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A recommendation framework for remote sensing images by spatial relation analysis

Jung-Hong Hong[a,*], Zeal Li-Tse Su[a], Eric Hsueh-Chan Lu[b]

[a] Department of Geomatics, National Cheng Kung University, No. 1 University Road, Tainan 701, Taiwan, ROC
[b] Department of Computer Science and Information Engineering, National Taitung University, No. 684, Sec. 1, Zhonghua Road, Taitung City, Taitung County 950, Taiwan, ROC

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ABSTRACT

In recent years, Remote Sensing Images (RS-Images) are widely recognized as an essential geospatial data due to their superior ability to offer abundant and instantaneous ground truth information. One of the active RS-Image approaches is the RS-Image recommendation from the Internet for meeting the user's queried Area-of-Interest (AOI). Although a number of studies on RS-Image ranking and recommendation have been proposed, most of them only consider the spatial distance between RS-Image and AOI. It is inappropriate since both of the RS-Image and AOI not only have the spatial information but also the cover range information. In this paper, we propose a novel framework named *Location-based rs-Image Finding Engine* (*LIFE*) to rank and recommend a series of relevant RS-Images to users according to the user-specific AOI. In *LIFE*, we first propose a cluster-based RS-Image index structure to efficiently maintain the large amount of RS-Images. Then, two quantitative indicators named *Available Space* (*AS*) and *Image Extension* (*IE*) are proposed to measure the *Extensibility* and *Centrality* between RS-Image and AOI, respectively. To our best knowledge, this is the first work on RS-Image recommendation that considers the issues of *extensibility* and *centrality* simultaneously. Through comprehensive experimental evaluations, the experiment result shows that both indicators have their own distinguished ranking behaviors and are able to successfully recommend meaningful RS-Image results. Besides, the experimental results show that the proposed *LIFE* framework outperforms the state-of-the-art approach *Hausdorff* in terms of *Precision*, *Recall* and *Normalized Discounted Cumulative Gain* (*NDCG*).

1. Introduction

The recent development of geospatial application has brought a revolutionary change on how Internet-based geospatial technology is perceived by the general public. Take a scenario as an example. Scientists may be interested in understanding and tracking the impact range of some important disaster events such as typhoon and hurricane for a specific region. The relevant satellite/remote images benefit scientists to evaluate the disaster region. The shooting time and covered range of image are two critical conditions to decide whether the image is available and useful. Nowadays, a number of web-based digital map platforms such as Google Maps and Microsoft Bing Maps are developed to provide the service of image query. However, the returned image is only based on the location specified by users, e.g., longitude and latitude. The image without considering the shooting time cannot benefit us to understand the impact of a disaster event. Compared with such images, the abstract geospatial information is more satisfied with users' expectations and needs. Hence, Remote Sensing Images (RS-Images) are widely recognized as an essential type of geospatial information to offer abundant and instantaneous ground truth information. Google Maps provides a realistic illustration about the ground truth by using RS-Images to increase users' interests during their visual browsing process. Besides, the continuously produced RS-Images have been successfully used to monitor that how reality changes over time, e.g., assessing the damage after a natural hazard strikes (Tralli et al., 2005). A survey completed by NASA RSD in the year of 2012 indicated there have been already more than 60 categories of RS-Image are widely used in a variety of applications. Because satellite-based RS-Images are now produced on a regular basis, the accumulated volume of RS-Images has been growing in an extra-overwhelming speed in recent years. However, when the number of candidate images becomes overwhelming and keeps on growing, the image selection is no longer an easy task and the visual browsing approach also becomes impossible. Therefore, the main

* Corresponding author. Tel.: +886 6 2757575 63837.
E-mail addresses: junghong@mail.ncku.edu.tw (J.-H. Hong), zeal0820@gmail.com (Z.L.-T. Su), luhc@nttu.edu.tw (E.H.-C. Lu).
URL: http://www.geomatics.ncku.edu.tw/staff-1.php?view=junghong&lang=en (J.-H. Hong).

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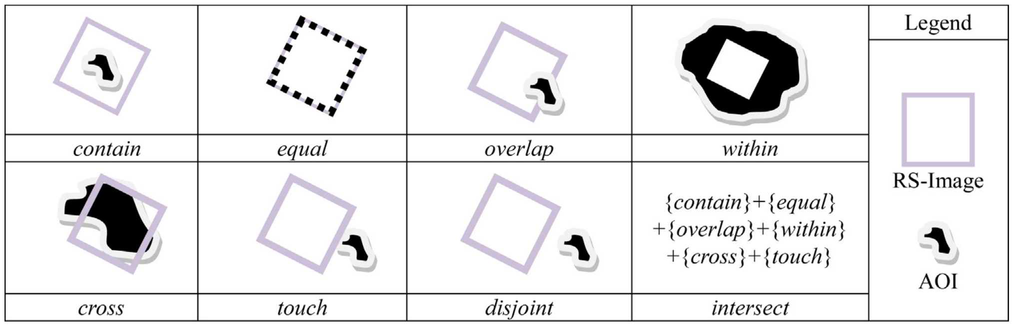
Table 1
Relationships between RS-Image and AOI.



challenge is to retrieve images that best meet users' demands and constraints.

The recent progress of web-based search engine has made users to intuitively expect that everything can be "searched" and "accessed" via the Internet. There are four capabilities for the popular search engines like Google, Bing and Yahoo: (1) Data Collection; (2) Data Analysis; (3) User Interest Specification; and (4) Search Result Presentation. While we are amazed by the tremendous number of qualified homepages the search engine returns, we seldom really browse all the returned results. Instead we prefer the search engine to "rank" the results based on how "close" their contents are with respect to the given constraint, such that we can only browse those homepages with higher rankings and ignore those with lower rankings. For example, Google uses the "Page Rank" technique to rank the qualified homepages before responding to the users. However, the knowledge for ranking text-based data is hard to be directly applied to the image-based counterpart due to the natural feature of them is totally different. Similar to the ranking of text-based homepages, the RS-Images distributed in the Internet must also be searched and "ranked" for users' further reference. Although a number of previous studies have been proposed for RS-Image ranking, most ranking studies are only based on the semantic relations or location distance of special event. Such ideas are inappropriate rank RS-Images since both of the RS-Image and queried Area-of-Interest (AOI) have not only location information but also the cover range information. Only considering the spatial information on RS-Image ranking may not be satisfied by users. Users' constraints for RS-Image retrieval can be generally subdivided into two major phases: (1) Determining the acceptable types of RS-Images; and (2) Filtering RS-Images based on the geographic conditions. A spatial search of RS-Image typically starts with users specifying their AOI. In the first phase, the scopes of RS-Images are narrowed down by checking the RS-Image metadata such as acceptable range, pixel resolution and spectrum. This type of constraint is totally dependent on the tasks at hands and the hardware specification of the RS-Image sensors. In the second phase, the constraints switch to the issue of "where". When an enormous number of RS-Images fulfill both types of constraints, the browsing order for the qualified RS-Images must be considered. Depending on users' application needs, the geometric representation of AOI can be modeled either by commonly used spatial data types such as point, curve and polygon, or complex data types like multi-curves or multi-polygons which has been defined in the international standards ISO19107 and ISO19136 to simplify the processing of geometric calculation among different systems. From a spatial perspective, the spatial extent of every qualified RS-Image must hold certain topological relationships with the AOI. Table 1 illustrates the possible scenario between an RS-Image and the AOI using the 8 topological relationships defined in OGCSFS. Based on the presumption that the AOI must be visible in the selected RS-Images, seven topological relationships (except "intersect") can be further subdivided into three distinct categories according to the intersection status between the interiors of AOI and RS-Image:

1. $\text{Interior (AOI)} \cap \text{Interior(RS-Image)} = \varnothing$. This category denotes the situations where no intersection exists between the interior of the AOI and the interior of the RS-Image. The relationships belong to this category, "disjoint" and "touch", are clearly not qualified and can be directly excluded during the filtering process.
2. $\text{Interior(AOI)} \cap \text{Interior(RS-Image)} \subset \text{Interior(AOI)}$. RS-Images belong to this category can only cover a portion of the AOI and need to be combined with other RS-Images to fulfill users' application needs. The relationships belong to this category, "overlap", "cross" and "within", are therefore included only when necessary. RS-Images belong to this category are given lower priority because a single RS-Image cannot provide a complete coverage of the AOI.
3. $\text{Interior (AOI)} \cap \text{Interior(RS-Image)} = \text{Interior(AOI)}$. The intersection result of this category is the entire interior of the AOI, meaning the AOI is completely covered by a single RS-Image. This category of relationships, "equal" and "contain", clearly denotes the best selection of RS-Images and should be given higher priority for further evaluation. By comparing the two relationships, "contain" is a preferable choice because it can provide additional neighboring information about the AOI than "equal" does. Meanwhile, RS-Images with AOI located near its center are also preferred because of the less effect of building blocking and relief displacement.

Based on the above discussion, three ideal conditions for suggesting "preferred" RS-Images are summarized as follows: (1) The coverage of a single RS-Image "contains" the spatial extent of the AOI, (2) The RS-Image can provide additional neighboring information as much as possible, and (3) The AOI is located as near as possible to the center of the RS-Image. In this paper, we propose a novel framework named *Location-based rs-Image Finding Engine* (*LIFE*) for ranking and recommending a series of relevant RS-Images to users according to users' queries AOI. In *LIFE*, we first propose a cluster-based RS-Image index structure to efficiently maintain the large amount of RS-Images. Then, two quantitative indicators named *Available Space* (*AS*) and *Image Extension* (*IE*) are proposed for scoring and ranking of each RS-Image according to a user-specific AOI query. Both of *AS* and *IE* represent the mathematical formalizations of users' behaviors of RS-Image selection. *AS* and *IE* measure the *Extensibility* and *Centrality* of queried AOI for a RS-Image. The ranking strategies and deficiencies of *AS* and *IE* are analyzed by a series of statistics based on different aspects. Through an extensively experimental evaluation, we show that the proposed *LIFE* framework delivers an excellent performance in terms of recommendation quality. To our best knowledge, this is the first work on RS-Image recommendation that considers the issues of *extensibility*