporting network.

The communication connection between the edge node and the central node is also very important. The telephone is a traditional tool of communication in China. This method is not only time-consuming but also inconvenient. In this study, short messages based on GSM have been used for disaster information reporting. In China, the fee for sending SMS is very cheap, at only 0.1 Yuan per message, and group messages can be even cheaper. Meanwhile it is free to receive a short message. So SMS is widely used and reporters are very accustomed to using short messages.

3 Working principle of the reporting network

3.1 Disaster information collection based on the network

Taking Jiangsu province as an example, three criteria should be taken into account for the reporting network to be activated:

1. An earthquake of above $M_s = 4.0$ occurs in Jiangsu province;

2. the earthquake occurs in the neighbouring provinces, causing a great impact on Jiangsu province;

3. The shaking feeling caused by the earthquake in Jiangsu province has a great social influence.

As long as any of the above conditions are met, the network should be started up immediately. The reporters should collect disaster information promptly and report the disaster information to the city earthquake bureau.

So the reporters should be trained in earthquake emergency and disaster knowledge in ordinary time. Once the start conditions are met, the staff of the city earthquake bureau will send short messages to those reporters who are located in the earthquake region and order them to report the disaster information which they have observed. Then, these trained reporters will describe the disaster information in a

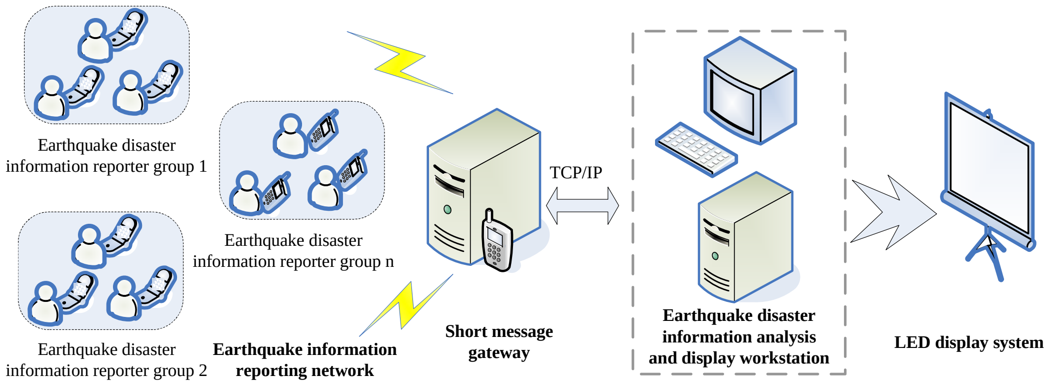

Fig. 2. Working principle of the disaster information collection system.

previously specified format and report to the designated disaster information collection system using short messages. The city earthquake bureau will extract useful disaster information from the messages and display it.

In the whole process, the disaster information collection system is the key, and it is developed using the GIS secondary development tool. It manages and stores the reporting network. It is used not only to send the disaster information collection command but also to analyse the short messages according to a predetermined format and to extract useful disaster information. As time goes on, the number of disaster information messages received will increase. Then, the tool will analyse the disaster report messages from time to time to realise the dynamic extraction and display of the disaster information.

The working principle of the disaster information collection system based on the network is shown in Fig. 2, and from left to right the system is composed of four parts:

1. The earthquake disaster information reporting network. It realises the collection of disaster information on the spot.

2. The disaster information short message gateway. It is responsible for sending and receiving short messages about the disaster.

3. Earthquake disaster information analysis and display workstation. The disaster information short messages analysis and effective information extraction will be realised in the workstation. It extracts the information from the reporting messages using the analysis module, forms the earthquake information tables, and saves the disaster information into the database. Then with the support of related GIS mapping tools, the useful disaster information will be dynamically displayed.

4. LED display. The dynamic disaster information display can be watched by connecting it to the LED.

3.2 Mass sending and receiving of short messages about disasters

The short message gateway realises the communication between the edge and central nodes by using short messages based on GSM. So solving the problem of mass sending and receiving of short messages about disasters is one of the key technologies in the collection of disaster information. There are two kinds of methods: one is the GSM modem pool method; the other is the mobile agent server method.

The GSM modem pool is one kind of industrial mobile short message communication hardware used. Usually a pool can be composed of eight GSM modules, such as those from WaveCOM and Siemens. The GSM modem pool usually sends or receives short messages by using AT commands to control each GSM module or to send or receive short messages. Now most GSM module hardware vendors have packaged the AT command into a uniform interface program for sending and receiving single short messages.

Usually about 0.5 s are required for a GSM module to receive one message and about 6 s are required to send one message. The GSM modem pool caters for those networks which do not contain a large number of reporters. For example the Nanjing disaster reporting network has only 147 members, and so in this case the GSM modem pool can be used.

But some reporting networks have a large number of reporters, such as the Changzhou network. A command from the central node to 1048 network members requires $6 \times 1048 = 104.8$ min. Although the efficiency can be improved by using a plurality of modules in parallel, on the whole it is still difficult to fully meet the speed requirements of the emergency response for the rapid collection of earthquake disaster information. When the number of reporters increases, the reliability of the GSM modem pool decreases and some short messages may be even lost.

Therefore, in this case a mobile agent server (MAS) should be used to realise the mass sending and receiving of short messages about disasters. The MAS is an information technology application service provided by China Mobile Communications Corporation (CMCC), which deploys mobile agent servers for the user to provide SMS, MMS, and WAP based services (http://baike.baidu.com/view/736443.htm). The CMCC has set up a special mobile messaging server in the Changzhou earthquake bureau and uses special fibres to connect with the SMS server in CMCC. So a point-to-point short message service has been established to send and receive short messages.

For example, to realise the mass sending and receiving of short messages about disasters, Changzhou earthquake disaster information short message gateway has been developed, which encapsulates a special API of the mobile agent service of CMCC and is dedicated to the receiving and sending of short messages about disasters. Using the MAS to send short messages can achieve sending rates of nearly 100 messages per second, which greatly increases the speed at which short messages can be sent and meets the need for rapid collection of earthquake disaster information.

4 Managing and modelling the reporting network

After an earthquake, the quantity of data related to all kinds of disaster information is very large in the disaster area and there are various types of data; the data also contain a lot of redundant and wrong information. How to effectively transfer disaster information and quickly extract useful disaster information is also very important. Modelling and management of the reporting network is one of the key technologies for solving this problem.

4.1 Coding disaster information

Using numbers to code disaster information is convenient not only for quick reporting of disaster information by reporters but also for analysing and extracting effective disaster information. With reference to GB/T17742-1999 (1999), earthquake disaster information is classified into six kinds, namely: the feeling of the earthquake shaking, number of people dead, number of people injured, damage to buildings, secondary disasters, and infrastructure damage. This disaster information is what is most needed by the emergency command staff. These codes will be transferred by means of short messages. We try to keep each type of disaster message to below 70 words, which is the maximum length of a single short message. So the code should be concise and have a clear meaning.

At present, there are three main information coding methods: tree structure coding, chain coding, and hybrid structure coding (Xu et al., 2010b). The tree structure is characterised by a subordinate relationship between different code bits, which contains more information with fewer codes, but it cannot be easily coded and identified. For the chain structure, each bit of the code has an independent meaning, which contains less information than the tree structure but the structure is simple and easily coded. The hybrid structure is a combination of these two coding methods.

Referring to common geographical information coding methods and the existing information coding methods in earthquake emergency field, the chain coding method is selected and used to design disaster information codes. Taking into account the information coding scalability, compatibility, the designed codes are shown in Table 1.

These codes are composed of two or three numbers. The first number refers to the type of disaster information; for example “1” refers to the “feeling of the earthquake shaking” and “2” refers to fatalities. The second number represents the disaster grade; for example in the “feeling of the earthquake shaking”, “1” means “no shaking” and “4” means “strong feeling”. In some types of disaster information, the disaster scale should be described. In such cases, we express the information by using a small range and a large range. For example, if the earthquake causes a small-scale power failure, we will use 531, while for a large-scale power failure, 532 is used. Similar codings can be used for gas stoppages, fire disasters, and so on. According to the *Chinese Seismic Intensity Scale* (GB/T17742-1999), large scale means more than half of infrastructure damaged and otherwise it is a small scale.

4.2 Grouping of the disaster reporting network members

In order to effectively manage the reporting network, the disaster reporters should be divided into several groups. There are three reasons for the group management. The training of disaster reporters can benefit considerably from group management. For example, in Changzhou there are 1048 reporters. It is difficult to train 1048 reporters at the same time. They should be trained in turn with different groups. And some earthquakes only have an effect on part of a city, so only some of the reporters need to report disaster information. Thus only those groups in affected areas report the disaster information. This can also speed up the collection of disaster information. When using the GSM modem pool to send short messages about disasters, dividing the reporters into different groups can also increase the speed of collection of disaster information.

In order to divide up a disaster reporting network, two criteria have been considered in grouping the disaster reporting network, as follows:

1. The geographical location principle. It has been found that different reporters are usually distributed throughout different streets and communities in a city. And according to the Chinese administration management, streets and communities are the smallest administrative units. The upper level is the area county. So the grouping can be done according to the area county to which the disaster reporters belong.

Table 1. Earthquake disaster information codes.

Disaster information type	Disaster information description and code				
Feeling of earthquake shaking	No shaking (11)	Slight feeling (12)	Moderate feeling (13)	Strong feeling (14)	
Number of people dead	None (21)	A few people (21)	More than a dozen people (23)	Dozens of people (24)	More than 100 (25)
Number of people injured	None (31)	A few people (32)	More than a dozen people (33)	Dozens of people (34)	More than 100 (35)
Proportion of buildings damaged	No damage (41)	A few damaged (42)	Most buildings damaged (43)	Large numbers of buildings damaged and partially collapsed (44)	Most buildings collapsed (45)
Secondary disasters	None (51)	Without water (1 = small range; 2 = large) (52)	Power failure (1 = small range; 2 = large range) (53)	Gas stoppages (1 = small range; 2 = large range) (54)	Fire disaster (1 = small range; 2 = large range) (55)
Infrastructure damage	Accessible (61)	Road damage (62)	Road congestion (63)	Bridge damage (64)	Bridge collapse (65)

2. The 150 data principle. This principle is also a basic theory in social network theory (Wang, 2011) and the research (Hill and Dunbar, 2003) shows the maximum network size is 153.5 individuals in average, with a mean network size of 124.9 for those individuals explicitly contacted (Hill and Dunbar, 2003). So the core of the "150 rule" is that when a network gathers more than 150 people, it should be subdivided. Namely, keeping the size of the network of people to less than 150 seems to be the best and the most effective way to manage the network. Even with emergence of new modern communication methods like Facebook and RenRen, they still do not change the fact that the size of the human brain allows stable networks of about 150. It has become famous as "the Dunbar number" (http://en.wikipedia.org/wiki/Dunbar%27s_number). In essence the disaster reporting network is also a kind of social network. So this rule has provided an important reference for the network grouping.

The Changzhou earthquake disaster reporting network has been divided into several groups. In the process of grouping the reporters according to the 150 rule, the size of each group is kept at around 150. If the size of each group is smaller, this will naturally lead to the creation of too many groups, which is not good for the management. So for regions with smaller numbers of reporters, we merge the reporters from nearby areas into one group. Similarly, if the size of a group is too large that is also unhelpful for the management. If there are too many reporters in one area, the group should be divided into two groups.

Based on the above principles, the Changzhou network is divided into seven groups. On average each group has 149 people.

4.3 The GIS based modelling of the disaster reporting network

In order to realise rapid extraction and display of useful disaster information, it is necessary to store the disaster reporting network on a computer and to model it in GIS. GIS technology can integrate the geographic information of the disaster reporting network with the content of the disaster information and realise the integration of geographic information and its mobile phone numbers. The basic component of the disaster reporting network is a single reporter. So, the modelling of the network needs to begin from the modelling of each member. In the modelling process, the following methods are used:

1. The layer management method of GIS is used, in which all the disaster reporters are organised into a GIS layer. That means that a GIS layer (called a disaster information reporters layer) is established to manage the disaster reporting network. Then the street or community of each reporter is found and matched to the corresponding map location by using the geocoding functions of GIS. So the transformation from the geographical position to the geographic coordinates is realised, which lays the foundation for displaying the disaster information. Because the disaster reporters belong to groups, group information also needs to be designed in the layer properties.

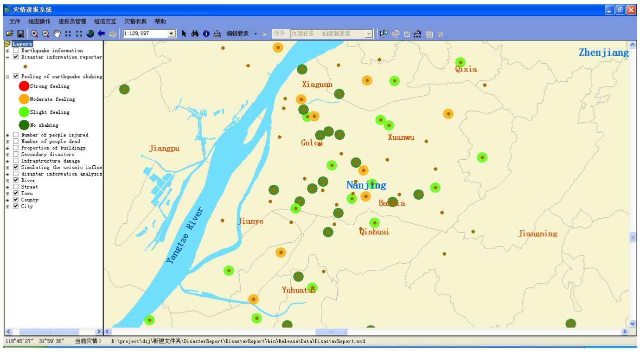

Fig. 3. Disaster information distribution of the 20 July 2012 $M_S = 4.9$ Yangzhou earthquake.

2. GSM telephone number information is integrated with disaster reporter information. SMS is the method used to transfer disaster information in this paper. Therefore, it needs to integrate the geographic information with the mobile phone number information of the reporters. The mobile phone number information is regarded as attribute data and is managed with the geographic information of each disaster reporter.

The Reporter Information Layer consists of the following information: "shape", "name", "work place", "group Name", "mobile phone number", "feeling of earthquake shaking", "number of people dead", "number of people injured", "proportion of buildings damaged", "secondary disasters"', and "infrastructure damage". The shape type is a point, which means that each disaster reporter is considered as one point on the layer.

5 System development and application

5.1 Realisation of the disaster information reporting system

By using ArcGIS Engine 9.3 and Visual Studio.Net 2008 C#, the city earthquake disaster information rapid reporting system is developed, which realises the management of the reporting network and its application in disaster information collection. The system includes two parts: the disaster information short message gateway system and the earthquake disaster information analysis and display system. Taking Nanjing city as an example, the main interfaces of the disaster information analysis and display systems are shown in Fig. 3.

After an earthquake, a disaster information reporting command can be sent to the disaster information reporters by using the function of the system. After a period of interaction, the system will automatically extract effective disaster information from the messages received and will use different symbols and colours to represent the disaster information.

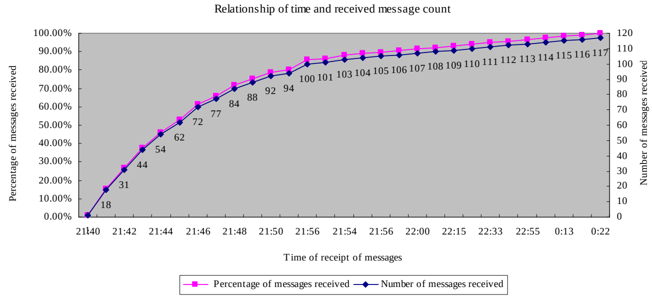

Fig. 4. Relationship between time and disaster information messages received.

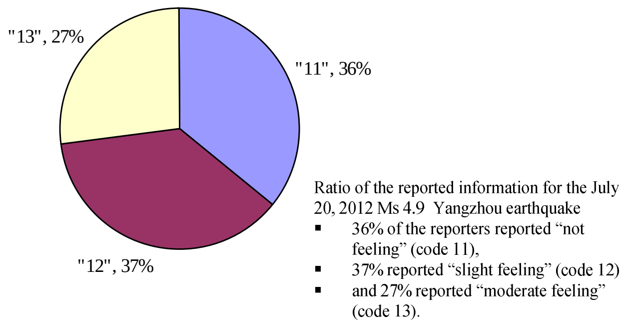

Fig. 5. Ratio of "feeling of earthquake shaking" disaster information.

Figure 3 shows the disaster information collected regarding the feeling of the earthquake shaking. In the system, symbols of different shapes represent different types of disaster information. For example, a circle is used to represent the "feeling of the earthquake shaking" and a square is used to represent "number of people injured". Different colours represent the different disaster grades. A dark red symbol means the disaster is more serious. As shown in Fig. 3, from green to red, the feeling of the earthquake shaking varies from "no shaking" to "strong feeling"

5.2 Application of the reporting network

On 20 July 2012 at 20:11 LT a $M_S = 4.9$ earthquake occurred in Jiangsu province near to Nanjing. The epicentre was located at Yangzhou (Lat. 33.0° N, Lon. 119.6° E), and the depth was 5 km. The earthquake was felt in Nanjing. At 21:30 (about 1 h after the earthquake), the earthquake disaster reporting system had been initiated and the disaster information reporting command was sent out within 5 min. The first disaster information was reported only about 5 min after the command was sent.

From Fig. 4, we can see that the first disaster information was reported at 21:40 on 20 July and the last disaster information was reported at 00:22 on 21 July. The total number of disaster information reports was 147. By 21:46, the number of disaster information messages received was 72 and the

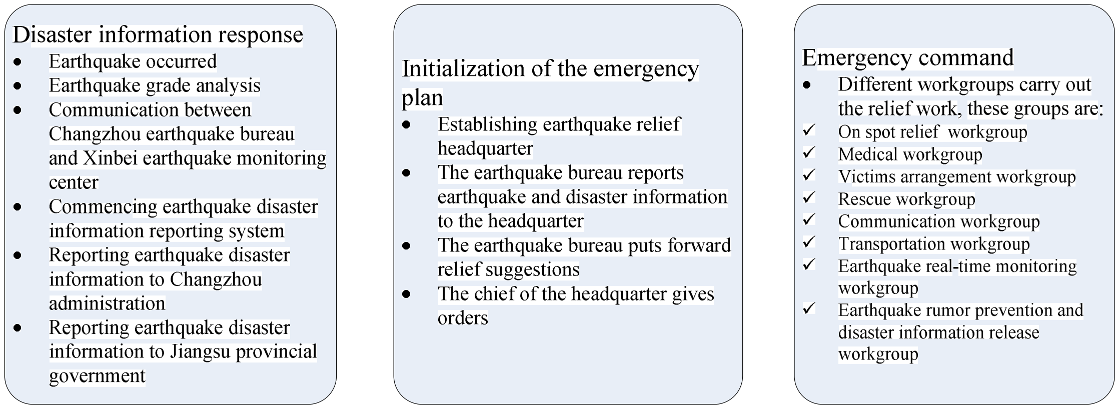

Fig. 6. Contents of the Changzhou drill scenes.

percentage of total messages was 49 %, which means that half of the disaster information was reported within six minutes of the first disaster information report. At 21:51 the number of reported disaster information reports was up to 94 and the percentage was up to 90.6 %. From 21:40 to 21:51, the percentage of the disaster information reported changed from 0.85 % to 90.6 %. That also means that most of the disaster information can be reported in about ten minutes. Only three disaster information messages were reported on 21 July.

From the analysis of the disaster information content, only the "feeling of the earthquake shaking" type of disaster information was reported. This is because that earthquake did not cause other damage. The disaster information reported is shown in Fig. 5. Disaster information code "11" was reported by 36 % of reporters, which means that 36 % of disaster information reporters did not feel the earthquake. Disaster information code "12" was sent by 37 % of reporters, which means that 37 % of reporters felt the earthquake slightly. 27 % of the reporters reported that they felt the earthquake moderately. So, from the reported disaster messages, we can conclude that in this earthquake most people noticed a feeling of shaking and some people experienced a moderate shaking feeling in Nanjing, but the earthquake did not cause any deaths among people or damage to buildings. The distribution of the disaster information is shown in Fig. 3. This disaster information was quickly reported to the Nanjing government and then released to the public. The public quickly knew the disaster information and did not worry about the earthquake, which had a good effect on the earthquake emergency.

The system has been used not only in the collection of real earthquake disaster information but also in emergency drills and training. Taking Changzhou system as an example again, on 15 December 2011, the "Changzhou and South Jiangsu Province Earthquake Emergency Collaborative and Integrated Operation Area Earthquake Emergency Drill" was held in the Changzhou earthquake emergency preparation command centre. The participating units included three Jiangsu government departments and more than 30 Changzhou government departments. In the emergency drill, a simulated $M_s = 4.8$ earthquake occurred in Changzhou. There are three drill scenes: disaster information response, initiation of the emergency plan, and the emergency command. The more detailed information about these drill scenes is shown in the Fig. 6. The system has been used in the scene of disaster information response. 1048 reporters took part in this drill and the simulated disaster information was quickly acquired within 5 min from the reporting network. In the drill, the system showed rapid collection of the disaster information and gained the praise of the participants. Currently, the system has become one of the key business support systems in the daily duties of the Changzhou earthquake bureau.

6 Conclusions and future work

With the rapid development of modern science and technology, many technology networks have also become an important part of social networks. The paper explores a digital social network based on disaster information reporters and its application in the rapid collection of earthquake disaster information. As a digital social network, the components of the reporting network are introduced. We analyse the hierarchical structure of the network. Then the working principles of the network are discussed in detail; that is, after an earthquake, the earthquake bureau quickly collects the disaster information by interaction with the reporting network through a number of short messages.

In order to effectively extract disaster information from the reported disaster messages, brief disaster information codes are designed. The group management principles of the disaster reporting network are described and the GIS modelling method of the network is discussed. Then the disaster information rapid reporting system is developed with the support of the reporting network. The system has been used to collect disaster information quickly in a real earthquake. The use of earthquake emergency drills and training is also described. Now the system has become one of the core business systems among the daily duties of some city earthquake bureaus, such as Nanjing, Changzhou, Suzhou, and Shenyang.

As a new method, the aim of this study is mainly focused on quickly acquiring disaster information. It is not perfect yet and some topics need to be further studied:

1. The reporting network discussed is based on communication via short messages, which has some limitations. For example communication may be interrupted after a very large earthquake. This will affect the collection of disaster information. Of course, if after an earthquake no disaster information is reported from the entire reporting network, this also means the disaster may be very serious. In such case, this method may fail. With the development of communication technologies, there are many other substitutable communication methods, such as WiFi or Zigbee. Moreover, the cost of satellite communication has become less expensive and it can be more widely used.

2. In this study, the reporters use common mobile phones. They report disaster information via short messages. These messages are simple and plain. The development of mobile device and mobile GIS makes complex mobile applications easier. In the future more versatile reporting application software will be developed, which will include the function of positioning, picture taking, video recording.

3. In comparison to the Chinese city territory, the number of reporters in a city is small. And in an earthquake, some of them may fail to report disaster information. The reporters mentioned in this study are all professional and official reporters. Volunteer GIS as a new GIS technology considers everyone as a sensor, which means everyone of the public could be a disaster information reporter. So we will try to extend current study by introducing volunteer GIS into earthquake disaster information collection. In which some issues should be studied, for example the data cleaning and quality control, volunteer network management based on GIS.

4. The disaster information acquired from different methods has different format and display methods. How to merge the reporters' disaster information into other multi-source and heterogeneous disaster information is also a subject that needs to be further studied. This is also a way to solve the problem when one of the disaster information acquiring methods has failed.

5. The reporters are occupied part-time by other official staff. These staff's duty may be changed sometimes, so regular training for the reporters should be considered as important work in future.

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References

China Earthquake Administration: Report on earthquake emergency disaster information recognition and evaluation technologies, Institute of Geology, China Earthquake Administration, Beijing, China, 1253 pp., 2010.

Corbane, C., Lemoine, G., and Kauffmann, M.: Relationship between the spatial distribution of SMS messages reporting needs and building damage in 2010 Haiti disaster, Nat. Hazards Earth Syst. Sci., 12, 255–265, doi:10.5194/nhess-12-255-2012, 2012.

Dunbar's number: available at: http://en.wikipedia.org/wiki/Dunbar%27s_number, last access:13 November 2012.

Faulring, J. W., McKeown, D. M., Van, A. J., Casterline, M. V., Bartlett, B. D., and Raqueno, N.: Supporting relief efforts of the 2010 Haitian earthquake using an airborne multimodal remote sensing platform, in: Proceedings of SPIE – The International Society for Optical Engineering, Orlando, FL, United States, 25–28 April, 2011.

Flake, G. W., Lawrence, S., and Giles, C. L.: Self-organization and identification of web communities, IEEE Comput., 3, 66–71, 2002.

GB/T17742-1999: China earthquake intensity table, Quality and technical supervision of the People's Republic of China, 1999.

Graham, E. A., Henderson, S., and Schloss, A.: Using mobile phones to engage citizen scientists in research, EOS, Transactions American Geophysical Union, 92, 313–315, 2011.

Hajime, M., Masashi, M., Fumio, Y., Hitoshi, T., and Yujiro, O.: Determination of the areas with building damage due to the 1995 Kobe earthquake using airborne MSS image, in: Geoscience and Remote Sensing Symposium, 2002 IEEE International, 5, 2871–2873, 2002.

Haubrock, S., Wittkopf, T., Grünthal, G., and Dransch, D.: Community-made earthquake intensity maps using Google's API, in: Proceedings of the 10th AGILE International Conference on Geographic Information Science, Aalborg, Denmark, 2007.

Hill, R. A. and Dunbar, R. I. M.: Social networks size in humans, Human Nature, 1, 53–72, 2003.

Hisada, Y., Murakami, M., and Zama, S.: Quick collection of earthquake damage information and effective emergency response by collaboration between local government and residents, in: 14th world conference on earthquake engineering, Beijing, 12–17 Oct 2008, 1–8, 2008.

Li, P. and Tao, X. X.: Integrating RS technology into a GIS-based earthquake prevention and disaster reduction system for earthquake damage evaluation, Earthq. Eng. Eng. Vib., 1, 95–101, 2009.

Liao, J. J. and Shen, G. Z.: Detection of land surface change due to the Wenchuan earthquake using multitemporal advanced land observation satellite-phased array type L-band synthetic aperture radar data, J. Appl. Remote Sens., 3, 031680, doi:10.1117/1.3142466, 2009.

Liu, J. H., Yang, J. F., Wei, C. J., and Guan, Z. Q.: Remote sensing for earthquake damage information technology, history, current status and trends, Nat. Disasters, 6, 46–52, 2004.

Ma, Z. J., Du, P. R., Gao, X. L. Qi, W. H., and Li, X. L.: Analysis of earthquake distributions in East Asia and in the world, Earth Sci. Front., 5, 215–233, 2010.

MAS: available at: http://baike.baidu.com/view/736443.htm, last access: 23 August 2012.

National earthquake science and technology development outline (2007–2020): available at: http://www.cea.gov.cn/manage/content/docmanage/download.jsp?filePath/1/3.doc, last access: 22 August 2012.

Newman, M. E. J.: Detecting community structure in networks, Eur. Phys. J. B. – Condens. Matter Complex Syst., 3, 321–330, 2004.

Nie, G. Z., Chen, J. Y., and Li, Z. Q.: The construction of basic database for earthquake emergency response, Earthquake, 3, 105–112, 2002.

Ronald, T. E., Charles, K. H., Shubharoop, G., and Beverley, J. A.: The application of remote sensing technologies for disaster management, in: 14th World Conference on Earthquake Engineering, Beijing, China, 12–17 October 2008, 1–17, 2008.

Sun, B. T. and Zhang, G. X.: Statistical analysis of the seismic vulnerability of various types of building structures in Wenchuan M8.0 earthquake, China Civ. Eng. J., 5, 26–30, 2012.

Tsai, K. J., Chen, K. T., and Lin, C. C.: An establishment on the disaster GIS mapping system for Nantou county in Taiwan, in: Proceedings of the 18th (2008) International Offshore and Polar Engineering Conference, ISOPE 2008, Vancouver, BC, Canada, 6–11 July, 649–653, 2008.

Wang, L.: Semantic network, social network computing and web resource sharing, Publishing House of Electronics Industry, Beijing, 2011.

Wang, X. Q., Ding, X., and Dou, A. X.: Study on model base system of earthquake damage extraction from RS in ENVI/IDL environment, in: 2004 IEEE International Geoscience and Remote Sensing Symposium Proceedings: Science for Society: Exploring and Managing a Changing Planet. IGARSS 2004, Anchorage, AK, United States, 20–24 September, 2252–2255, 2004.

Xu, J. H., Yang, Y., and Deng, M. X.: GIS-Based disaster information report and rapid determination, J. Nat. Disaster, 4, 141–146, 2010a.

Xu, J. H., Nie, G. Z., and Han, Y.: Multiple and heterogeneous earthquake disaster information fusion, in: Proceedings of 2nd International Conference on Information Engineering and Computer Science, ICIECS 2010, Wuhan, China, 25–26 December 2010, 353–356, 2010b.

Yamada, H., Furuto, T., Urayama, T., Suetomi, I., and Kakumoto, S.: Earthquake disaster prevention information system based on risk adaptive regional management information system concept, in: 13th World conference on earthquake engineering, Vancouver, BC, Canada, 1–6 August 2004, 1–12, 2004.