Image Segmentation Applied To Satellite Imagery For Monitoring Water In Lakes And Reservoirs

Image segmentation applied to satellite imagery for monitoring water in lakes and reservoirs

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Abstract
Here we show that a method of image processing, an image segmentation recently developed and used for the analyses of micrographs, can be applied to the monitoring of the water in lakes and reservoirs by means of the related satellite imagery. The image segmentation allows measuring surfaces and perimeters of the inundated basins. Here the segmentation is applied to the Sarygamysh Lake in Central Asia.

The monitoring of rivers, lakes and reservoirs is fundamental for meeting the human need of water and for assessing ongoing climatic changes [1]. This monitoring can locate quickly the problem of regional droughts as well as help in the estimation of the crop production for the regions that are downstream from the monitored lakes and water reservoirs. Of these basins, the inundated surfaces and the time variations of their extent can be easily evidenced by the satellite imagery, as we can see, for instance, by means of Google Earth and its time-series of images. In addition, the data of the heights of several large lakes around the world are available publicly from the web site of the United States Department of Agriculture [2], which is providing the related radar altimeter data. In [3], for instance, we used these altimetric data for studying the behavior of some lakes in Africa (Nasser, Tana, Chad and Kainji) by means of recurrence plots.

As stressed in [4], the presence of large reservoirs along rivers can be used to generate hydropower and to store water for irrigation and for the needs of urban areas. For this reason, the reservoir managements are critical, particularly for trans-boundary basins, where coordination between riparian countries is necessary [4]. This is especially true when the water resources are shared between countries having potentially opposite interests. Moreover, in the case of semiarid regions, it can happen that the downstream users of water "may be totally reliant on upstream reservoir releases". The research in [4] is considering the example of the Syrdarya river in Central Asia, giving remote sensing data from radar altimetry and optical imagery, to highlight the importance of satellite data for the monitoring of water resources.

Other researches on the subject are given in [5-20]. Among these references, we find works on specific regions and on global scale. For instance, in [5], the researchers have investigated the Pantanal wetland in South America, using radar satellite imagery. In [6], the remote sensing for long-term monitoring is considered for the study of climatic change; the research is concerning a technique, which derives the lake level changes from TOPEX/POSEIDON geophysical data. In [8], measurements use the chlorophyll-a (chl-a) concentration in lake water, which can be monitored with airborne (or space-borne) optical remote sensing instruments. In [20], it is shown that bands 6 and 7 of the MERIS spectrometer allow the detection of cyanobacteria, if they are present in relatively high quantities. Actually, cyanobacterial blooms can present treatment problems of water and hazards to human and animal health.

The use of images from space for monitoring lakes was discussed also in [21-24], for the case of the Toshka Lakes and the Merowe reservoir. In both cases, it is the water of the Nile being involved. In the case of the Toshka lakes, the water of the Nile is conveyed from the Nasser Lake through a canal in the Toshka Depression. From space, the astronauts of the International Space Station noticed the growing of a first lake, the easternmost one, in 1998. Then additional lakes grew in succession due west, the westernmost one between 2000 and 2001. The satellite images showed that, from 2006, the lakes started shrinking. Today, we can easily see the evolution of the Toshka lakes in the time series of Google Earth. Let us note that, as stresses in [25], water management models are fundamental for the future of the Toshka depression. The same is true for other lakes, like Lake Urmia for instance [26,27].

Besides the Toshka and Urmia Lakes, another striking example (the most popular one) of the human influence on the environment is the Aral Sea, formerly one of the four largest lakes in the world [28]. The Aral Sea has been shrinking since at least 1850, although with some interruptions. "Early in the 20th century, the shrinking was blamed on the rate of evaporation exceeding the rate of inflow; … Shrinking has accelerated since the 1960s after the rivers that fed it were diverted by Soviet irrigation projects. … Satellite images taken by NASA in August 2014 revealed that for the first time in modern history the eastern basin of the Aral Sea had completely dried up. The eastern basin is now called the Aralkum Desert" [28,29].

Approximately midway between the Caspian Sea and the Aral Sea, it is situated the Sarygamysh Lake [30]. Today, the main source of water of Sarygamysh Lake is a canal from the Amu Darya. Some water from the surrounding irrigated lands is also feeding the lake [30]. This lake "and many other "unintended" lakes, such as Aydar Lake on the Syr Darya" [30] are receiving the water that in the past was flowing in the Aral Sea. Here we use the Sarygamysh Lake for applying an image segmentation, recently developed and used for the analyses of micrographs [31-39], to the satellite imagery for monitoring water in lakes and reservoirs. The segmentation is based on a thresholding, which is converting the input image into a black and white one. Then, the black and white image is "segmented" in order to find the black domains and measure their area and perimeter.

First, let us consider three satellite images from Google Earth, here shown in the Figure 1.

Figure 1: The Sarygamysh Lake in three images from Google Earth.

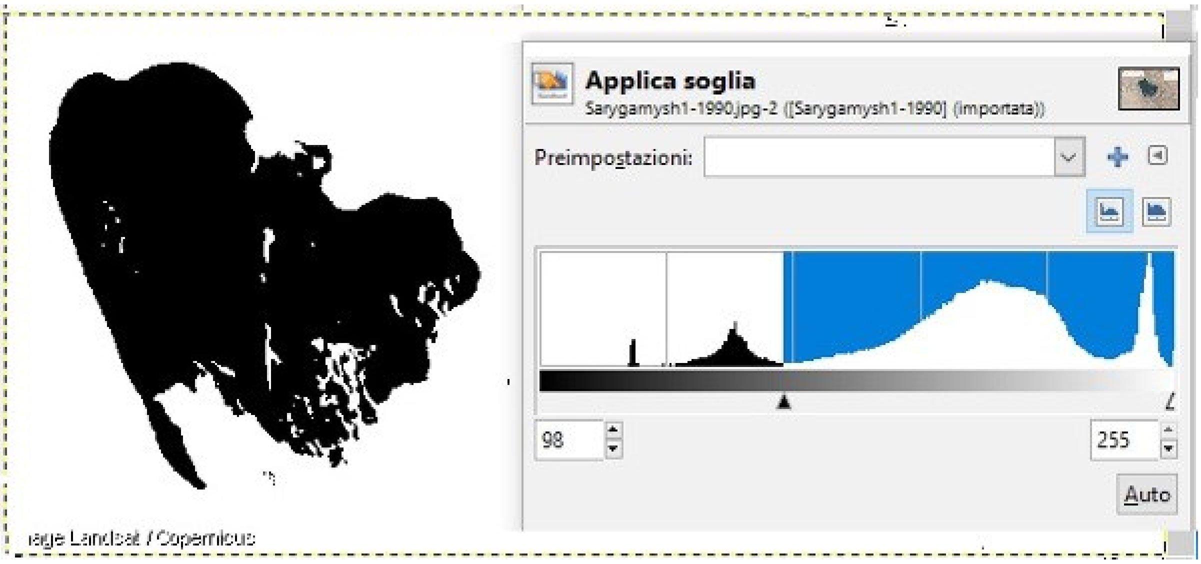

Figure 2: Thresholding of an image, to render it in a binary (black and white) image, obtained by means of GIMP, the GNU Image Manipulation Program.

Figure 3: The binary images obtained from the images in Figure 1.

Each of the images is thresholded by means of a visual inspection of the histograms of the corresponding gray-tones. An example of thresholding in given the Figure 2 for one of the images in Figure 1. The best choice of the threshold is given by a gray-tone value between two peaks of the histogram.

After the thresholding, we have the binary images in the Figure 3. Applying the segmentation proposed and discussed in [31-39], we obtain areas and perimeters of the "segments", which are the black domains. The three largest segments in the image are representing the inundated surfaces of the lakes for years 1990, 2000 and 2015.

The processed image, like that shown in the Figure 3, was 801 x 280 u^2, where u was the size of its square pixel. The first domain on the left has an area of 30769 u^2 and perimeter 1713 u long. In the middle, the domain has an area of 35299 u^2 and perimeter of 1053 u. On the right, we have the domain having the largest area, 37225 u^2, and the smallest perimeter, 926 u. It means that from 1990 to 2015, the inundated surface had increased of about 21%. It is also easy to have a correspondence between the size of the pixel and the meters on earth’s surface. In the case of Google Earth, the software is providing a ruler for measurements, and also elevation profiles (an example is given in the Figure 4). In the case of the Figure 3, u corresponded to 333 meters. Therefore, the surface of the lake passed from 3412 km^2 to 4128 km^2 in 25 years.

Figure 4: An elevation profile of Sarygamysh Lake that we can obtain by means of Google Earth.

Actually, the date of an elevation profile, as that shown in Fig.4, is not given. Moreover, it seems not possible to have a time-series of elevation profiles. For this reason, an estimate of the variation of the volume of water in the basin is not immediate.

Here we have shown that an image segmentation, which has been developed and used for the analyses of micrographs [31-39], can be applied to the monitoring of lakes and reservoirs. After a thresholding of the satellite images, surfaces and perimeters of the inundated basins can be measured. The proposed approach has been applied to the Sarygamysh Lake in Central Asia.

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