Application of BeiDou navigation satellite system in emergency rescue of natural hazards: a case study for field geological survey of Qinghai–Tibet plateau

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GEO-SPATIAL INFORMATION SCIENCE 2018, VOL. 21, NO. 4, 294–301
https://doi.org/10.1080/10095020.2018.1522085

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1. Introduction

Currently, the geological survey work in China mainly focuses on the western areas, most of which are dead zones for the common mobile communication and ground communication network. The emergency rescue of field work mainly adopts satellite phone. As its application is limited by low degree of automation and high cost, it is difficult to satisfy dynamic tracking and navigation of moving targets in geological survey. Therefore, it is seriously in need to provide daily safety measures and technical guarantee for personnel engaged in field geological survey through new technical means.

Qinghai–Tibet Plateau covers the entire area of Tibet and Qinghai, northern Yunnan, western Sichuan, southwestern Gansu, southern Xinjiang, etc., with an area of 2.5 million square kilometers. Qinghai–Tibet Plateau is the concentrated expression area of modern crustal motions, the window for observation of geodynamic processes, a natural laboratory for study on the global environmental change, and a gene pool of biological species. Qinghai–Tibet Plateau has become the hot study field for a number of disciplines, for example, geoscience, life science, environmental science, etc. However, the special natural conditions of Qinghai–Tibet Plateau have determined its characteristic of “life-forbidden zone”. Various natural hazards (alpine hypoxia, seriously changeable weather, complex road conditions, and beast attacking) have caused serious threats to the life safety of field geological personnel. The scientific investigation over 100 years has cost the precious life of numerous geological personnel. How to reduce and avoid casualties in the field is an urgent problem to be solved.

So far, the main survey and positioning satellite systems include GPS from America, GLONASS from Russia, BDS (BeiDou Navigation Satellite System) from China, and Galileo from EU. In addition, India and Japan prepare to set up their own navigation and positioning systems (Yang et al. 2013; Zhu 2010). GPS from America is a global, all-weather, all-day and high-accuracy navigation and positioning and time transfer system. The total quantity of in-orbit satellites of GLONASS from Russia has reached 26, 21 of which are working in orbit, 2 are stand-by, and 3 are under maintenance (Luo, Xiang, and Bian 2012). Galileo from EU consists of 30 MEO satellites and 3 GEO satellites (Liu 2012). Its dominant advantage is

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ARTICLE HISTORY
Received 15 June 2017
Accepted 5 July 2018

KEYWORDS
BeiDou navigation satellite system (BDS); natural hazard; emergency rescue; Qinghai–Tibet plateau

ABSTRACT
In recent years, geological and mineral resources exploration in China has expanded to deep hinterland of the Qinghai–Tibet Plateau and other regions with complex geological conditions. The special natural conditions of Qinghai–Tibet Plateau determine the characteristics of “life-forbidden zone” that is characterized by alpine hypoxia, changeable weather, complex road conditions, and beast attack. In particular, the work in wild depopulated zones with severe environment and poor communications imposes serious threats to the life safety of geological personnel. Therefore, how to guarantee the safety of geological personnel working on the Qinghai–Tibet Plateau and how to reduce or even avoid casualty of geological personnel have currently become the urgent challenge. In this study, an emergency rescue information system for field geological survey is constructed based on BeiDou Navigation Satellite System. A case study of emergency rescue has been conducted in the depopulated zone of the Qinghai–Tibet Plateau and good effects have been achieved, providing security assurance for personnel engaged in field geological survey on the Qinghai–Tibet Plateau and technical support for the emergency rescue in case of natural hazards on the Qinghai–Tibet Plateau. The BeiDou Navigation Satellite System (BDS) can be effectively used to locate and communicate in the emergency rescue for rigorous Geological survey task where there is no network signal for the mobile phone, and the emergency rescue guarantee system is independent, reliable, and relatively cheap. The application value of BDS is demonstrated in the geological field.
accurate positioning. As BDS adopts satellite communication that is not influenced by ground network, region, landform, weather condition, and other factors, it can realize communication timely when ground communication network is not available (Feng, Zhou, and Wu 2013; Li et al. 2015; Liu 2012; Liu and Liu 2014; Sun et al. 2012).

On 25 October 2012 (23:33 PM), China sent the 16th BeiDou Navigation Satellite to preset orbit successfully by “CZ-3C” rocket in Xichang Satellite Launch Center, with the officially operation of Chinese BDS (Beidou satellite navigation system) at the end of 2012, currently including valid 14 in-orbit satellites—5GEOs, 5IGSOs, and 4MEOs (Chen et al. 2013; Zhou et al. 2014; Yang et al. 2013). Comparing with traditional satellite navigation and positioning systems, in addition to navigation, positioning, and timing functions, BDS also has the function of short message, which is its unique technical advantage. The depopulated zone on Qinghai–Tibet Plateau is a dead zone of communication without cell phone signal. In case of hazards, it is difficult to obtain external assistance. The emergency rescue and guarantee system for field geological survey based on BDS has solved this difficulty, providing technical guarantee for the life safety of personnel engaged in field geological work (Lv et al. 2014; Shi et al. 2012; Xie and Liu 2013).

Based on the Beidou satellite, investigation of natural disaster relief was carried out through a lot of applications, such as demonstration application of Beidou satellite technology in detailed geological disaster investigation in Yushu, Qinghai province (Shi, Wang, and Wu 2012); debris flow monitoring early warning system based on Beidou short message (Wu, Ren, and Wang 2014); geological disaster monitoring system based on Beidou satellite system: crustal stress and water table monitoring in Tibet (Luo et al. 2011), design of landslide monitoring system based on Beidou communication (Liao et al. 2014), a new wireless system for geological disasters monitoring based on Beidou (Zhu et al. 2010). In this article, a case study of emergency rescue has been conducted in the depopulated zone of the Qinghai–Tibet Plateau and good effects have been achieved, providing security assurance for personnel engaged in field geological survey on the Qinghai–Tibet Plateau and technical support for the emergency rescue in case of natural hazards on the Qinghai–Tibet Plateau.

2. Emergency rescue guarantee system for field geological survey

The system deployment mainly includes the following three modules (Figure 1): (1) BeiDou function module of Digital Geological Survey Information System (DGSInfo); (2) BeiDou function module of Regional Geological Mapping System (RGMap); (3) GSIGrid BeiDou Emergency Supporting System;

Central Commanding Machines will be set up in China Geological Survey, the geological survey centers in each area and other large fixed management nodes; general commanding machines will be set up in field station and other middle or small fixed management nodes. Field geological personnel would have PDA and terminal of BeiDou in their hands to realize connection, communication, and messaging with abovementioned stations (Tan, Li, and Xie 2012).

2.1. DGSinfo BeiDou functions

Digital Geological Survey Information System (DGSInfo) is deployed in the center commanding machine and mobile commanding machine, and covers all functions of its mobile terminal as well as partial functions of management program installed.

![Figure 1. Illustration of the system deployment.](image-url)
in BeiDou server. BeiDou devices are accessible through serial ports that could be used to connect the general commanding machines (with monitoring function) and vehicle-embedded machines, Bluetooth module, etc., functioning as the fixed monitoring and management nodes. The system framework is shown in Figure 2 and the main functions are shown in Table 1.

2.2. **RGmap Beidou functions**

BeiDou functions in Regional Geological Mapping System (RGMap) are applicable to those mobile nodes in field operation and run on palmtop. The system supports the mobile Bluetooth module and BeiDou mobile all-in-one of the most kinds. The system framework is shown in Figure 3 and the main functions of BeiDou mobile positioning and communication system are shown in Table 2.

2.3. **GSIgrid Beidou emergency supporting system**

GSIGrid BeiDou Emergency Supporting System mainly depends on BeiDou satellite technologies and is supported by digital geological survey grid platform to realize real-time monitoring of the trail and communication information in each mobile node, as well as communication with field station and moving target, to offer data support to the management of disposal of natural hazards and emergency events and decision making.

It primarily consists of real-time monitoring (positioning, communication) personnel information query, BeiDou historical information (positioning, communication) query, route tracking, emergency rescue and interactive communication, path analysis, and other functions. Beidou information data use ORACLE database management. The functional design is shown in Figure 4. The interface of system visualization window is shown in Figure 5 and the main functions are set out in Table 3.

2.4. **Main features of the three modules**

Here we summarize the main features of the three modules as follows:

1. BeiDou functions in DGSInfo are applicable to the fixed management nodes in field station.
2. BeiDou functions in Regional Geological Mapping System (RGMap) are applicable to those mobile nodes in field operation and run on palmtop.

![Figure 2. DGSInfo system framework.](image-url)
GSIGrid BeiDou Emergency Supporting System mainly depends on BeiDou satellite technologies and is supported by digital geological survey grid platform to realize real-time monitoring of the trail and communication information in each mobile node, as well as communication with field station and moving target, to offer data support to the management of disposal of natural hazards and emergency events and decision making.

Table 1. Main functions of BeiDou monitoring and command system.

| Function                          | Description                                                                 |
|----------------------------------|-----------------------------------------------------------------------------|
| Positioning and communication    | Basic functions of BeiDou, self-positioning and messaging                   |
| Group messaging                  | Choose n persons as the receivers and sharing n frequencies                 |
| Broadcasting                     | Send broadcast message to all users in the jurisdiction, sharing 1 frequency|
| National map positioning         | When the object under monitoring goes out of the scope of chart, positioning can be carried out on the map of China at the scale of 1:5,000,000 |
| BeiDou mobile node real-time monitoring and command | Position monitoring against and information exchange with BeiDou mobile nodes |
| Calling function                 | Send a call command to the mobile node to require it to feed the position information back |
| BeiDou user database management  | Include wide field table, institute table, personnel table, BeiDou card list and other data sheets |
| BeiDou information management    | Store, inquire, and display BeiDou positioning and communication data       |

Table 2. Main functions of BeiDou mobile positioning and communication system.

| Function                          | Description                                                                 |
|----------------------------------|-----------------------------------------------------------------------------|
| Positioning and communication    | Basic functions of BeiDou, self-positioning and messaging                   |
| National map positioning         | When the object under monitoring goes out of the scope of chart, positioning can be carried out on the map of China at the scale of 1:5,000,000 |
| Emergency alarm                  | Edit the content of emergency SMS and the list of addresses to be sent in advance, then in case of an emergency, the message could be sent by one click rapidly, together with positioning information (or GPS positioning information) |
| Position report                  | Send your present position information to the commanding nodes in message, namely GPS positioning information |
| Calling back                     | Automatically position and feed information back once calling is received from the commanding nodes, sharing 2 frequencies. If BeiDou positioning fails, then the last GPS positioning information will be fed back |
| Management of address book, inbox, and drafts | Use XML file to store the related data of the BeiDou |
| Inquiry of last users            | Send a command to the commanding machine for card number of the BeiDou users near the machine |
| Off-line message inquiry         | In case of power off or no signal, messages will be cached in the master station of BeiDou, which could be inquired offline when signal becomes stable |

Figure 3. RGMp system framework.
Table 3. Major functions of GSIGrid BeiDou emergency supporting system.

| Function                          | Description                                                                                                                                 |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Real-time monitoring             | Send SMS or calling command to users, returning equipment card number, positioning location, position time, name, unit, last communication time, etc. |
| Personnel information query      | Include personal information, unit information, job information, latest positioning coordinate information, and communication information               |
| BeiDou historical information (positioning, communication) query | It query the positioning information and communication information within the set period                                                    |
| Route tracking                   | Track inquiry of users’ route track within the set period                                                                                   |
| Emergency rescue                 | Analyze the buffer of person in danger, querying all users, and displaying according to the distance away from the person in danger, sending SMS to all users, giving rescue instructions to provide relief for the person in danger |
| Interactive communication        | It supports four types of instructions, i.e. positioning, communication, calling, and broadcast                                               |
| Path analysis                    | It realizes path analysis between any two points                                                                                           |
3. Analysis of demonstrative application examples

3.1. Overview of demonstrative area

Demonstrative application was done in Ngari Prefecture, Tibet, with the consideration of field geological survey project, which is shown in Figure 6. The demonstrative area is located in northern Tibet Autonomous Region, in Dahu Basin Area of Qiangtang Plateau and within the jurisdiction of Ngari Prefecture. The terrain of the demonstrative area is steep and more disparity in relative elevation. With an average elevation of above 4800 m, it is entitled as the Roof of the World. The gullies are deep, valleys long, beaches irregular, and swamps countless. The place is windy and cold with annual average temperature below −2°C and the lowest temperature at −40°C.

The demonstrative area suffers from severe natural conditions that result to discommodity in communication. Signals only cover the downtown area of the county, and it is difficult to provide support and rescue in case of vehicle breakdown, from the threat of wild animals, natural disasters, injuries, and other emergency situations. Then, we draw out a conclusion that the application of BDS will be proved in a better way in such a demonstrative area.

3.2. Demonstrative application

Geological technicians took BeiDou mobile device for the research in demonstration area, and they could use BeiDou mobile device to send SMS to the field station for reporting safety. Members of several groups could send messages to each other for positioning and conducting comprehensive study and demonstration of the performance of Emergency Supporting System, as shown in Figure 7.

Someday, a group of people encountered car trapping on the way back. Several geological personnel placed stones under the wheels and pushed the car. However, they could not get the car out. Then, it was dark night with very low temperature and the food and drinking water had been run out of. Such circumstance was frequent on the plateau and very dangerous. Traditional self-help methods, for example, waiting for help on the spot, walking to the field station for sending message for help, etc., imposed extremely high death threats. If they chose to wait for help on the spot, as the rescue message could not be sent out because there was no signal or satellite phone, it would be uncertain for rescuers to find their location; If they chose to walk to the field station, it was not easy to walk for scores or hundreds of kilometers when there was no obvious marker on the plateau and it was very possible to encounter various hazards on the way.

Fortunately, they immediately used BeiDou mobile terminal to send out message calling for help to the field station and utilized the positioning function to report the location information and distress situation to the commanding center. Upon receipt of alarm information, the commanding center of field station immediately conducted route tracking on BeiDou Emergency Supporting System, found out the location of persons in danger and conducted path analysis to select the most suitable path for rescue. Finally, the persons in danger were successfully rescued.

There are also other dangers, which will not be enumerated. The research demonstration shows that the construction of emergency rescue guarantee system for field geological survey based on BeiDou navigation satellite system has obtained good effects in the emergency rescue for natural hazards and emergency
events on Qinghai–Tibet Plateau. Figure 8 shows a route tracking map in the geological survey on Qinghai–Tibet Plateau.

4. Discussion
The major functions of the emergency rescue guarantee system for field geological survey based on BeiDou Navigation Satellite System in the emergency rescue for various natural hazards on Qinghai–Tibet Plateau are summarized as follows:

1. Geological personnel send a message to the commanding center of field station at the idle time for reporting their safety, so as to grasp the safety status of geological personnel at all times.

2. In case of danger, it is required to give an alarm to report the location and status, so that the commanding center will arrange rescue force and rescue scheme in a reasonable way.

3. If geological personnel encounter dangers and have lost their action capability or are in a coma, and do not have the capacity to send a message or “one button alarm”, the commanding center may utilize the calling function and automatically return the positioning information of called BeiDou car number, thus providing the accurate location for rescue.

4. BeiDou Navigation Satellite System may conduct buffer analysis for the persons in danger and display all the BeiDou users in the area in the form of list. It can conduct path analysis for arranging rescue force and path in the most reasonable way.

Generally, comparing with the traditional satellite phone, BDS is all-weather, all-round, and independent with concurrent processing ability, etc. Those features could be evidenced in following aspects: (1) The system’s space section works in the range of L/S and is of little possibility to be suffered from signal attenuation effect caused by severe weathers such as rain, snow, and frog. This would provide sufficient guarantee for the system’s processing ability to meet all-weather working requirements basically; (2) Its terminal device is integrated and modularized, which takes up little space, dissipates little power, and is easy for installation; (3) Its intellectual property right is possessed by China; therefore, its operation and maintenance can be independent and feasibly ensured for some cases, for example, favorable encryption could effectively ensure the safety of users’ key business data in processing, storage, and delivery. As the BDS communication is relatively cheap, it is very useful to guarantee that each field geologist can be equipped with a BeiDou terminal for daily use. Therefore, providing technical guarantee for emergency rescue is of profound significance for the development of geology in China.

5. Conclusions
The emergency rescue guarantee system for field geological survey has been constructed based on BDS and the demonstration application research in the depopulated zone on Qinghai–Tibet Plateau has obtained good effects, indicating that this system can provide assurance for the geological personnel’s life safety and technical support for emergency rescue. With the rapid development of Beidou satellite

Figure 8. GSIGRID field route tracking in demonstration area.
technology and network technology in China, BDS will play an important role in the fields of geology and other industries.

**Funding**

This study was supported by the Public Beneficial Industrial Funds by the Ministry of Land and Resources of China [grant number 201011010].

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