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A remote sensing data management system for sea area usage management in China

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ABSTRACT

In China, remote sensing data play an important role in sea area usage management. With the enrichment of available remote sensing platforms and sensors, the volume constantly growing, and more and more complicated data processing operations on data products, remote sensing data overload has been an obvious problem for anyone who is trying to set planning policies and monitor sea area usage activities based on the valuable data products. In order to solve the problem, this paper presents a customized remote sensing data management system (RSDM) for archiving and distributing the remote sensing data products for sea area usage management. This paper has identified a set of key domain requirements by reviewing the workflow of sea area usage management. In the RSDM, a metadata interpreter tool allows data managers to classify the data products into categorical data types according to a set of domain-specific business rules, and a data model based on data lineage is developed to support tracing all relevant data products along processing chains. In addition, a unified procedure, which is used to create Quick Look images with transparent border areas from different remote sensing data sources, is developed. What is more, the system provides summary information about the available data suitable for auditing and exploratory data analysis by using a series of statistic graphs from different perspectives for data managers and users. This paper demonstrates that the RSDM improves data managers' day-to-day working arrangements, and facilitates the application of the remote sensing technology in sea area usage management.

1. Introduction

In China, sea areas refer to the areas of coastal waters which extend seaward up to 12 nautical miles from shorelines and are as important as land, belonging to territorial resources. Sea area usage means a continued occupancy of a certain sea area over three months for carrying out exclusive activities by humans (Song et al., 2015). With marine economic development, there is an increasing demand for sea area usage (Yang et al., 2016). For example, in 2015, China's gross ocean product was 6466.9 billion RMB yuan, 7.0% up from that in 2014, accounting for 9.6% of the Gross Domestic Product (GDP) (2016 China Marine Economic Statistic Bulletin, 2016). A total of 8480 certificates for the sea area usage right were issued throughout the year, and the increased sea areas with the ownership of patent rights reached 253,613.13 ha. The collection of charges for sea area usage (CSAU) was 8.206 billion RMB yuan (2016 Sea Area Use Management Bulletin, 2016). However, sea area usage is a double-edged sword. Influenced by immediate profits without long term planning, these developments are always extensive, unordered, crude and inefficient, which results in running out of marine resources, deteriorating the marine ecological environment, and threatening the sustainable development of the marine economy (Li, 2012; Zhang et al., 2012). For example, because of unordered and blind sea reclamations, China has already lost more than 57% of its natural coastal wetlands since the 1950s, in which mangrove has been reduced by 73% and coral reef has been reduced by 80% (Coastal Wetland Conservation and Management in China, 2015).

According to a sea area usage classification system developed by State Oceanic Administration (SOA) in China (Fu et al., 2008), sea areas are mainly used for fishery and aquaculture, industrial purposes, transportation and communications, tourism and recreation, submarine engineering, sewage discharge and dumping, and sea reclamation. All of these activities compete for space and natural resources. It was acknowledged that without any clear spatial guidance and effective management on these types of activities, it is unable to deliver

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sustainable development in China's marine environment. Hence, SOA puts great emphasis on how to effectively manage sea area usage activities (Cao et al., 2012; Wang et al., 2015). Since 2006, SOA has been trying to establish a tiered sea area usage management framework for collaborative actions to achieve national, provincial, municipal and country level objectives. The National Marine Environmental Monitoring Center (NMEMC), as the central government agency, is responsible for developing sea area usage plans and monitoring sea area usage activities at national level. However, as a country with a vast area of territorial waters, traditional methods, such as field observations, may be costly and time-consuming. In contrast, remote sensing technologies, which possess the non-contact, low cost, wide field of view, and fast response capacities, have been drawn more attention (Chen et al., 2005; Ryu et al., ; Wu et al., 2017). Many Marine Spatial Planning (MSP) exercises and researches worldwide have highlighted that remote sensing technologies play an important role in monitoring and studying the marine and coastal environment (Martin and Hall-Arber, 2008; Foley et al., 2010; Kachelriess et al., 2014; Caldow et al., 2015) For example, Chauvaud et al. (1998) used aerial photographs to produce thematic maps of tropical coastal communities representing the spatial distribution of coral reefs, mangroves and seagrass beds. They thought the mapping technique is useful for preserving the environment, and also suited to the monitoring of coastal ecosystem evolution. Ouellette and Getinet (2016) reviewed the achievements of remote sensing technologies in Integrated Coastal Area Management and MSP practices. They concluded that remote sensing data can be used to directly and indirectly derive a variety of environmental, ecological, social and economic variables at different spatial and temporal resolutions, which facilitate to achieve the operational goals of MSP. By using remote sensing products, the NMEMC has made a great effort to enhance the capabilities of identifying targets in specific sea areas, counting the number of marine activities, measuring the occupying areas of some kinds of sea area usage activities, and detecting the changes of the length of the coastline.

However, with the accumulation of remote sensing data, the staffs in the NMEMC have realized that they overlooked the remote sensing data management, which hinders the application of remote sensing data for sea area usage management. While the local relevant government agencies become more interested in making use of remote sensing products for decision-making and daily grind, it is difficult to share remote sensing products and coordinate the efforts of different agencies and institutions by lack of an appropriate system for remote sensing data management. A few studies have been conducted on building information systems for coastal zones (Mabudafhasi, 2002; Stojanovic et al., 2010; Ma et al., 2017). However, they always focus on vector data or value-added information derived from remote sensing data. On the other hand, although there exists many mature remote sensing data management systems, such as the Multi-Satellites Data Service system operated by the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (RADI) (Dai et al., 2008), the USGS Global Visualization Viewer (GloVis), the USGS Earth Explorer system, and the Earth Online platform from the European Space Agency. They are too generic to be easily adapted to sea area usage management. Hence, a customized system for the remote sensing data management (RSDM) was proposed and has been developed. In addition to taking into account the generic needs for remote sensing data management, the RSDM is supposed to meet the specific requirements: (1) each data can be flexibly assigned to a categorical data type based on domain-specific attributes, (2) users can search a data and then trace all relevant data based on its data lineage, (3) users can view the georeferenced Quick Look images derived from different remote sensing data on a web browser, and (4) the RSDM can provide a rich set of tools to visualize the statistics of the archived data products.

The rest of the article is structured as follows. Section 2 describes the remote sensing data products which are applied to sea area usage management in China, and reviews the development of data models for remote sensing data management. Section 3 briefly introduces the infrastructure of the RSDM. Section 4 goes into the details of technical solutions of the four special requirements. The article ends up with a discussion on the effectiveness of the RSDM for sea area usage management and conclusions.

2. Data products and development of data models

This section introduces the major kinds of remote sensing data sources being used by the NMEMC, and describes the required processing operations for these data. In addition, it provides a historical context for the development of data models in the remote sensing data management field.

2.1. Data sources

The data sources which are applied to sea area usage monitoring in the NMEMC are mainly from satellite-based passive optical remote sensing data, which mainly use energy in the visible and near infrared portions of the spectrum. In the recent years, the number of such remote sensing satellites has increased rapidly so that it is able to acquire various satellite remote sensing imagery in a cost-effective manner. Table 1 shows the major kinds of data sources being used by the NMEMC. These images lend themselves to accurate sea area usage mapping in part because sea area usage information can be visually interpreted more or less directly from evidence visible on satellite remote sensing images and because objects can be seen in the context of the neighboring features (Wang et al., 2010). The staffs in the NMEMC apply the elements of image interpretation (e.g., tone, texture, shadow, pattern, association, shape, size and site), combined with professional knowledge of sea area usage, to delineate regional and linear features on the sea surface, and to monitor changes over time (Chu et al., 2006, 2012). Based on the visible features on the sea surface, some kinds of sea area usage can be identified and measured, such as aquaculture, sea reclamation, tourism, and some industrial activities, whereas other kinds of sea area usage like fishing, transportation and communications, submarine engineering and sewage discharge and dumping, cannot be detected by these remote sensing data, due to the fact that the areas occupied by these activities are not easily distinguished from the surrounding environments on the images.

As shown in Table 1, the NMEMC adopts a strategy of collecting satellite imagery at different spatial resolutions. Based on the strategy, the data at spatial resolutions of more than 10 m are thought as low-resolution satellite images, while high-resolution images provide finer spatial detail at meter and submeter resolutions (Pan and Duan, 2009). Although high-resolution imagery is appropriate for site-specific investigations and analysis, its low spatial extent and the irregular time intervals of imagery acquisition limit its use for national assessments of sea area usage, particularly in areas with persistent cloud cover. In contrast, the low-resolution satellite images may excel in these aspects. As shown in Fig. 1, with these remote sensing data, the NMEMC is able to publish reports and maps seasonally and annually on different themes: the current situation of sea area usage, suspected and increased sea reclamation regions, the progress of key marine construction projects, and marine georesources (Zhao et al., 2008; Xu and Zhao, 2016).

2.2. Processing operations

The data sources directly acquired from various data centers are called “Original Products”. Once these products are ready, some certain processing procedures should operate on them step by step for improving the quality of images for later analyses that will extract information from the images (Wang et al., 2010). In the NMEMC, three processing operations are frequently used, which can be thought as a list of standard processing steps. They are image geometric correction, data fusion, and subsetting.