FEASIBILITY OF IMAGE PROCESSING TECHNIQUES FOR LAKE LEVEL EXTRACTION WITH C-BAND SRTM DEM

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ABSTRACT

Lake studies play an important role in water management, ecology, and other environmental issues. Typically, monitoring lake levels is the first step on the lake studies. However, for the Prairie Pothole Region (PPR) of North America having millions of small lakes and potholes, on-site measurement for lake levels is almost impossible with the conventional gage stations. Therefore, we employed Geographic Information System (GIS) and remote sensing approach with the Shuttle Radar Topography Mission data to extract lake levels. Several image processing techniques were used to extract lake levels for January, 2000 as a one-time snapshot which will be useful in historic lake level reconstruction. This study is associated with other remote sensing datasets such as Landsat imagery and Digital Orthophoto Quadrangle (DOQ). In this research, firstly, image processing techniques like FFT filtering, Lee-sigma, masking with Canny Edge Detector, and contouring were tested for lake level estimation. The semi-automated contouring technique was developed to accomplish the bulk processing for large amount of lakes in this region. Also, effectiveness of each method for bulk processing was evaluated.

KEY WORDS: image processing, SRTM, FFT, Lee-sigma, canny edge detector, contouring, filtering

1. INTRODUCTION

Image processing in the remote sensing approach is the major concern in detecting features that operators want to extract. For spectral imagery, various band combinations provide different features or properties for the objects we are interested in. Extracting feature properties from the remote sensing data is not an easy process because several noise and errors are typically involved. Due to these reasons, selecting or developing algorithms for optimized image processing techniques depends on data processing operators.

For hydrologic applications, lake levels are important because hydrologists usually have an insight for the neighboring environment simply by looking at lake levels, typically a series of level changes or levels at a specific time. The current limitation of the remote sensing approach is the difficulty of acquisition of water levels. Many scientists developed algorithms for water level detection and one of good methods is using the altimetry technique. For hydrologists, however, the altimetry technique has been difficult to employ for water levels. Access to altimetry datasets is very limited to those who are not involved in the group of a project team or a special user group.

However, the Shuttle Radar Topography Mission (SRTM) data is available for all public domains. The dataset can be characterized by the accessibility, availability, consistent accuracy, and global coverage. Because topography is one of the most important data in hydrologic applications, the SRTM data can be used for various purposes typically in hydrology. However, the SRTM data had a few problems. First, the old version of the SRTM data called Version 1 SRTM data has great amount of water-type noise (Bhang and Schwartz, 2008) due to no or small amount of radar return over water surface (dielectric property of water) so that lake elevations were not properly represented as constant values or represented as voids with no elevations. Also, 1.5 m of the identified bias by Bhang et al. (2007) was not reflected to the newer version of SRTM data (Version 2 SRTM data). This caused large differences in identifying lake levels from the datasets.

This paper dealt with the processing techniques to extract water from the SRTM C-band data. These techniques were mainly focused on water-type noise reduction. Also, we evaluated lake level extraction techniques. The measure of the techniques included accuracy of resulting lake levels, processing time, and easiness of methods during the processing. This study used a few remote sensing images and discussed the accuracy of each technique for hydrologic applications.

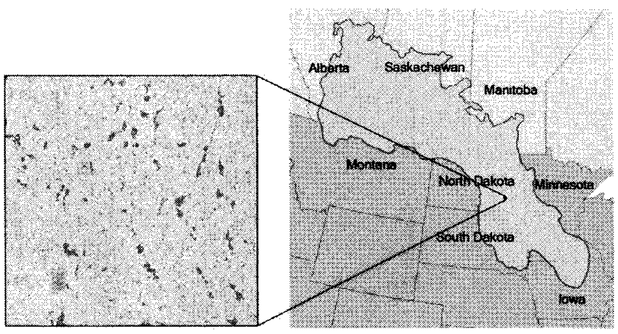

Figure 1 Small dots on the left image indicates all potholes and lakes in the corresponding area on the right image. The blue line boundary on the right map portrays the Prairie Pothole Region of North America.

2. STUDY AREA

The study area is a part of the Prairie Pothole Region (PPR) of North America and located in Otter Tail County, MN, USA. This area is characterized by millions of potholes and lakes so conventional measuring approach for lake levels is practically impossible.

3. METHODOLOGY

The techniques introduced in this paper were categorized into two groups. The first group (Group A) has Fast Fourier Transform (FFT) and Lee-Sigma methods and the second group (Group B) includes Canny Edge Detector (CED), contouring, and masking. The first group is an existing methods frequently used in image processing. The second group were modified and developed with other existing methods.

3.1 Datasets

Several datasets were used for the lake level extraction. The SRTM data was the primary dataset for lake level extraction. The dataset was acquired by the cooperation of NASA, Italian, and German Space Agency on January 2000 and published in late 2001 after data processing. The data are known to be the most complete global topographic dataset covering 60°N ~ 58°S with consistent accuracy. Additionally, Landsat imagery was used for water coverage extraction. The water coverage, however, is currently available in the SRTM database provided by USGS. To measure the accuracy of water coverage derived from Landsat, we used Digital Orthophoto Quadrangle (DOQ) with 1 m resolution.

3.2 Fast Fourier Transform (FFT)

FFT is a well-known filtering method in noise reduction. Typical usage for reduction of the water-type noise is the high-pass filtering. The filtering returns smudged resulting image reducing small fluctuation due to noise. The FFT processing for the water-type noise reduction in the SRTM data can delete small fluctuations over land area.

3.3 Lee-sigma filtering

Lee-sigma filtering was developed for reduction of speckle noise in SAR imagery. This method uses statistics to smooth specific size of noise. Firstly, the algorithm calculates the overall statistics such as mean and standard deviation and then according to the user defined kernel, the kernel window scans the whole image and changes the pixel values by replacing the local statistics in the kernel window with the global statistics acquired from the image itself. By defining the kernel size, the effect of smoothing varies. In this study, we used a variety of kernel size from 3× 3 to 50 × 50 pixels and showed the result with the 7 × 7 window in a diagram.

3.4 Canny Edge Detector (CED)

The algorithm searches the maximum gradient of pixel values and set one for largest gradient pixels and zero for others. The specific detail is beyond the scope of this paper. The search results were relatively good to other line detection methods. This algorithm depends on operator's insight or experience in detecting details of boundary lines of features because operators should input a few parameters to obtain the best results.

3.5 Contouring

The framework of the method was based on the assumption that the water-type noise over water does not exist on lake shores because lake shores are typically bare ground. The procedure of the method is first calculated the possible lake elevation range from the clipped lake elevations. The clipping was conducted with the classified Landsat water coverage. Then, from the elevation range, a single level of contour was delineated from the minimum value in the range and the contour level was added at a specific interval of contours, for example, in this study, the interval was set up as 0.5 m. This contour lines were cleaned up except a target contour. Area and perimeter of the contour which a lake in the given contour coverage were calculated. Then, they are plotted in a graph representing contour level and area/perimeter vs. contour level. Due to the noise around contours, area and perimeter have not perfectly clean in lake shape (Figure 2a and b) so that lake boundaries with noise were very noisy and meandering. Therefore, perimeters become longer and area smaller than the actual lake size/perimeter (i.e. Area and perimeter in Figure 1a and b for the given lake are shorter and longer than them in Figure 1c and d, respectively.). Using these properties, the graph could determine the optimized lake boundary with a lake level. This process is programmed and determined by computer.

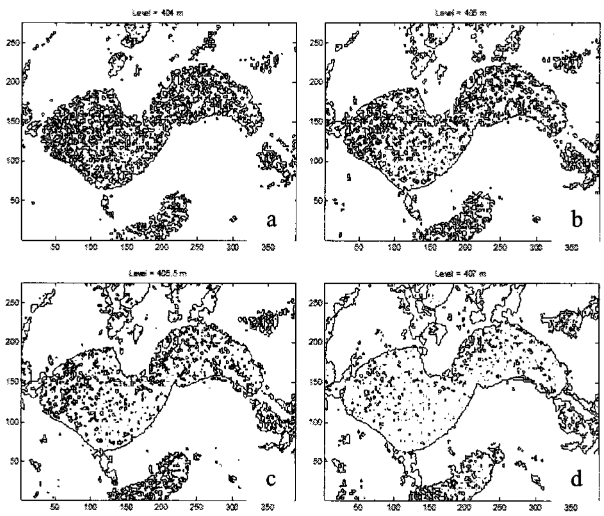

Figure 2 Contours at (a) 404, (b) 405, (c) 405.5, and (d) 407 m

3.6 Masking

The Landsat lake boundary coverage was used to generate masks for lake boundaries. The boundary masks were used to extract lake boundary elevations. Also, the boundary by the Canny Edge Detector (CED) used to reduce discrepancy among boundaries of the SRTM data and Landsat-derived water coverage. The extracted boundary elevations, then, was counted so that each elevation value was sorted and counted. The maximum count was selected and determined as a lake level.

3.7 Efficiency Test

To measure the efficiency among the methods, we checked accuracy, processing time of each method, and convenience to use.

4. RESULTS

We investigated two different groups of processing methods. Each method in Group A showed similar results in lake level difference (Figure 3a). Typical difference for large lakes greater than 20 km^2 was 1 m. Small lakes less than 20 km^2 were significantly fluctuated, which means that larger lakes have rather a fixed bias than smaller lakes. This indicated that larger lakes can be adjusted simply by adding 1 m to the resulting lake levels. Figure 1b shows the result for Group 2. Lakes larger than 15 km^2 were similar to the Group 1 case. For others, however, the difference between real gage readings and estimates by Group 2 were positively biased.

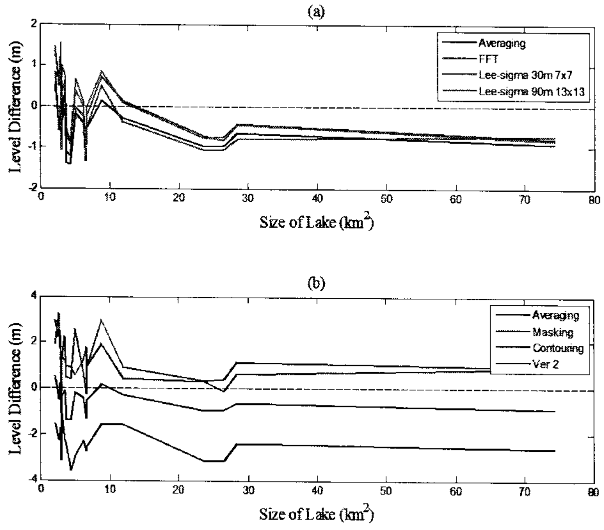

Figure 3 Differences of lake levels in each group, (a) Group 1 and (b) Group 2.

Even though the level differences between two groups were significantly different, the pattern of fluctuation seemed very similar. We suspected that this fluctuation pattern was correlated with lake size. Because Group A used all elevation values to estimate lake levels (i.e. smoothing), noise elevations in lakes can actually affect lake levels. For example, because larger lakes have more chances that the fluctuating elevations can be cancelled out one another, the elevation fluctuation due to noise does not significantly affect the lake level estimates. On the other hand, smaller lakes are relatively small enough so that small number of noise (i.e. hills and pits) can fully occupy each lakes and dominant noise (hills or pits) can cause to have biased lake levels..

For Group 2, the level difference was produced by the search algorithm for contours. Because the methods in Group 2 were mainly involved with the boundary search along which there was less noise (clean boundaries rather than meandering ones), the processing led the algorithm to use rather higher elevation values, thus, resulting boundary elevations did not represent the best levels.

In terms of effectiveness, we measured processing time. However, we used different software for each processing because software does not include all functionality requiring for each processing. Erdas Imagine was used for FFT and Lee-Sigma and also test in Matlab, ArcGIS for contouring, and Matlab and ArcGIS for CED. FFT and Lee-Sigma filtering were relatively faster than any other software platform such as Matlab based on our test. In fact, Matlab had a memory problem with the FFT processing and required a large physical memory space. Contouring method showed actually the best results but its processing time was too expensive. To extract one lake level, the approximate processing time was 15 minutes on our test. However, the processing time could be significantly reduced to the second level of time if the input coverage of DEM is reasonably small. Note that we used a 1 x 1 degree tile as an input coverage of DEM. The CED scheme seemed to be very an ineffective method but the processing itself for CED spent just a few seconds to extract the lake boundaries. The CED scheme included boundary extraction and masking so that total processing time was the longest among the methods used in this study.

The results were also compared with the Version 2 SRTM data (Figure 2b). The main difference between our estimates and the Version 2 SRTM data is that we fixed the 1.5 m bias problem introduced in Bhang et al (2007) in our processing. In fact, if the bias is reflected to the Version 2 data, the estimates of the data are similar to ours but our estimates were still slightly better than the Version 2 estimates.

5. DISCUSSION

We confirmed that the FFT or Lee-Sigma filtering can be easily used with the bias correction of the SRTM data for hydrologists. Because FFT is typically easy to implement with other programming language, the public domain users can conveniently program or obtain source codes for FFT. In terms of accuracy, both group showed similar accuracy level so that considering data processing, FFT might be the best one. However, depending on what they need, the selection of method can be the operators choice. The resulting accuracy for each method may not be satisfied but considering the local bias, the estimates can be useful for hydrologic applications.

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