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Indexes establishment and capability evaluation of space-air-ground remote sensing cooperation in geo-hazard emergency response

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Abstract. Geo-hazard emergency response is a disaster prevention and reduction action that multi-factorial, time-critical, task-intensive and socially significant. In order to improve the rationalization and standardization of space-air-ground remote sensing collaborative observation in geo-hazard emergency response, this paper comprehensively analyzes the technical
10 resources of remote sensing sensors and the emergency service system, and establishes a database of technical and service evaluation indexes using MySQL. A method is proposed to evaluate and calculate the cooperative observation effectiveness in a specific remote sensing cooperative environment by combining TOPSIS and RSR. For the evaluation of remote sensing cooperative service capability in geo-hazard emergency response, taking earthquake as an example, establishing a remote sensing cooperative earthquake emergency response service chain, and designing a Bayesian network evaluation model.
15 Through the evaluation of observation efficiency and service capability, the operation and task completion of remote sensing collaborative technology in geo-hazard emergency response can be effectively grasped and a basis for decision making can be provided for space-air-ground remote sensing collaborative work.

Keywords: Geo-hazard; Remote sensing cooperation; Index database; Capacity evaluation

1 Instruction

20 Geo-hazard refer to earthquakes, mountain collapses, landslides, debris flows, ground collapses, ground fissures, land subsidence and other hazards related to geological processes that endanger people's lives and property caused by natural factors or human activities. According to the United Nations Office for Disaster Risk Reduction (UNDRR), the human casualties caused by geological hazards since 1990 have been concentrated in the Asia-Pacific region and Africa for a long time, with 2010-2019 being the decade with the highest economic losses caused by disasters (UNDRR Annual Report ,2019;
25 UNDRR GAR 2019) .In order to respond to sudden geological hazards and mitigate the damage, it is necessary to carry out hazard emergency response quickly after the occurrence of a hazard, providing emergency assistance for victims and seek to stabilize the situation and reduce the probability of secondary damage (Johnson,2000).

Earth observation technology is an important technical support in geo-hazard emergency response (Butler et al.,2005), with the development of global earth observation technology, the performance of remote sensing technology is constantly improving,

30   the number of sensors continue to increase, and gradually establish a multi-platform observation system for satellite, aerial, UAS, and ground(Toth et al.,2016). There are many online resources for recording remote sensing information, and the NASA master directory (NSSDC,2020) provides a mechanism for retrieving satellite names, classifications, or launch dates to obtain descriptions of relevant satellite information and data collection. The CEOS Missions, Instruments, and The Measurements (MIM) Database is divided into the Agencies, Missions, Instruments, Measurement, Datasets modules, with a

35   focus on current and future satellites, sensors, and measurement capabilities(CEOS,2020). Observing Systems Capability Analysis and Review tool (OSCAR, 2020) database is divided into the description of information about the satellite and its sensors and the sensor capability assessment analysis.

At present, most of the earth observation technology resources operate independently, and when faced with specific geo-hazard emergency response tasks, the space-air-ground remote sensing sensor resources will show both "many" and "few".

40   That is, although the sensor resources are abundant, it is difficult to find suitable and available sensors quickly, which affects the efficiency of observing mission response. The main reason for this is that remote sensing systems of various types are very different in terms of observation modes, applications, and processing methods, and the resources are deployed in a distributed fashion, described in their own independent formats, lacking correlation mechanisms, and cannot be detected in a timely manner(Li et al.,2012). In order to improve the efficiency of emergency response, a number of organizations and

45   mechanisms have been established internationally to synergism these resources, including the Committee on Earth Observation Satellites (CEOS), the Integrated Global Observing Strategy (IGOS), the International Charter Space and Major Disasters (CHARTER), the United Nations International Strategy for Disaster Reduction (UNISDR). International Strategy for Disaster Reduction (UNISDR), the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER), the Disaster Monitoring Constellation (DMC).and the Copernicus EMS, etc., these are

50   mainly oriented to the international major disaster emergency response, such as the Wenchuan earthquake(PAN et al.,2010), Haiti earthquake (Duda et al.,2011), Japan earthquake(Kaku et al.,2015), and so on. In addition to collaborative emergency response between satellite remote sensing, in the face of the diversified needs of actual geo-hazard emergency response, collaboration between satellites and other multiple remote sensing platforms has also become an important development direction of remote sensing technology (Li et al.,2017), which is characterized by the ability to integrate the observation

55   advantages of each platform to effectively shorten the observation time, expand the coverage, and improve the accuracy of observation data(Asner et al.,2012; Nagai et al.,2009). Paolo Canuti et al. (2007) integrated remote sensing techniques in the landslide emergency response phase and described the use of data from different types of sensors, Ventisette et al. (2015) described data acquisition using satellite and ground-based sensors in landslide disaster response, and Huang et al. (2017) proposed a complete set of methods for geo-hazard emergency investigation using UAS. In these remote sensing

60   collaborative disaster emergency applications, by linking different types of remote sensing sensors and coupling them to form an independent and dynamically adaptable and configurable space-air-ground remote sensing collaborative observation system, the complementary advantages of remote sensing observation platforms are brought into full play, but there is no

sensor discovery process in these studies, and there is a lack of selection criteria and capability evaluation of sensors in different collaborative applications.

65 The observation tasks under geo-hazard emergency are complex and diverse, and have certain requirements in terms of timeliness and accuracy, and it is especially important for decision makers to make comprehensive discovery, accurate collaborative planning and rapid scheduling of massive sensors in a specific emergency response situation. How to quickly and rationally arrange the sensors that meet the geo-hazard emergency response needs in the sensor web environment to optimize the resource utilization is the key issue for remote sensing collaborative observation. This work focuses on

70 establishing a link between geo-hazard emergency response events and sensors, constructing indicators for evaluating the technical capabilities of sensors, and evaluating geo-hazard emergency service capabilities. Wang Wei et al. (2013) proposed a mission-oriented assessment of the observational capabilities of imaging satellite sensor applications with horizontal resolution, revisit period and observation error as indicators. Hong Fan et al. (2015) proposed a sensor capability representation model to describe typical remote sensing sensor capabilities for soil moisture detection applications. Hu et al.

75 (2016) proposed geospatial environmental observation capability for discovering and planning environmental sensors, and Zhang Siyue et al. (2019) proposed a model for evaluating the effectiveness of observations and data downlink for low orbiting satellites. The current research data on remote sensing sensor capabilities are relatively scarce, basically focusing on the evaluation of the inherent capabilities of individual satellite remote sensing sensors, with a single object of evaluation, making it difficult to meet the needs of multi-sensor and multi-geo-hazard emergency response tasks, so it is very necessary

80 and timely to establish collaborative observation capability indexes for space-air-ground remote sensing sensor resources and to conduct geo-hazard emergency response service capability evaluation.

2 Data

With the richness of remote sensing sensor technology resources, the service system for emergency response to geo-hazards has been improved in the application practice, in which it is an important question how to fully discover and use the existing

85 sensor technology to meet the target observation needs and achieve the optimal effect of resource utilization for different application services. In order to allocate sensor resources scientifically, improve the rationality and effectiveness of cooperative observation and obtain the required information to a greater extent, this section establishes an index database for the comprehensive analysis of the technical performance and emergency service system of space-air-ground remote sensing and realizes the integrated management of the technical performance data of various types of remote sensing sensors and

90 emergency service information.

2.1 Sensor technology resource emergency service system

The current remote sensing sensors can be divided into satellite, aerial, and terrestrial according to the platform they are mounted on (Grün,2008). Satellite remote sensing is divided into land satellites, meteorological satellites and ocean satellites

according to their fields of operation. Land satellites are mainly used to detect the resources and environment on the earth's
95 surface and contain a variety of sensor types such as panchromatic, multispectral, hyperspectral, infrared, synthetic aperture
radar, video, and luminescence(Belward et al.,2015). Meteorological satellites observe the Earth and its atmosphere, and their
operations can be divided into Sun-synchronous polar orbit and geosynchronous orbit (NSMC, 2020; Wang et al.,2018).
Oceanic satellites are dedicated satellites for the detection of oceanic elements and the marine environment, with optical
payloads generally including watercolor water thermometers, coastal zone imagers, etc., and microwave payloads including
100 scatterometers, radiometers, altimeters, SAR, etc.(Fu et al.,2019). The countries and regions in the world that currently have
autonomous remote sensing satellites are the United States, France, ESA, Germany, Israel, Canada, Russia, China, Japan,
Korea, India, etc., and the main satellite launches are shown in Table A1. Aerial remote sensing is a technology that uses
aircraft, airships, and UVA as sensor carriers for detection (Colomina et al.,2014), and different airborne remote sensing
devices have been developed to face different remote sensing tasks, including digital aerial cameras, LiDAR, digital cameras,
105 imaging spectrometers, infrared sensors, and min SAR. Ground remote sensing systems have two states: mobile and static.
The mobile measurement system is a system of rapid movement measurement by means of vehicles (e.g., cars, boats),
consisting of sensors such as CCD cameras, cameras, laser scanners, GPS, and inertial navigation systems (INS)(Li et
al.,2015), which can acquire the geospatial position of the target while collecting realistic images of the features, and the
static state measurement refers to the installation of sensors in a fixed place such as laser scanners, cameras, ground-based
110 SAR, surveying robots, etc., can form a ground sensor web through computer network communication and geographic
information service technology.

In the face of geo-hazard emergency response, the space-air-ground remote sensing sensors establish association through
collaborative planning to form a collaborative observation service system based on the process of "observation-transmission-
processing-distribution", as shown in Fig.1. In the event of a geological disaster, the emergency command center responds
115 quickly, planning observation missions according to observation needs and the current technical environment; after remote
sensing systems carry out observation missions, they receive, process and distribute observation data through the data center,
providing emergency services mainly based on geographic information.
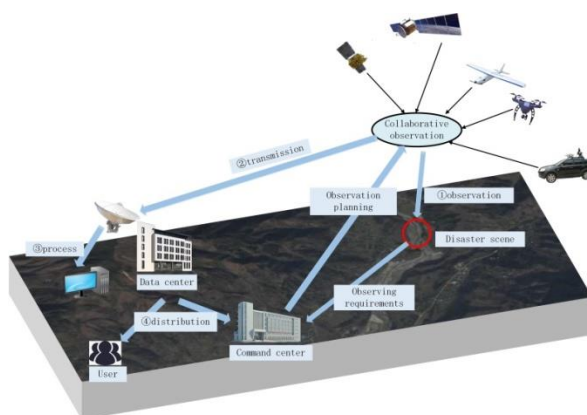

Figure 1.Collaborative remote sensing observation service system for geo-hazard emergency response

120 The geographic information services provided by the remote sensing emergency service system are shown in Fig.2. It includes data processing, data products, data services, model services, functional services, and warning services. Data processing refers to the process and method of obtaining effective emergency information from the collected data, including data processing method, feature extraction, image classification and image analysis; data products refer to the quality and current potential of various types of remote sensing products; data services provide disaster-related basic data, thematic data

125 and analysis data through WMS, WCS, WFS and WMTS; functional services provide quantitative, qualitative, characterization and visualization studies of geospatial phenomena through spatial analysis services, terrain analysis services and visualization services; model services provide various models for calculation, analysis, anomaly identification, damage assessment, situational assessment, evaluation, decision-making and optimization; and warning services provide early warning of disasters in space, time and situation.
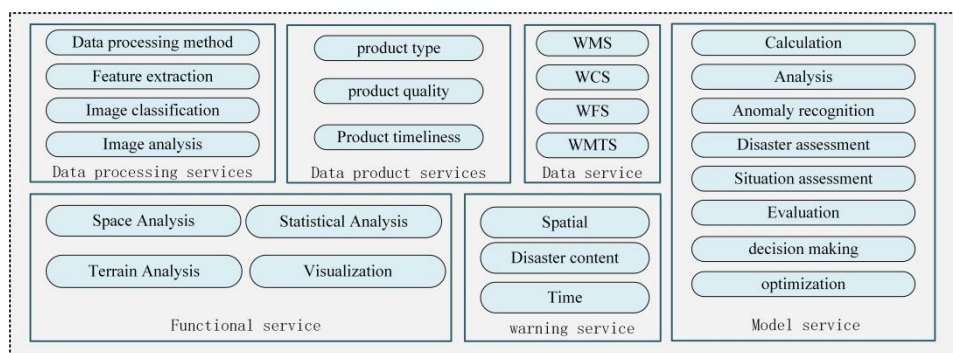
Figure 2.Geographic Information Emergency Services

2.2 Indexes of technology and services

Sensor technical performance indexes are its various ability characteristics under normal operation, reflected by technical parameters, relatively independent between different types of sensors, parameters vary, technical indicators are also diverse,

135 in the face of complex geo-hazard emergency response needs, how to choose the right sensor to complete the observation task, the need for the existing sensors according to the ability to classify the technical indexes of the integrated. In this paper, we analyzed the information of various types of sensors and established a universal sensor technical index system, as shown in Table 1.

Table 1. Sensor technical indexes

Type	Technical indexes
	Spatial resolution
	Spectral resolution
Optical satellite	Radiation resolution
	Revisit time
	Swinging ability

	Swath width
	Wave band
	Polarization
SAR satellite	Spatial resolution
	Revisit time
	Swath width
	Incidence angle
Photogrammetry	Resolution
	Data type
	Preparation time (UAV)
	Point cloud density
LiDAR	Measuring range
	Measurement accuracy
	Endurance time
UAV	Cruising speed
	Payload
Mobile measurement	Measuring range
	Data type

140 Based on the remote sensing emergency service system, the space-air-ground remote sensing geo-hazard emergency service capability evaluation index system is shown in Table 2, which is measured from the three aspects of data acquisition, processing and information service, and the specific content of the index should be determined in conjunction with the response emergency event.

Table 2.Indexes for evaluation of emergency service capacity

Constitute	Criterion
Data acquisition	Technology, Data Volume, Timeliness, Responsiveness
Data processing	Methodology, Speed, Quality
Information services	Demand, Quality, Timeliness

145 **2.3 Space-air-ground remote sensing index database**

The existing databases focus on satellite remote sensing resources and do not form a unified management of aviation, UAV, ground remote sensing platforms and their sensor information. Faced with the actual demand for collaborative geo-hazard emergency remote sensing response, this paper proposes the establishment of an integrated space-air-ground sensor technology performance index database SAT_RS and emergency service evaluation index database SE_RS covering satellite,

150 aerial, and terrestrial remote sensing platforms. The database uses MySQL for storage management, MySQL is an open source relational database management system, supports MyISAM, InnoDB and other storage engines, supports spatial data objects in geographic information in compliance with OGC's OpenGIS Geometry Model, provides a variety of API interfaces, and supports multiple operating systems. and development languages that can provide great web service applications.

155 The database design process is divided into information analysis, structure design, storage settings and data storage. By analyzing the massive sensor information, we set the attribute fields from the carrying platform, technical characteristics of each type of sensor and operation status, store the corresponding data in the database and establish unified management, and finally designed 20 kinds of tables, as shown in Fig.3. The technical performance index database SAT_RS records the basic information of satellite, aerial and terrestrial through three tables, RS_Satellite, Sensor_Aerial and RS_Terrestrial, and then

160 establishes the technical characteristics index table for different types of sensors on different platforms according to the technical index system shown in Table 1, including SatelliteSensor_Optical, SatelliteSensor_SAR, UAS, ImageSpectrometer, DigitalCamera, AirbronrLiDAR, MinSAR, MMS and other 11 types of tables. The RS_Task table in the emergency service evaluation indicator database SE_RS links tasks among sensors and records the observation tasks performed by them, including observation equipment, observation time, etc. The evaluation indexes in RS_DataProcessing and RS_Service are

165 set according to the guidelines of the Table 2 and the specific geo-hazard remote sensing emergency service events.
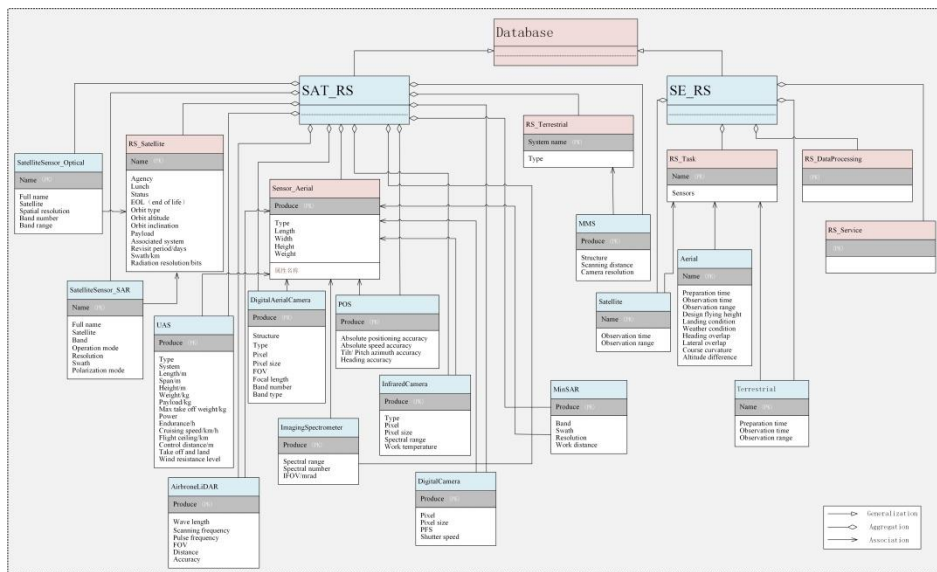

Figure 3. UML of database

At present, the SAT_RS database records about 150 satellites and their corresponding sensor data from many countries and organizations including the United States, France, ESA, Russia, Japan, Korea, India and China, more than 100 commonly

170 used aerial remote sensing sensor product families, more than 50 UAV products and dozens of ground mobile measurement systems, and the partial display is shown in Fig.4. Its features are: (1) wide data coverage, support for satellite, aviation

(including UAV) and terrestrial these multi-platform, multi-types of remote sensing sensors. (2) indexing of sensor technical performance, support for evaluation calculations, (3) data support Sensor ML description.

Figure 4. SAT_RS database (partial)

3 Methodology

The commonly used evaluation methods are: AHP (Emrouznejad et al.,2017), fuzzy integrated assessment (Kahraman et al.,2015), TOPSIS (Zhang2015), Rank Sum Ratio (Tian,2002), Bayesian Network（BN）(Ejsing et al.,2008), etc., all of which have their own characteristics. The evaluation studied in this paper is a complex and flexible multi-system, multi-influential problem, and in order to improve the scientific validity of the evaluation and take full advantage of the various methodologies, TOPSIS and BN were used to evaluate remote sensing cooperative observations and service capabilities, respectively. In the calculation of TOPSIS, RSR is nested in it to determine the weights, which has no strict restriction on the distribution, quantity and scope of the evaluation data, is applied flexibly and can adapt to the changes of indexes involving many types of sensors, and at the same time, RSR determines the weights by combining RS and empirical weights, so that the evaluation results can better reflect the objective facts.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

3.1. TOPSIS

TOPSIS is commonly used in multiple-criteria decision-making (MCDM). The basic principle is to rank the evaluated objects by detecting the distance between the positive ideal solution (PIS) and the negative ideal solution (NIS), the evaluation object is best if it is closest to the PIS and at the same time furthest away from the NIS, where the PIS is composed of the best value of any alternative under the corresponding evaluation index and the NIS has got the opposite logic. The evaluation process is as follows:

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(1) Identify a decision matrix: Assuming that a MCDM problem has m evaluation objects, n evaluation indicators, and the

195 value of the j evaluation indicator for the i object is a_{ij} $(1 \leq i \leq m, 1 \leq j \leq n)$, then the decision matrix $A = (a_{ij})_{m \times n}$ as

follow:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

(2) Indicators are treated with the same trend. In order to maintain the same direction of change for all indicators, a reciprocal method was used to convert negative indicators into positive ones.

(3) Normalization the decision matrix. The evaluation indicators have different attribute dimensions, it is need to transforms

200 various attribute dimensions of the indicators into non-dimensional attributes. The normalization decision matrix is

$B = (b_{ij})_{m \times n}$, and the normalized value is computed as:

$$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \tag{2}$$

(4) Calculate the weighted normalized decision matrix. Multiplying the normalized processed matrix with the determined

weight vector $W = [w_1 \cdots w_n]^T$ obtain the weighted normalized decision matrix $C = (c_{ij})_{m \times n}$:

$$c_{ij} = b_{ij} \bullet w_j \tag{3}$$

(5) Computation of the PIS and NIS.

205 The positive ideal solution:

$$c_j^+ = \max c_{ij} \tag{4}$$

The negative ideal solution:

$$c_j^- = \min c_{ij} \tag{5}$$

(6) Computation of distance each alternative from PIS and NIS:

Distance from the PIS is:

$$d_j^+ = \sqrt{\sum_{i=1}^{m} (c_{ij} - c_j^+)^2} \tag{6}$$

Distance from the NIS is:

9

$$d_j^- = \sqrt{\sum_{i=1}^{m}(c_{ij} - c_j^-)^2} \tag{7}$$

210 (7) Computation of relative closeness and ranking of alternatives:

The relative closeness is defined as:

$$s_i = \frac{d_j^-}{d_j^+ + d_j^-} \tag{8}$$

3.2. RSR

RSR is a statistical analysis method that combines the advantages of classical parametric estimation and modern non-parametric estimation. RSR refers to the average of the sum of rank sums of indicator values. This approach is based on the

215 concept of transforming indicator values into dimensionless statistical ranks and ratios.

In an n-row (n evaluation objects) m-column (m evaluation indicators) matrix, the RSR is calculated as follows.

$$RSR_i = \frac{\sum_{j=1}^{m} R_{ij}}{m \cdot n}(1 \le i \le n, 1 \le j \le m) \tag{9}$$

The formula for determining the weight of each indicator using RSR is as follows.

$$W = \frac{SR \cdot W^{'}}{\sum SR \cdot W^{'}} \tag{10}$$

The SR reflects the proportional relationship between the levels of each indicator and is calculated from RSR (Eq.(11)). $W^{'}$ is the empirical weighting factor.

$$W = \frac{SR \cdot W^{'}}{\sum SR \cdot W^{'}} \tag{11}$$

220 3.3. Bayesian Network

The BN also known as the Belief Network, is a probabilistic graph model that was first proposed by Judea Pearl in 1985. The BN applies probability theory to the reasoning of uncertainty problems, and its network topology is a directed acyclic graphical (DAG) with the ability to express and reason about uncertainty knowledge.

The nodes of a BN represent random variables, and the directed links (edges) between the nodes indicate the conditional

225 dependencies between the random variables. All nodes pointing to node M are called the parent nodes of M and M is

10

called the child node of its parent, and variables without a parent node are called root node variables. All nodes have a corresponding node probability table (NPT) expressing the probability of occurrence of a random event, with the probability of the root node being the prior probability and the probability of the child node indicating all possible conditional probabilities of that node relative to its parent node (posteriori probability).

230 Fig.5 illustrates a simple BN where A, B, C and D are four variables, parent node A is the root node, B and C are child node of A, and D depends on variables B and C. The joint probability distribution of the nodes is expressed as follows:

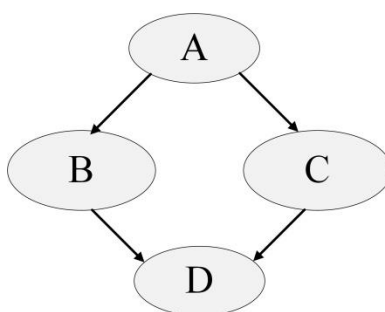$$P(A,B,C,D) = P(A)P(B \mid A)P(C \mid A)P(D \mid B,C) \tag{12}$$

Figure 5. Diagrammatic Depiction of a Bayesian Model

Probabilistic reasoning is one of the main uses of BN. The reasoning process is essentially the process of calculating a 235 posteriori probabilities, using conditional independence among random variables to calculate the a posteriori probability distribution of some other variables if the values of some variables in a BN are known.

4 Results and Discussion

On the basis of the management of indicators through the database, the evaluation of the collaborative capability of space-air-ground remote sensing technology in geo-hazard emergency response is established, and the evaluation is divided into 240 two parts: collaborative observation efficiency and emergency service capability. The synoptic observation efficiency refers to the overall working capability presented by the coordination among observation systems, which needs to take into consideration the inherent technical performance of heterogeneous sensors of dynamic scheduling and the degree of accomplishment of specific observation tasks by the synergy among platforms; the evaluation of emergency service capability refers to the dynamic performance of remote sensing service systems in performing specific tasks, which is related 245 to the application requirements of disaster emergency response.

4.1 Evaluation of the effectiveness of coordinated space-air-ground remote sensing observations

The collaborative observation system consists of several distributed remote sensing sensor resource systems. This section comprehensively analyzes the remote sensing collaborative application model and proposes a method to evaluate the

effectiveness of the specific collaborative observation environment using TOPSIS nested RSR on the basis of the sensor
250 technology index database.

4.1.1 Coordination observation model

Remote sensing coordination technology mainly enhances the observation capability from both data quantity and accuracy,
and the typical coordination modes according to the technical characteristics and emergency needs of geo-hazards are
satellite-satellite, satellite-aviation, satellite-terrestrial and aviation-terrestrial. The two modes of coordination between
255 satellites are single satellite repeatedly observing multiple targets at the same or different times and multiple satellites
repeatedly observing multiple targets at the same or different times, which can realize the dynamic observation of geological
disasters on a large scale, all-weather and around the clock. The coordinated observation between satellite and aerial remote
sensing mainly takes advantage of the wide range of satellite image observation and the fact that aerial remote sensing can be
deployed in real time, fly under the cloud, be highly mobile and acquire data quickly. In the event of a geological disaster,
260 ground mobile measurement can be used as an emergency mapping vehicle to send image data back to the emergency
command center in time to obtain information on disaster sites, post-disaster building damage, post-disaster road damage,
rescue facilities, etc., providing basic road network data and environmental information for disaster relief facility
management, command and decision-making, while ground mobile measurement data can be combined with satellite images
or aerial photography measurement data to realize the combination of geographic information and image information to
265 build a visual geographic information system to provide services for disaster emergency response.

4.1.2 Simulation calculations

Several remote sensing synergies through planning services after a mudslide disaster at a certain location were set up as
follows: (A) the GF-2 satellite and the KC2600 UAV with Sony NEX-7 camera, (B) the Pleiades satellite and the EWZ-D6
UAV with Nikon D800 camera, and (C) the IKONOS and DMC aerial cameras. The evaluation of their synergy
270 effectiveness was calculated as follows：

(1) Identify evaluation indicators. Through the synergy of high-resolution satellites and aerial remote sensing, the emergency
response time can be effectively shortened, the timeliness of data acquisition at disaster sites can be improved, and
effectiveness indicators can be established as shown in table 3.

Table 3. Effectiveness indicators

Indicators	Implication
Spatial resolution of satellites	The higher the resolution, the more accurate the disaster information obtained
Flight preparation time	Time required for pre-flight arrangements of aircraft
Flight operating hours	Total hours of in-flight observation

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| Flight coverage | The larger the area covered, the more data there is. |
| Data processing | Quality of data processing |

275 (2) The data of the sensor type indicators involved in the synoptic observation program are extracted, a decision matrix A is created, and it is trended and normalized to obtain matrix B.

$$A=\begin{bmatrix} 1 & 90 & 1.8 & 0.82 & 2 \\ 0.5 & 45 & 0.65 & 0.73 & 2 \\ 1 & 150 & 3.4 & 0.94 & 1 \end{bmatrix} \qquad (13)$$

$$B=\begin{bmatrix} 0.41 & 0.43 & 0.46 & 0.57 & 0.41 \\ 0.82 & 0.86 & 0.17 & 0.51 & 0.41 \\ 0.41 & 0.26 & 0.87 & 0.65 & 0.82 \end{bmatrix} \qquad (14)$$

(3) Using RSR to determine the weights. Table 4 shows the rank and RSR of the indicator values for each scenario, and Table 5 shows the final weights determined.

Table 4. Indicator rank and RSR

Indicators	A	B	C	*RSR*
Spatial resolution of satellites	1	4	2	0.47
Flight preparation time	3	5	1	0.60
Flight operating hours	4	1	5	0.67
Flight coverage	5	3	3	0.73
Data processing	1	2	4	0.47

280 **Table 5. Weighting of indicators**

Indicators	SR	$W^{'}$	W
Spatial resolution of satellites	0.16	0.25	0.20
Flight preparation time	0.20	0.16	0.17
Flight operating hours	0.23	0.18	0.21
Flight coverage	0.25	0.21	0.26
Data processing	0.16	0.20	0.16

(4) Calculate the weighted matrix C to obtain PIS and NIS.

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$$C = \begin{bmatrix} 0.08 & 0.07 & 0.10 & 0.15 & 0.07 \\ 0.16 & 0.14 & 0.03 & 0.13 & 0.07 \\ 0.08 & 0.04 & 0.18 & 0.17 & 0.13 \end{bmatrix} \tag{15}$$

$$C^{+} = \begin{bmatrix} 0.16 & 0.14 & 0.18 & 0.17 & 0.13 \end{bmatrix} \tag{16}$$

$$C^{-} = \begin{bmatrix} 0.08 & 0.04 & 0.03 & 0.13 & 0.07 \end{bmatrix} \tag{17}$$

(5) Calculation distance.

$$D^{+} = \begin{bmatrix} 0.15 & 0.16 & 0.13 \end{bmatrix} \tag{18}$$

$$D^{-} = \begin{bmatrix} 0.07 & 0.13 & 0.16 \end{bmatrix} \tag{19}$$

(6) Calculation of the composite valuation.

$$S = \begin{bmatrix} 0.07 & 0.13 & 0.16 \end{bmatrix} \tag{20}$$

According to the evaluation results, the preferential order of the planning scheme is C, B and a, that is, IKONOS and DMC
285   aerial camera have the strongest synergistic effect, Pleiades satellite and EWZ-D6 UAV equipped with Nikon D800 camera
take the second place, and GF-2 satellite and the KC2600 UAV with Sony NEX-7 camera have weak cooperation.

4.2 Evaluation of the capacity of geo-hazard emergency response services

Emergency response to geo-hazard is a kind of disaster management, which requires the coordination of multiple
technologies for rescue and disaster relief. The top priority is to ensure personnel safety, save lives and save lives, and on
290   this premise to avoid or reduce property losses to the greatest extent. In the rescue work, there is a "golden 72 hours", during
which the survival rate of the victims is extremely high, which is the golden rescue period after the occurrence of geological
disasters. Remote sensing technology, as the main technical support for emergency response, should provide effective
service for rescue in time and achieve fast investigation, fast characterization, fast decision and fast implementation of
emergency work through cooperative work. As for the evaluation of the service capability of remote sensing collaborative
295   system in geo-hazard emergency response, this section takes earthquake emergency as an example, analyzes the demand to
establish emergency response service chain, and combines BN design evaluation model.

4.2.1. Earthquake emergency response service chain

Earthquake is a sudden movement of the earth's surface caused by the release of the slowly accumulating energy inside the
earth, which can cause huge damage to life and property and further aggravate the impact of disasters and losses by

300 triggering secondary disasters such as landslide, debris flow and barrier lake. This paper refers to the process of remote sensing technology service in the Wenchuan earthquake emergency(PAN et al.,2010;Zhang et al.,2009), and analyzes it from the aspects of spatial information demand for rapid response and information technology support for disaster relief and rescue, and combines multiple remote sensing information services to form an earthquake remote sensing emergency service chain, as shown in Fig.6. The need for emergency response to earthquakes is mainly reflected in the rapid acquisition of

305 high-resolution remote sensing images, the rapid processing of remote sensing data and the extraction of hazard information. The "golden 72 hours" after the earthquake is a critical period for rescue, and high-resolution remote sensing images need to be quickly acquired and updated for analyzing casualties, infrastructure damage, rescue and resettlement and other detailed information. The processing of remote sensing data in disaster relief needs to achieve real-time or near real-time efficiency, including rapid image correction, alignment, stitching and uniform color. The disaster information is divided into three parts:

310 building damage, lifeline damage and secondary disaster monitoring. Buildings reflect the main distribution of affected people. Roads are the lifeline of earthquake relief, and change analysis and feature extraction are the mainstay, combined with basic data and mathematical methods to analysis and calculate the scope of disaster impact and damage to buildings and roads, and make rapid assessments. Secondary disasters derived from earthquakes, such as landslide, debris flow and barrier lake, are mainly monitored dynamically by remote sensing technology and simulated to forecast their development and
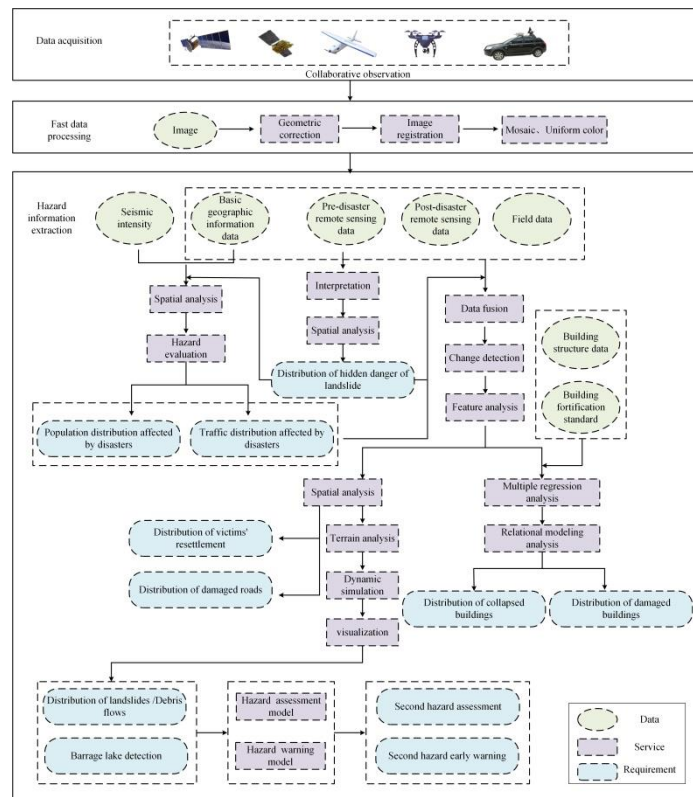
315 impact.

Figure 6. Earthquake-remote sensing emergency response service chain

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4.2.2 BN model for Emergency Services Evaluation

BN is a probabilistic graph model based on dependencies between variables, and its expected value is reliable when the
320 causal chain is correct and has an appropriate probability distribution. The seismic emergency response service chain is a coherent link before and after, suitable for modeling by using a directed graph, while the links are flexible, there is uncertainty, and suitable for handling with probability. Based on the theory established by BN, the BN model design for the evaluation of the earthquake disaster emergency response service capability was carried out using GeNIe Version 2.3 Academic software.

325 (1) Identify evaluation indicators. The system of indicators for evaluating the establishment of capacities according to the earthquake emergency response service chain is shown in Table 6.

Table 6. Evaluation system for emergency response service capacity

First-level index	Second-level index	Third-level index
Data acquisition	Planning	Response time
		Reliability
	Observation	Technique
		Range
Fast data processing	Correction	Timeliness
		Accuracy
	Registration	Speed
		Accuracy
		Reliability
	Mosaic	Definition
		Color equalization
		Accuracy
Hazard information extraction	Function	Change detection
		Spatial analysis
		Terrain analysis
	Visualization	Expression
		Timeliness
		Reliability
	Forecast and Assessment	Content
		Timeliness
		Accuracy

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(2) Design the BN structure. From the above evaluation system, the emergency response service capability is divided into three levels from data acquisition, fast data processing and disaster information extraction, and each level indicator is the

330   parent node of the corresponding indicator of the previous level, and this convergence relationship is represented by the directed edge from the parent node to the child node, i.e., from the lower level indicators to the corresponding upper level indicators finally converge to the total indicators. Through the above analysis, the BN topology of the cooperative observation system earthquake emergency response service capability assessment model is constructed as shown in Fig.7.
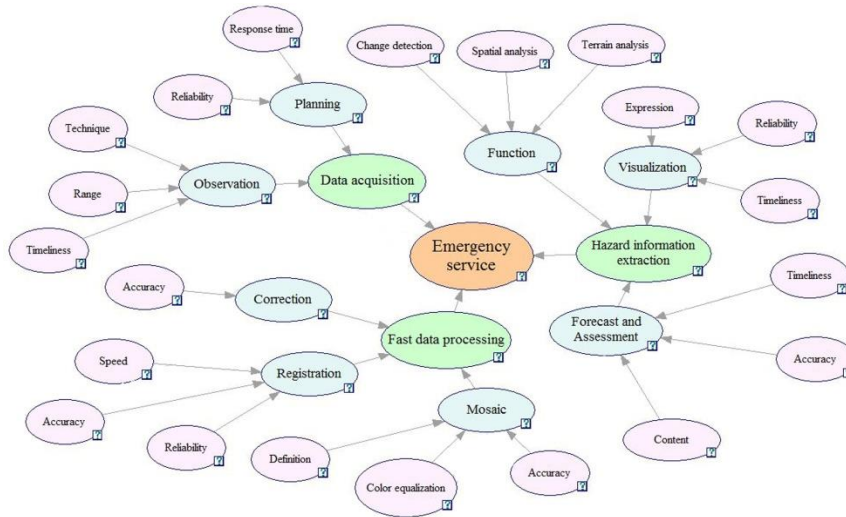

335   **Figure 7. BN topology of the service capacity evaluation mode**

(3) Construct the BN model. Each node in the BN model has a finite number of mutually exclusive states, where the root node is classified into three levels. Determine the conditional probability of each node to build the assessment model of the seismic emergency response service capability of the cooperative observation system as shown in Fig.8.

17
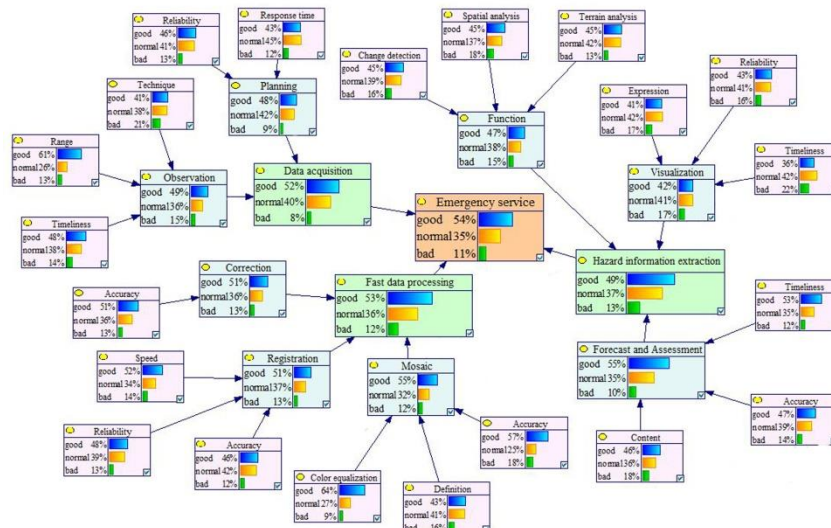
340 **Figure 8. Assessment model for the capacity of the coordinated observation system earthquake emergency response service**

(4) Capacity assessment. The capability of the cooperative observing system can be predicted by Bayesian inversion if the values of some nodes in the evaluation model are known. Set the root node: response time, observation range, correction accuracy, spatial analysis, and forecast accuracy of the state is known (response time = good, observation range = normal, correction accuracy = good, spatial analysis = normal, forecast accuracy = normal), using these as evidence variables, to

345 predict the capacity of the collaborative observation system, as shown in Fig.9, the emergency response capacity of good probability increased to 60%, the probability of hazard information extraction is concentrated in the normal, can be initially judged by improving the disaster information extraction link to further improve the effectiveness of disaster emergency services.
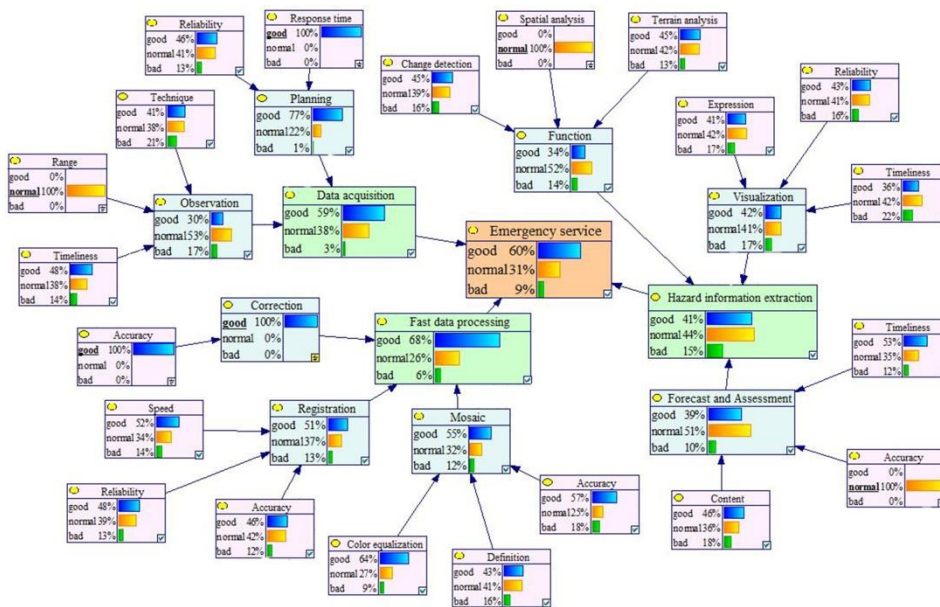
350 **Figure 9. Collaborative emergency services capacity projection**

4.3. Analysis

For the application of remote sensing technology in geo-hazard emergency response, several remote sensing cooperative emergency response application modes have been proposed, but in the face of massive remote sensing technology resources, there is a lack of unified management and selection judgment mechanism for remote sensing sensors, and the investigation

355 of remote sensing capabilities is concentrated in the field of satellite remote sensing. In order to improve the efficiency of space remote sensing technology in geo-hazard emergency response, this paper conducts a comprehensive analysis of space-air-ground remote sensing sensor technology resources and emergency services system, and a database of sensor technology performance indicators covering satellite, aviation and ground, SAT_RS, and a database of emergency services evaluation indicators, SE_RS, are established by using MySQL to realize the unified management of multi-platform and multi-types of

360 heterogeneous sensor resources, reflect their capability characteristics through technical parameters, and correlate the tasks of sensors to record their emergency services. Based on the database, the collaborative capability of remote sensing technology in geo-hazard emergency response is evaluated in terms of collaborative observation efficiency and emergency service capability. The collaborative observation effectiveness needs to establish evaluation indexes for specific collaborative observation scenarios, and use TOPSIS and RSR for evaluation and calculation. In the evaluation of disaster

365 emergency service capability, this paper refers to the remote sensing service process in the Wenchuan earthquake disaster emergency response, establishes the remote sensing collaborative earthquake emergency response service chain, and designs the evaluation model with Bayesian network. The analytical approach to geo-hazard emergency response capability through the evaluation of cooperative observation effectiveness and service capability for heterogeneous sensor cooperative planning services is provided with the support of space-air-ground remote sensing technology and service indicator database. Several

370 points should be noted here.

(1) Database data cannot be dynamically linked to evaluation calculations. The database needs to be further developed to allow dynamic manipulation of the data.

(2) Determination of the effectiveness of cooperative observations. The cooperative observation efficiency is related to the cooperative environment, and the evaluation indexes are influenced by the performance of the sensors and the cooperative

375 mode, some of which can be obtained directly from the database, while others need to be calculated in conjunction with the actual situation.

(3) The uniqueness of Bayesian model design. The structure, level classification and probability distribution of Bayesian evaluation model design are closely related to the type of geological hazards and the demand for emergency services, and the actual emergency services are complex, which need to be specifically adjusted in specific applications.

380 **5. Conclusions**

In this paper, various remote sensing sensor technologies are analyzed, and a database of space-air-ground remote sensing indicators is established to realize data management of sensor technology resources covering satellite, aerial, and terrestrial. On the basis of the index database, the association between sensors and geo-hazard emergency events was established, and TOPSIS nested RSR and Bayesian network were used to evaluate the cooperative observation efficiency and emergency

385 service capability respectively, and their feasibility was proved by calculations, providing a basis for the decision of establishing space-air-ground remote sensing cooperative observation in geo-hazard emergency response.

The follow-up research work will be carried out from (1) further enrichment of the database, development of Web service functions and realization of data connection, (2) integration of more practical application scenarios and revision of the evaluation calculation model.

390 **Author Contributions:** Liu, Y.H. and Zhang, J. designed the study. Liu, Y.H. performed the data collection, analysis, and database establishment. Liu, Y.H. completed the design, calculations, and validation of the methods and models. Liu, Y.H.

wrote the manuscript and led the revision with contributions from Zhang. J. Zhang. J. managed the project schedule and budget.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Global satellite launch situation

Type of satellite	Satellite	Country (area)
	Landsat	USA
	SPOT	France
	CBERS	China-Brazil
Landsat series	ERS	ESA
	ALMAZ	Russia
	IRS	India
	JERS	Japan
	IKONOS	
	QuickBird	
	WorldView-1/2/3/4	USA
Land satellite	GeoEye1	
	Orbview3	
	SPOT-5/6/7	France
	Pleiades-1A/B	
High resolution satellite	RapidEye	Germany
	ALOS	Japan
	EROS-A/B	Israel
	Resurs-DK1	Russia
	IRS-P7	India
	ZY-2	
	GF-1/2/6/7	China
	Formosat 2	

	Kompsat	Korea
	THEOS	Thailand
	EOS-AM1	
	EOS-PM1	USA
Hyper spectral satellite	EO-1	
	HJ-1A	China
	GF-5	
	ERS-1/2	ESA
	ENVISAT-1	
	TerraSAR-X	Germany
SAR	RADARSAT-1/2	Canada
	ALOS	Japan
	COSMO-Sky Med	Italy
	GF-3	China
	HJ-1C	
	SkySat	USA
	LAPAN-Tubsat	Indonesia
	BJ-1	
	TH-1	
	SuperView-1	
Small satellite	JL-1	China
	OVS-1A/B	
	TT-2	
	LJ-1	
	BNU-1	
	NOAA	USA
Meteorological satellite	FY	China
	GMS	Japan
	SeaStar	USA
	Jason	France
Ocean satellite	Sentinel-3	ESA
	Okean	Russia
	ADEOS	Japan

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