SAR remote sensing monitoring of the Yushu Earthquake disaster situation and the information service system

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Abstract: The SAR system with its all-weather and all-time imaging capabilities emerged as a very important remote sensing data source for earthquake monitoring and disaster relief. After the recently occurred earthquake in Yushu county, Qinghai province, an airborne SAR system equipped with X-band dual antenna interferometric sensor and P-band fully polarized sensor has been successfully used in disaster monitoring and relief actions. The system is the first airborne SAR system with full intellectual property owned by China. This paper summarizes the Yushu Earthquake remote sensing monitoring and information service system, including the data, processing methodologies and information service. The emphasis is put on the application of airborne SAR images to disaster information extraction and assessment. First, the parameters characterizing the content of earthquake disaster remote sensing monitoring are determined, which include the information of urban and rural residence, infrastrcucture, geological disasters and farmland damage. The processing methodologies of optical and SAR data for earthquake disaster information interpretation, mapping and risk evaluation are presented. The process chain consists of quick geometric processing, change detection, quick target interpretation and quick spatial risk assessment for disaster. On the basis of the earthquake information including those extracted from remotely sensed images and other existing social and geospatial data, a system of Yushu Earthquake disaster situation geographic information service has been developed, to facilitate the management, visualization, and statistical analysis of the earthquake disaster information.

Key words: Yushu Earthquake, SAR, remote sensing, disaster monitoring and assessment

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1 INTRODUCTION

China is an earthquake country. Therefore, it is vital to effectively monitor and to assess earthquake disaster situation promptly after the earthquake, which can help protect against losses of lives and property. Synthetic Aperture Radar (SAR) is an important and indispensable technical means for disaster precaution, alleviation and relief at both national and regional levels because of its all-weather and all-time capability (Liu *et al.*, 2010). After the Ms 8.0 Wenchuan Earthquake happened on May 12, 2008, Chinese Academy of Surveying and Mapping developed a Geographic Information Service System on Wenchuan Earthquake Disaster Situation, and achieved the management, visualization, and statistical analysis on earthquake disaster information. But at that time, SAR data was mainly provided by foreign countries, and its spatial-resolution was also limited.

At 7:49 AM, April 14, 2010, there happened a Ms 7.1 earthquake in Yushu county, Qinghai province. The emergency preplan supported by surveying and mapping was immediately launched by State Bureau of Surveying and Mapping. An airborne SAR system equipped with X-band dual antenna interferometric sensor and P-band fully polarized sensor quick responded and was successfully used in disaster monitoring and relief actions. The system is the first airborne SAR system with full intellectual property owned by China, where Chinese Academy of Surveying and Mapping is the leading developer. It took advantage of its all-weather capability and no limitation on flight height for image spatial-resolution, while avoiding the space and time occupied by rescue aircrafts. About 2000km^2 X-band and P-band airborne SAR images with 0.5m and 1m resolution were acquired after 12 air routes of two sorties. By quick geometric processing, quick data quality analysis, quick change detection, and detailed target interpretation on SAR images, technical supports were provided for earthquake relief, disaster assessment, and reconstruction planning.

On the basis of the practical work in Yushu Earthquake disaster situation monitoring, this paper puts the emphasis on the

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methods and technical flow of SAR image processing in the application of monitoring and assessment of earthquake disaster situation. The existing problems are also analyzed.

2 METHODS AND TECHNICAL FLOW

2.1 Overall technical flow

The overall technical flow of establishing the earthquake disaster situation information service system of Yushu in Qinghai Province by SAR technology is illustrated in Fig. 1. The main processes include image preprocessing, disaster information interpretation, multi-source information integration, and information service system construction.

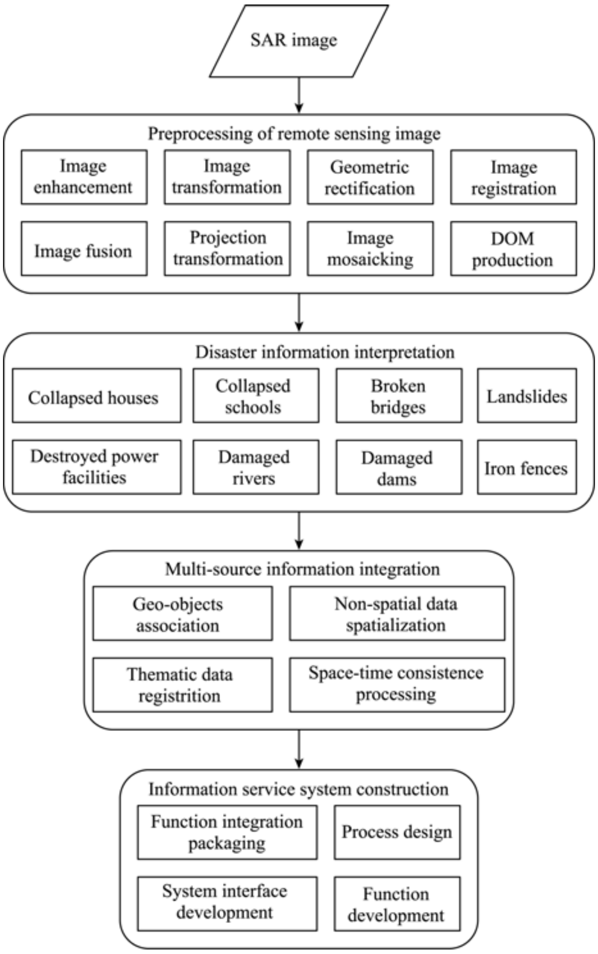


Fig. 1 Overall technical flow

2.1.1 Image preprocessing

By preprocessing remote sensing images, especially SAR images, the image quality is improved. The preprocessing includes image enhancement, image transformation, fast geometric rectification, image registration, image fusion, projection transformation, image mosaicking, DOM production, etc.

2.1.2 Disaster information interpretation

By integrating the semi-automatic information extraction results and visual interpretation results, the damages areas are completely outlined, which provides foundations for statistical analysis on disaster situation. At the same time, the interpretation accuracy for different type disaster situation parcels is discussed.

2.1.3 Multi-source information integration

By geo-object association on the interpreted objects, non-spatial data spatialization, thematic data registry, and space-time consistence processing, the disaster situation information including texts, statistics, images and multimedia is seamlessly integrated.

2.1.4 Information service system construction

Based on the governmental geographical information platform “Geowindows”, the disaster situation information service system of Yushu in Qinghai Province is constructed by function integration packaging, system interface development, process design and function development.

2.2 Fundamental data

Aerial photos, satellite images, fundamental geographic data, and thematic data of Yushu area are collected. SPOT5 image, IKONOS image and airborne SAR data before and after earthquake are used for interpretation. Detailed information for the adopted data is:

(1) Airborne SAR data: X-band dual antenna interferometric data and P-band fully polarized data.

(2) Optical image data: SPOT5 image and IKONOS image before and after earthquake, and aerial photos after earthquake.

(3) 1∶50000 scale fundamental geographic data.

(4) Field work data from State Bureau of Surveying and Mapping and Ministry of Land and Resources, population data, social economic data, hydrological data, geological data, etc.

2.3 Technical methods

2.3.1 Monitoring criteria for disaster situation

Multi-platform, multi-temporal, and multi-sensor remote sensing images including satellite images, digital aerial photos, airborne X-band/P-band SAR images, and UAV digital images are acquired in this monitoring work. The existing 1∶50000 and 1∶10000 scale fundamental geographic data, population distribution data, social economic data, as well as thematic maps in the fields of land resources, transportation, hydrology, geology, agriculture and forestry of earthquake-affected areas are also collected. The monitoring criteria for disaster situation are established by referring the existing criteria on fundamental geographic data production, land resources inventory, geological hazard monitoring by remote sensing (Chinese Geological Survey, 2008), etc.

In the earthquake-affected areas, high-spatial resolution images and SAR images are mainly used for the following types of fast investigation by remote sensing:

(1) Town, and rural built-up.

(2) Infrastructure: transportation and communications sys-

tems, water and power lines, and public institutions including schools, post offices, etc.

(3) Geological hazards and environmental information, including landslides and debris flow.

(4) Damages on farmlands and forests.

2.3.2 Multi-source data integration for remote sensing monitoring

The acquired optical image can cover only limited region of the disaster affected area. In order to monitor the whole disaster affected area, the multi-source remote sensing data should be used. Digital optical images of the center of Jiegu town were acquired, so optical images are the main remote sensing data source and SAR data is used as auxiliary data. The monitoring of the edge of Jiegu town mainly uses SAR data as well as optical images taken before the earthquake. In this work, the monitoring order is first the concentrated residential areas, and then the scattered settlements in rural areas. The multi-source data including SAR images, aerial photos and satellite images are used together to cover the whole area and to perform the fast and accurate image interpretation. Firstly, the coverage extent of the acquired images is analyzed. Then, imaging processing and polarization synthesis are performed. Finally, geometric rectification, fusion, mosaicking, etc. are carried out. Where, self-developed software "SARMapper" is used for SAR image processing, and module "PixelGrid" of self-developed software "ImageInfo" is used for optical image processing. Different types of images often have big contrast on color, so images are superimposed directly and then interpreted under GIS environment (Zhang *et al*., 2008), which greatly reduces workload and data volume during network transmission.

2.3.3 Complementary advantages of SAR image interpretation and optical image interpretation

SAR images have interpretation advantages on enclosed pasture and its surrounding settlements, iron tower and facilities. However, collapsed housed can be easily seen on optical images. By utilizing the complementary advantages of SAR image interpretation and optical image interpretation, which is illustrated in Fig. 2, the earthquake situation of Yushu county is accomplished.

2.3.4 Fast interpretation of SAR image

SAR system has all-weather and all-time imaging capabilities. After earthquake, SAR images of disaster affected areas are acquired. By comparing with the optical images acquired before earthquake, change information before and after earthquake can be obtained, which can be further used for quick monitoring on typical ground objects. X-band and P-band SAR images are used for earthquake situation interpretation. After earthquake, there are lots of collapsed houses in Jiegu town, which can be easily interpreted on SAR images. Besides, damaged roads, bridges, dams, and facilities such as power towers can also be clearly seen on SAR images, which are shown in Fig. 3.

2.3.5 Disaster risk analysis

Disaster rating scheme can be obtained according to model superposition in GIS software using its powerful spatial analysis functions (Hu *et al*., 2007). By using this map, the visual interpretation results can be further verified.

3 DISASTER SITUATION SAR REMOTE SENSING MONITORING AND THE SERVICE SYSTEM

Aiming at the Yushu Earthquake, this paper investigates the image preprocessing methods, including image enhancement, image transformation, geometric rectification, image registration, image fusion, projection transformation, image mosaicking and so on. The methods of extracting houses, bridges, schools, power facilities, rivers, landslides from remote sensing images are discussed. Multi-source and heterogeneous disaster information integration method and Yushu Earthquake disaster situation geography information system construction method are introduced. The service system can provide technical support to the governmental management and decision-making.

3.1 Disaster situation information interpretation of Yushu Earthquake

The service system mainly achieves the disaster situation information interpretation, such as collapsed houses, collapsed schools, broken bridges, destroyed power facilities, damaged rivers, damaged dams, landslides, etc. The information of the collapsed schools in Yushu is shown in Fig.4. The monitoring time and the area of parcels are shown in the information box of Fig.4. Fig. 5 shows the information of the collapsed houses. The area of parcels and the order of the parcels are shown in the information box of Fig.5.

3.2 Multi-source emergency information integration of Yushu Earthquake

Based on the basic geospatial data, a unified data integration framework is established. Through data transformation, projection transformation, data resample, geographical association, space-time consistence processing, spatial index generation, earthquake disaster situation information of collapsed houses, collapsed schools, broken bridges, damaged power facilities, damaged rivers, damaged dams, landslides, population, and earthquake intensity, is seamlessly integrated with multi-scale spatial information. At last, the Yushu Earthquake disaster situation information database has been formed. The integration of earthquake intensity information and spatial information is shown in Fig.6. The sensible radius is 83.6807 km (Fig. 6).

3.3 Emergency information service system construction of Yushu Earthquake

Based on fundamental geographic information service interface, using B/S structure, the service system integrates information display, query, comparison and analysis, which achieves two-dimensional map and three-dimensional scene efficiently display of Yushu Earthquake area based on network environment, multi-resolution aerial and space image information display,

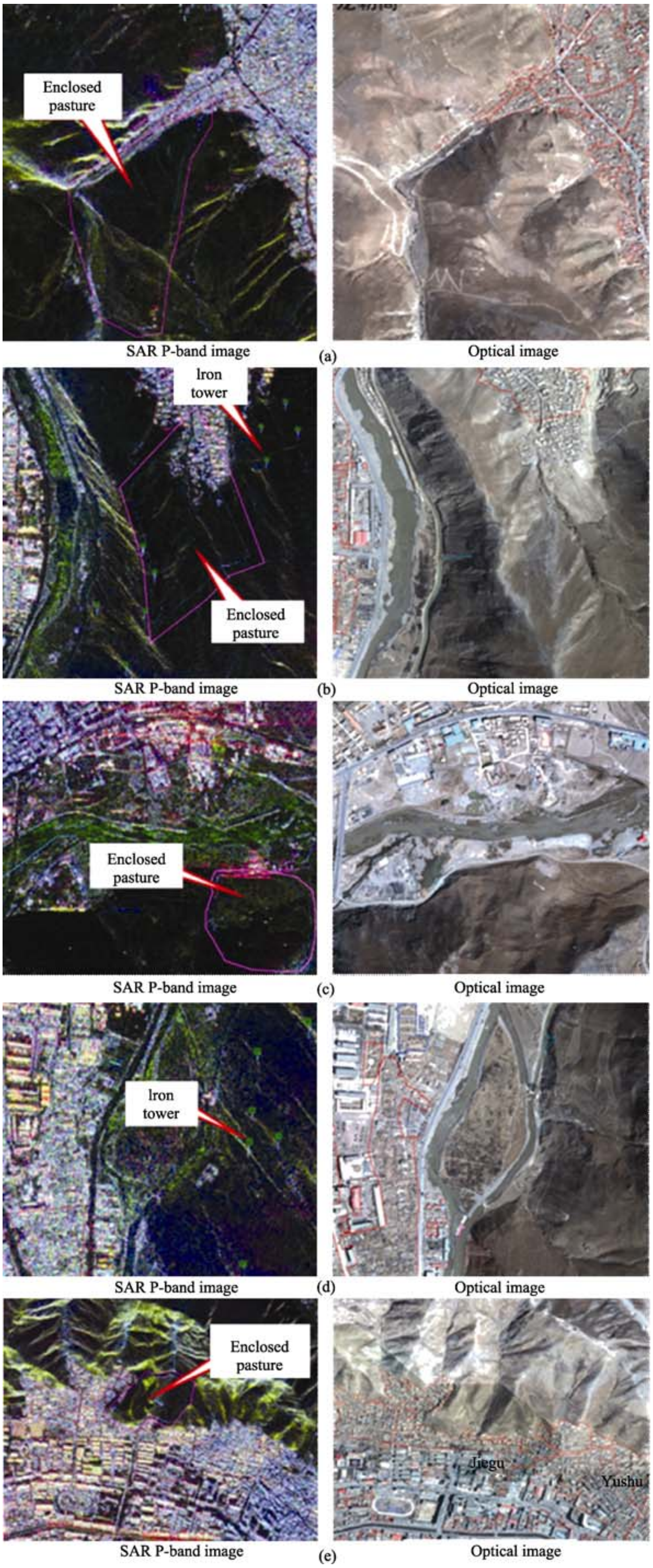
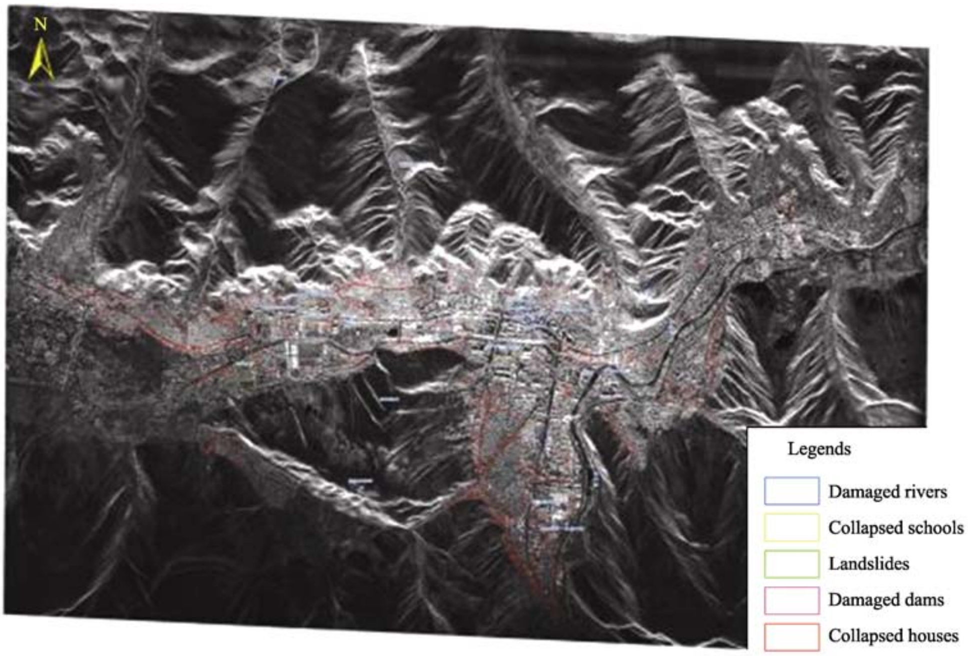
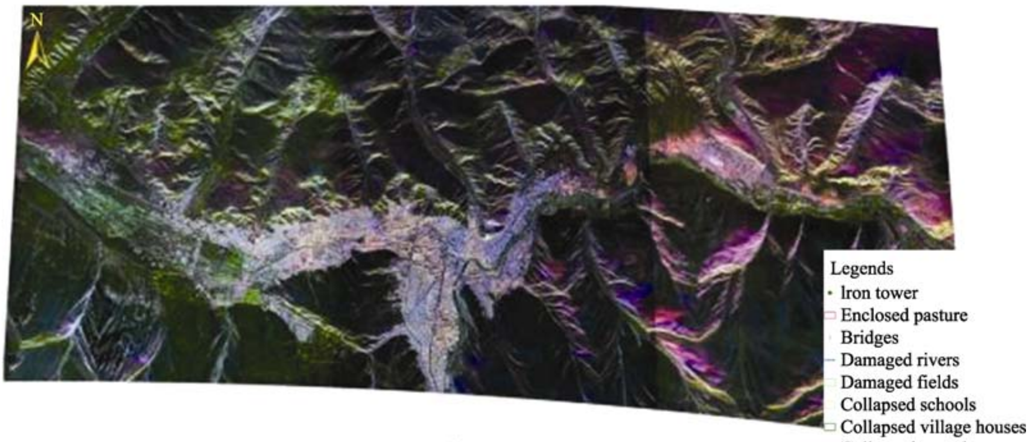


Fig. 2 Complementary interpretation advantages between SAR image and optimal image



(a)



(b)

Fig. 3 Interpretation plots of SAR image at X and P band about Yushu earthquake disaster situation
(a) X band; (b) P band

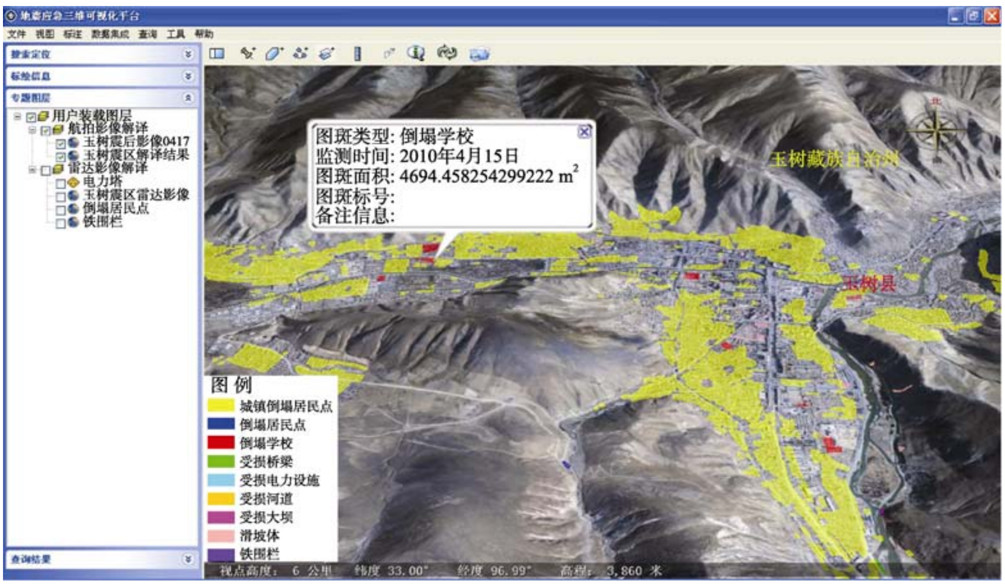


Fig. 4 Information of the collapsed schools

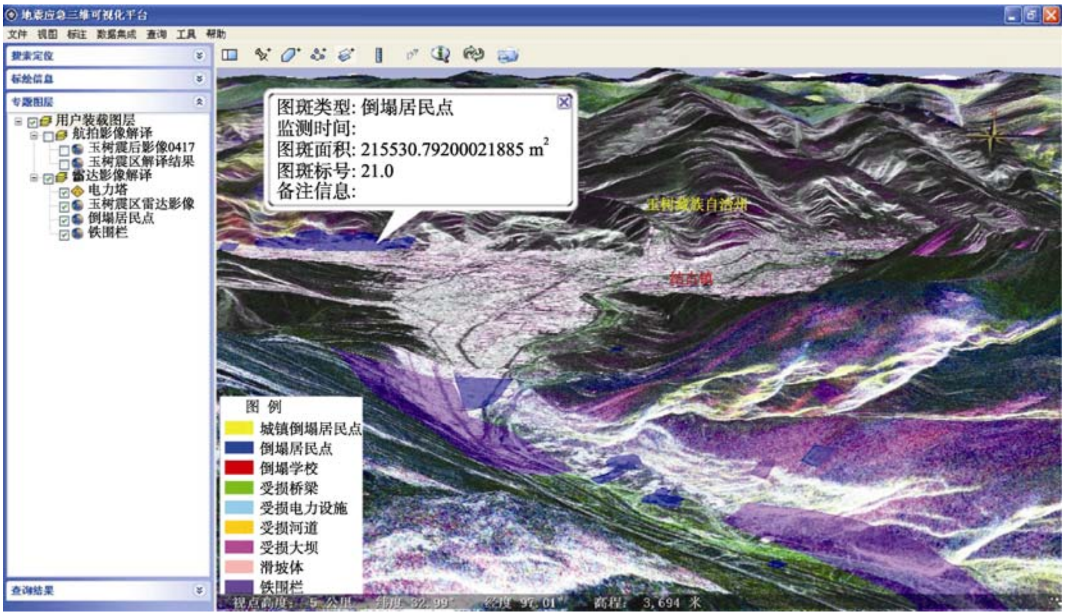


Fig. 5 Information of the collapsed houses

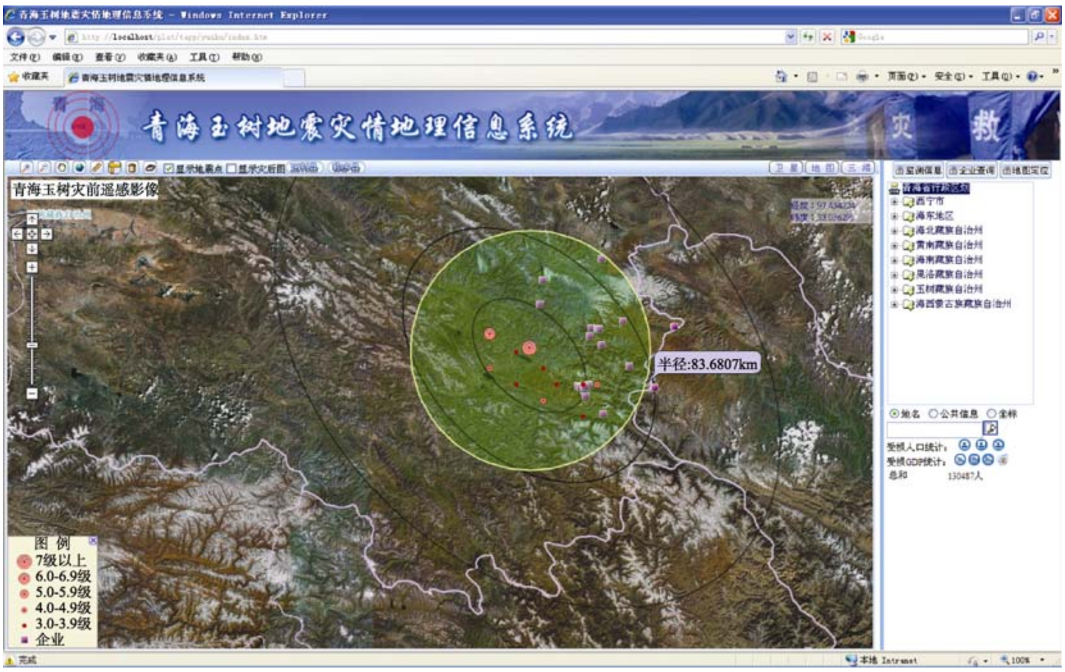


Fig. 6 Integration of earthquake intensity information and spatial information

Yushu Earthquake information query, earthquake monitoring and analysis, comparison of images before and after earthquake, spatial statistics of population and economic, query of the distribution of the enterprises and institutions in earthquake area and so on. The system can provide information services for disaster relief, disaster planning and reconstruction. The house comparison of images before and after earthquake is shown in Fig.7. From the Fig.7, The earthquake inflicted severe damage on the houses. The 3D aerial photograph image after earthquake is shown in Fig.8.

3.4 Application

According to the unified arrangements of the earthquake relief work by the State Bureau of Surveying and Mapping, Chinese Academy of Surveying and Mapping launched emergency response mechanism of governmental geographic information services immediately. In accordance with the work ideas of “information integration, decision support, rapid delivery”, the earthquake geographic information system of Yushu in Qinghai Province is fast set up. The system was deployed in General

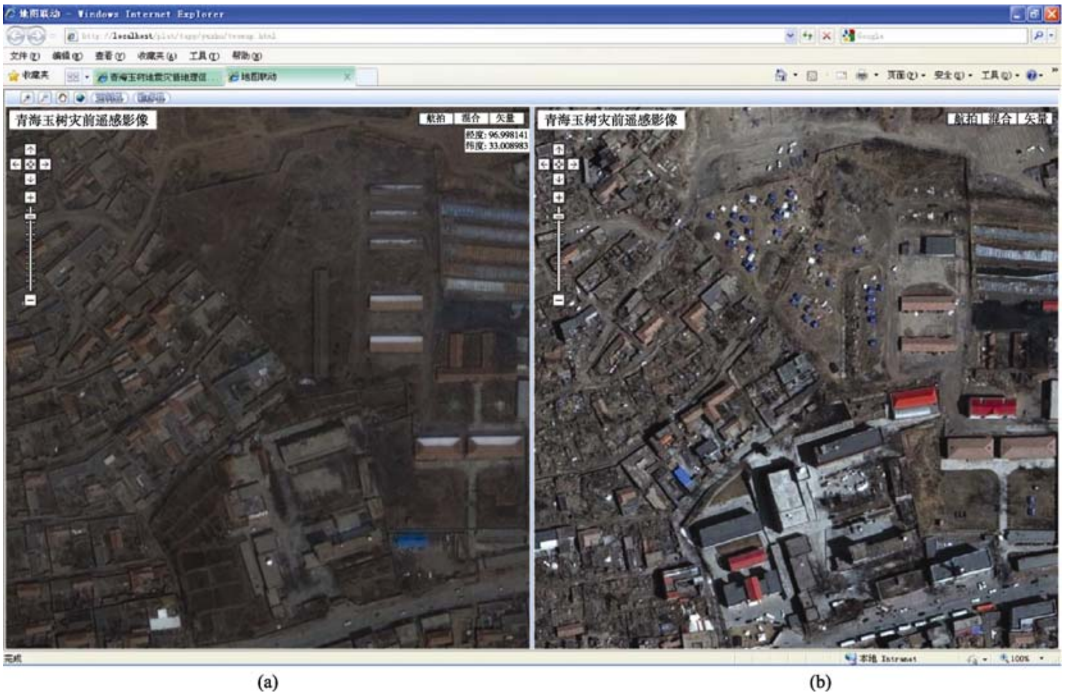


Fig. 7 House comparison of images before and after earthquake
(a) before earthquake; (b) after earthquake

Fig. 8 3D aerial photograph image after earthquake

Office of the e-government of the State Council and directly provided information services for the country based on geographic earthquake monitoring, comprehensive inquiry, and statistical analysis. On April 18, according to the arrangements of the State Bureau of Surveying and Mapping, the system was installed in Qinghai Bureau of Surveying and Mapping, and provided services to the Qinghai provincial party committee leaders, Qinghai provincial leader and Qinghai emergency office, provincial Development and Reform Commission, Department of Land and Resources through the network. On April 19, the system was installed in China Earthquake Administration and National Disaster Reduction Centre of the Ministry of Civil Affairs. It provides services directly to the professional sectors for the earthquake analysis and evaluation.

4 CONCLUSIONS AND DISCUSSION

Airborne SAR system has the advantage of flexibility, which is fully reflected in this earthquake disaster monitoring. Lots of data of disaster affected areas are quickly acquired shortly after the earthquake. This data are processed and then are used in the information service system construction to realize the interpretation, assessment and service for the comprehensive disaster situation information. Airborne SAR system plays an important role in disaster relief actions.

Because the available continuously running GPS base station is far away from the disaster affected area, the accuracy of differential GPS positioning is not good enough and the technique of geometric rectification without GCPs cannot be used at that moment. In this work, GCPs collected from optical images are used for SAR image rectification.

SAR image cannot be interpreted as easily as optical images. The interpreters must be trained in order to effectively understand information which is conveyed on SAR images. The absolute visual interpretation is time-consuming. Besides, because of the influence of SAR imaging mechanism and speckle noises, the subjective errors of visual interpretation are unavoidable (Yang *et al*., 2004). Therefore, interpretation algorithms of ground objects which are adapted for SAR images should be researched in order to improve the interpretation accuracy.

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玉树地震灾情 SAR 遥感监测与信息服务系统

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摘 要： 在玉树地震中，中国首套自主知识产权的机载多波段多极化干涉 SAR 测图系统，发挥全天时主动遥感的优势，成功服务于抗震救灾中。依据玉树地震灾情综合地理信息监测与评估工作，着重探讨 SAR 遥感影像用于地震灾情监测与评估中的处理方法和技术路线，研究制定了地震灾区灾情综合地理信息监测指标，通过快速几何处理、快速变化信息提取、快速目标判读和灾害空间危险性评估，实现了玉树地震震区灾情综合地理信息的解译、制图和统计评估。在此基础上，开发了玉树地震灾情综合地理信息服务系统，实现了灾情监测信息的综合管理、可视化查询和统计分析。

关键词： 玉树地震, SAR，遥感，监测与评估

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1 引 言

面对中国多地震的国情，在地震发生后的第一时间内对地震灾情进行有效的监测和评估，掌握地震及其次生灾害影响的发生发展状况，对于降低人员和生命财产损失具有至关重要的作用。合成孔径雷达(synthetic aperture radar, SAR)由于其全天候、全天时的工作特点，是国家和区域减灾防灾与抗灾救灾中不可缺少的重要技术手段(刘云华等，2010)。2008-05-12 汶川 8.0 级大地震发生后，中国测绘科学研究院开发了汶川地震灾情综合地理信息服务系统，实现了灾情监测信息的综合管理、可视化查询和统计分析。但当时 SAR 数据主要依靠国外雷达卫星提供，存在分辨率低、不能按需获取等问题。

2010-04-14 7 时 49 分，青海省玉树藏族自治州玉树县(北纬 33.1°，东经 96.7°)发生 7.1 级地震。国家测绘局立即启动应急测绘保障预案，中国首套由中国测绘科学研究院牵头，联合国内优势单位自主研制的“ 机载多波段多极化 SAR 测图系统 ”快速响应，利用 SAR 系统全天时、分辨率不受航高限制等优势，避开救援飞机飞行的繁忙时段和空间，选择飞机较少的高空和时间段，历经两个架次 12 条航线的飞行，获取了灾区约 2000km^2 的 0.5m、1m 分辨率机载 X、P 波段 SAR 影像。通过对灾区机载 SAR 影像开展的快速几何处理、快速数据质量综合分析、快速变化信息提取、精细解译等工作，及时为抗震救灾、灾情评估、灾害分析和重建规划提供了支撑保障。

2 方法和技术路线

2.1 总体技术路线

利用SAR技术进行青海玉树地震灾情综合地理信息解译与服务系统构建的总体流程如图 1，主要有遥感影像预处理、灾情信息解译、多源信息集成、服务系统构建 4 个主要过程。

2.1.1 遥感影像预处理

通过对玉树地震灾情遥感影像尤其是机载 SAR 影像进行影像增强、影像变换、快速几何纠正技术、

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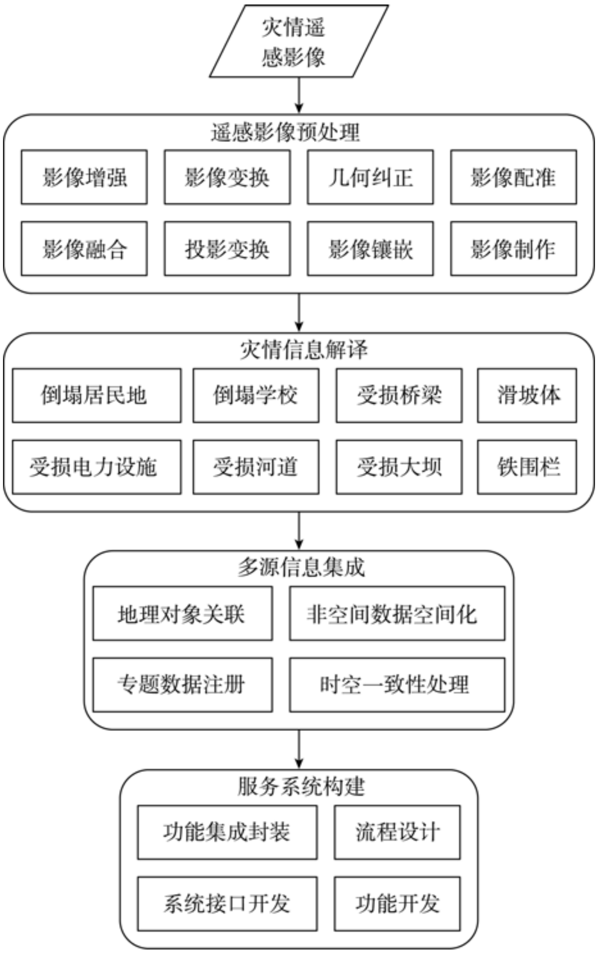


图 1　总体技术流程图

影像配准、影像融合、投影变换、影像镶嵌和正射影像制作等预处理, 提高了影像的质量。

2.1.2　灾情信息解译

结合玉树地震灾情遥感半自动信息提取和目视解译结果, 完整的勾画出了受灾区域, 为灾情信息的统计分析奠定了基础, 同时探讨了不同类型灾情图斑解译的精度。

2.1.3　多源信息集成

通过对提取的灾区解译内容进行地理对象关联、非空间数据空间化、专题数据注册和时空一致性处理, 实现了地震灾情信息(文本、统计、图像、多媒体等)与空间信息无缝集成。

2.1.4　服务系统构建

利用政务地理信息平台“地学之窗”, 通过功能集成封装、系统接口开发、流程设计和功能开发, 构建了青海玉树地震灾情地理信息系统。

2.2　基础资料与数据

收集了玉树地震区航空航天、基础地理信息及灾情专题信息等基础数据与资料。对受灾区主要使用灾前灾后 SPOT5、IKONOS 及机载多波段多极化干涉 SAR 影像进行对比解译。

具体数据及资料类型包括:

(1) 机载多波段多极化干涉 SAR 影像数据: 雷达 X 波段、P 波段影像数据。

(2) 光学影像数据。采用的数据来源包括: 震前 SPOT5、IKONOS 卫星遥感资料; 震后 SPOT5、IKONOS 光学卫星影像资料; 震后航空摄影资料。

(3) 受灾区 1∶5 万全要素基础地理信息。

(4) 国家测绘局、国土资源部地面调查资料、人口、社会经济、水文和地质资料。

2.3　技术方法

2.3.1　灾情综合地理信息监测指标

本次监测获取卫星、数码航空影像、机载 X 波段、P 波段 SAR 影像、无人机数码影像等多平台、多时相、多种传感器的航空航天遥感影像。收集受灾区已有的 1∶5 万及 1∶1 万(城区)比例尺基础地理信息。收集灾区人口分布及社会经济信息, 以及国土、交通、水文、地质、农业和林业等专题图件。在参考已有基础地理信息产品生产、国土资源调查监测及地质灾害遥感应急调查规范(中国地质调查局, 2008)等基础上, 制定了灾情综合地理信息遥感监测指标。

在灾区主要利用雷达、高分辨率卫星影像快速开展以下几类主要灾情综合地理信息的遥感调查, 掌握灾情分布及受损情况。

(1) 城镇、乡村建筑物: 包括城镇居民点和农村居民点等。

(2) 城乡基础设施; 公路、桥梁、电力设施、通信设施、沟渠、河道、堤岸、大坝等。

(3) 地质灾害与环境信息: 包括滑坡体、泥石流等。

(4) 农田损毁: 包括农田和林地等。

2.3.2　多数据源综合遥感监测

由于获取的灾区光学影像数据覆盖范围有限, 为了对灾区进行全覆盖区监测, 需要充分利用各种能够使用的资源。玉树结古镇城镇区由于获得了数码光学影像, 主要以光学影像为主, 雷达影像为辅, 周边郊区主要依靠雷达, 并结合灾前光学影像数据。本次工作采用“先居民集中区, 后农村散列居民点”的策略, 充分利用雷达影像、航空影像、卫星影像进行快速、准确的解译, 实现全覆盖区域的

监测。具体进行监测时，先分析所获取数据的具体覆盖范围，然后对影像进行成像处理、极化合成，再对影像选取控制点进行纠正、融合和镶嵌等处理。其中雷达影像处理采用自主研发的 SARMapper 软件进行成像处理、极化合成、纠正等，光学影像处理采用自主开发的 ImageInfo 软件 PixelGrid 模块进行 DEM 制作、纠正、正射影像生成。针对不同类型影像色彩反差较大的情况下，采取不进行镶嵌处理而直接在GIS环境下进行叠加后判读的方法(张继贤等，2008)，大大降低了数据处理量和判读时网络传输数据量。

2.3.3 SAR 影像解译与光学影像解译优势互补

SAR 影像对草库伦及其周边居民地、铁塔等地物和设施表现出很强的解译优势，而光学影像无法解译出这类地物，但在城镇倒塌房屋等地物表现出很强的解译优势。依据 SAR 影像与光学影像的解译优势互补，完成玉树地震解译工作。下面以 5 对解译结果图为例说明SAR影像与光学影像在解译中的优势互补关系(图 2)。

2.3.4 SAR 影像遥感信息快速判读

地震灾害发生后，获取灾区雷达影像，与光学遥感影像的历史数据进行对比，可获取震灾前后变化信息，有利于视觉判读，便于进行典型地物目标的快速灾情监测。采用 X 波段、P 波段雷达影像进行灾情信息的快速判读。玉树地震后，结古镇大面积房屋倒塌，可在雷达影像上得到明确判读；除此之外，对于受损道路、桥梁和大坝等灾害信息，还有一些基础设施如电力塔等也表现明显(图 3)。

2.3.5 灾害空间危险性评估

结合地理信息系统的强大空间分析功能(胡德勇等，2007)，在 GIS 软件中按照一定的模型叠加获得灾害等级图。然后，灾害评估结果与判读结果作对比分析，确证判读结果的正确性。

3 灾情 SAR 遥感监测成果与服务系统

针对玉树地震，研究了地震灾情遥感影像增强、影像变换、快速几何纠正技术、影像配准、影像融合、投影变换、影像镶嵌等预处理方法，研究了从震后遥感影像中提取居民地、桥梁、学校、电力设施、水系、山体滑坡等灾情信息的方法，研究了多源异构灾情信息的集成融合方法，快速构建玉树地震灾情地理信息系统，为政府管理与领导决策提供了技术支持。

3.1 玉树地震灾情信息解译

主要实现了从灾情遥感影像上对倒塌居民地、倒塌学校、受损桥梁、受损电力设施、受损河道、受损大坝、滑坡体等信息的解译。图 4 是玉树结古镇倒塌学校的信息，信息框中显示了倒塌学校的监测时间和图斑面积。图 5 是玉树结古镇倒塌居民地的信息，信息框中显示了倒塌居民地图斑面积和图斑标号。

3.2 玉树地震多源应急信息集成整合

基于基础地理空间数据，建立统一的数据集成框架，通过数据格式转换、投影变换、数据重采样、地理关联、时空一致性处理、建立空间索引关系等集成处理，实现对倒塌居民地、倒塌学校、受损桥梁、受损电力设施、受损河道、受损大坝、滑坡体、人口信息、地震烈度等各种地震灾情信息与多尺度(分辨率)空间信息的快速无缝集成，建成了玉树地震灾情信息数据库。图 6 是玉树地震烈度与空间信息的集成，有感半径是 83.6807km。

3.3 玉树地震应急服务系统快速构建

基于基础地理信息服务接口，采用 B/S 架构，开发集展示、查询、对比、分析为一体的服务系统，实现了网络环境下玉树地震灾区二维地图和三维景观高效展示，多分辨率航空航天影像信息浏览，玉树地震信息查询，地震灾情监测与分析，灾前灾后影像对比分析，人口与经济受灾空间统计，灾区企事业单位分布查询等专用服务功能，可以为救灾指挥、灾后规划重建提供信息服务。图 7 是玉树结古镇居民地灾情灾后影像对比，可以看出居民地损失严重。图 8 是玉树结古镇震后三维航拍影像。

3.4 应用情况

根据国家测绘局对抗震救灾工作的统一部署，中国测绘科学研究院立即启动突发事件应急政府地理信息服务机制，按照“信息集成，辅助决策，迅速提供”的工作思路，快速搭建了“青海玉树地震灾情地理信息系统”。系统部署在国务院办公厅电子政务办公室，直接为国办提供基于地理信息的地震灾情监测、综合查询、统计分析服务。2010-04-18，按照国家测绘局的安排，系统安装到青海省测绘局，通过网络为青海省委员会、青海省人民政府、青海省人民政府应急管理办公室、青海省发展和改革委员会、青海省国土资源厅等部门提供服务。2010-04-19，系统安装到中国地震局和民政部国家减灾中心，直接为专业部门地震灾情的分析、评估提供服务。

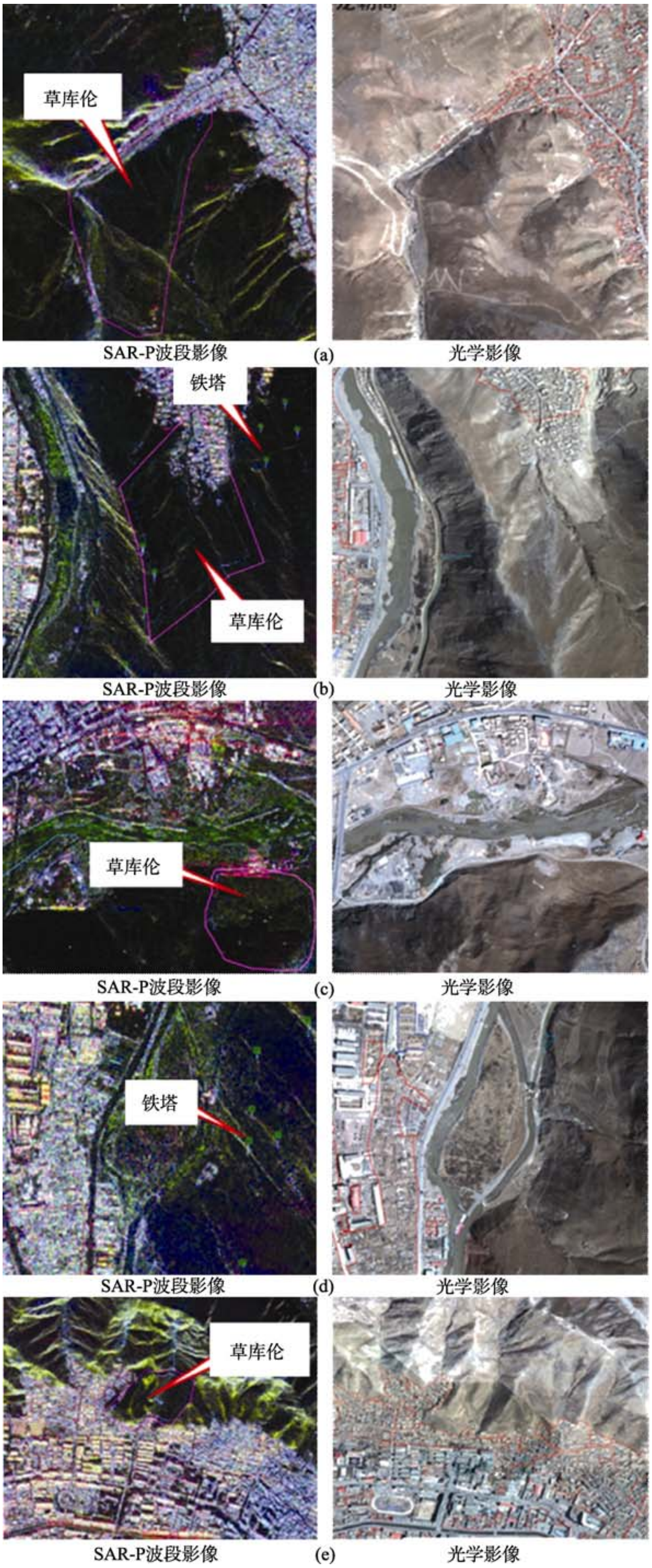


图 2　SAR 影像与光学影像解译的优势互补图

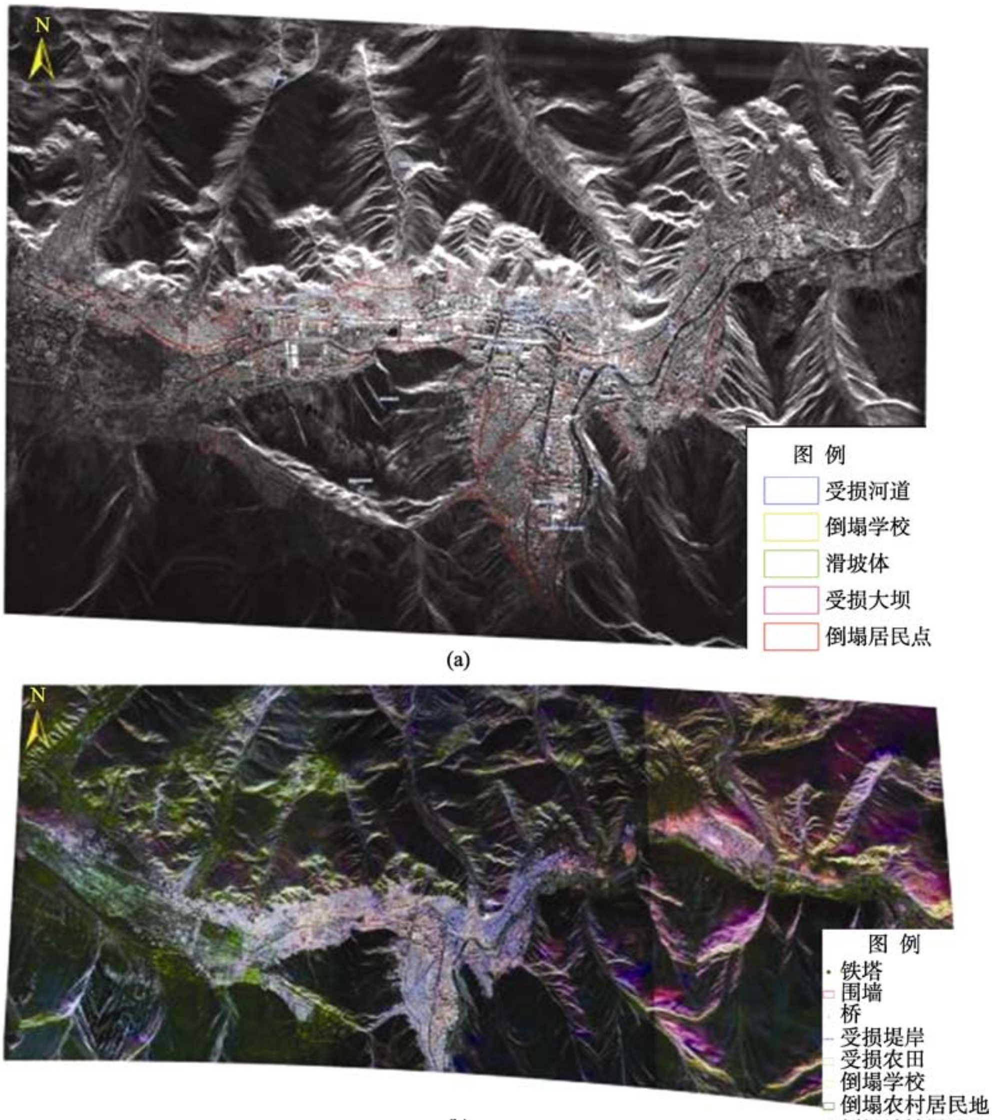


图 3 玉树地震灾情机载 SAR 影像解译图 (国土资源部国家测绘局)

(a) X 波段; (b) P 波段

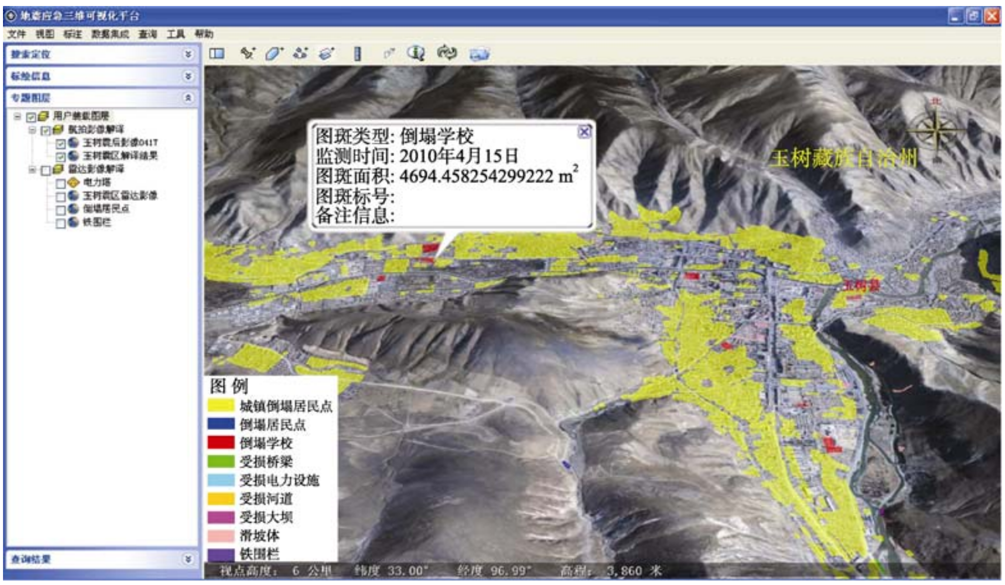


图 4 倒塌学校信息

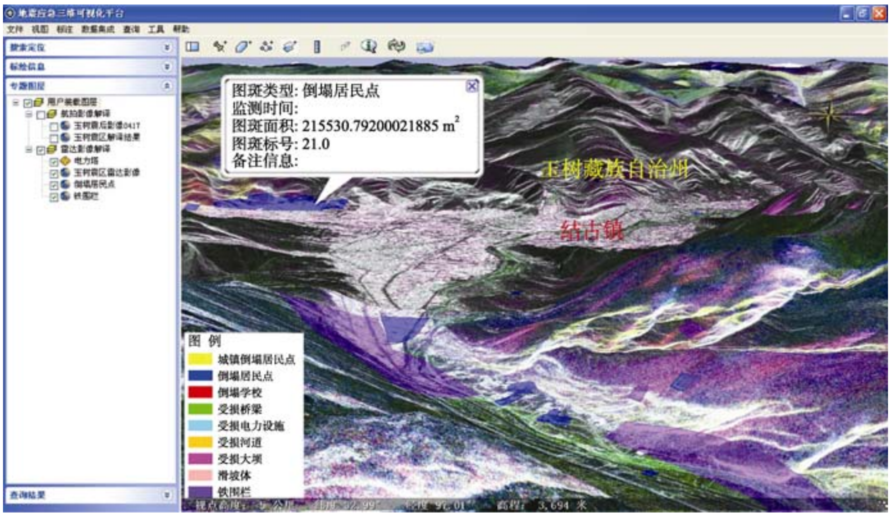


图 5　倒塌居民地信息

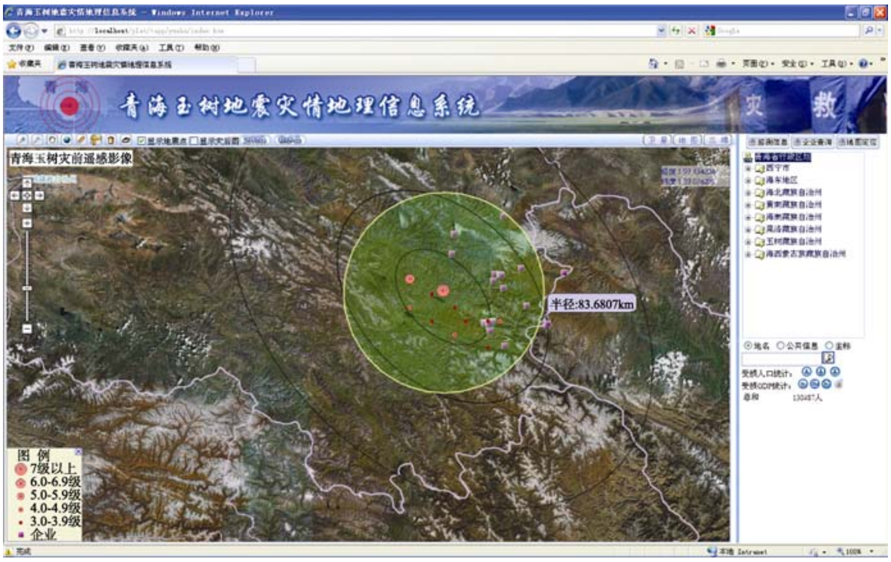
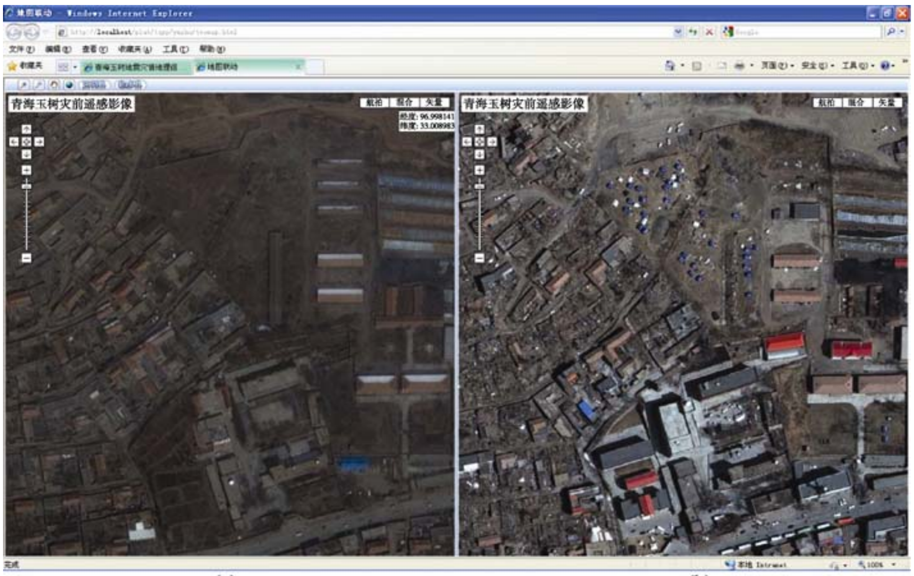


图 6　地震烈度信息与空间信息集成



(a) (b)

图 7　居民地灾前灾后影像对比

(a) 震前; (b) 震后

图 8 震后三维航拍影像

4 结论与讨论

此次灾情监测中，充分体现了机载 SAR 系统机动、灵活、受限少的优点，在灾后的较短时间内，快速响应，获取了大量灾区数据，并快速处理和构建的灾情服务系统，实现了灾区灾情综合地理信息的解译、评估和服务，在抗震救灾工作中发挥了重要作用。

当时可用的连续运行 GPS 地面基准站离灾区较远，GPS 差分精度不高，无控制的纠正技术不能使用。因此，利用了光学影像的控制点来完成纠正。

由于 SAR 影像没有光学影像直观和容易理解，判读人员必须经过训练才能确认雷达图像所传达的信息，而且完全的人工判读、理解不能适应某些应用上实时性的要求，另外，由于 SAR 特殊的成像机理和斑点噪声的存在，人工判读的主观错误和理解错误不可避免(杨文等，2004)。因此，需要研究更加适合于 SAR 影像地物的解译算法，以提高解译的准确性。

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