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Interface development for depth level compute in water zones through bathymetry (TOLTECA)

Desarrollo de una interfaz para el cálculo de los niveles de profundidad en cuerpos de agua a través de batimetría (TOLTECA)

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Abstract

Bathymetry is a method of quantifying depths to study the topography of water bodies, including oceans, seas, rivers and lakes. The measurement of bathymetry by means of satellite images is one of the fundamental investigations in the field of remote sensing (RS) of marine environment, which has a lot of applications for the coastal environment and its monitoring. The precise determination of depth water is essential for various purposes, such as the monitoring of underwater topography, the movement of deposited sediments and the production of maritime maps for navigation. Remote sensing allows the bathymetry modeling at spatial scales that are impossible to achieve with traditional methods. Bathymetry can be estimated using RS with several techniques, each with its own capacity for depth detection, accuracy, error, strengths, advantages, disadvantages and the best application environment. Before that, a GUI interface is developed in Matlab that contains enough data to be able to compute the bathymetry in multispectral images from the satellite LANDSAT 8, with the intention of being able to analyze how flooded an area will be.

Bathymetry, Multispectral image and flooding

Resumen

Batimetría es un método de cuantificación de profundidades para estudiar la topografía de masas de agua, incluidos océanos, mares, ríos y lagos. La medición de la batimetría mediante imágenes de satélite es una de las investigaciones fundamentales en el campo de la percepción remota (RS) del entorno marino, que tiene numerosas aplicaciones prácticas para el medio ambiente costero y su seguimiento. La determinación precisa de la profundidad del agua es esencial para diversos fines, como el monitoreo de la topografía submarina, el movimiento de los sedimentos depositados y la producción de mapas marítimos para la navegación. La percepción remota permite el modelado de batimetría a escalas espaciales que son imposibles de lograr con métodos tradicionales. La batimetría se puede estimar utilizando percepción remota utilizando varias técnicas, cada una con su propia capacidad de detección de profundidad, precisión, error, fortalezas, ventajas, inconvenientes y el mejor entorno de aplicación. Ante eso se desarrolla una interfaz en Matlab que contenga los datos suficientes para poder realizar el cálculo de la batimetría en imágenes multiespectrales provenientes del satélite LANDSAT 8, con la intención de poder analizar el grado de inundación de una zona.

Batimetría, Imágenes multiespectrales e inundaciones

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Introduction

The use of technology today is the most valuable tool to deal with different environmental problems. For instance, national, state and municipal organizations, which are water resource managers, need to obtain information on the volumetric behavior of water. Likewise, it is useful for the study or prevention of floods, so as to ensure making the best decision as soon as a problem occurs with rains or floods, without affecting the ecological and social environment. Due to the visible changes in the volumes of water in the country that has caused several effects, such as the increase in the area of lagoons and in some cases the rise on the creation of lagoons and wetlands, it is estimated that the monitoring of these changes is carried out only 10% by government institutions, especially for knowledge of water depths or levels. Given this, it is very important to carry out studies of multispectral images obtained from remote sensing (RS) systems, this with the idea of processing, improving and classifying them for future disaster prevention. The use of image processing techniques will help conduct better research and have the possibility of preventing disasters at some time due to increases in water levels.

There are multiple projects, investigations or works in which they mix image processing, image segmentation and even spectral indexes. A first work corresponds to Szabó (2016) who in this paper studies three spectral indices: Normalized Different Vegetation Index (NDVI), Normalized Different Water Index (NDWI), Modified Normalized Different Water Index (MNDWI), where they were investigated from the aspect of the types of land, bodies of water, forests, land plows, grasslands and urbanized areas using Landsat 8 system data.

A second work by Stumpf (2003) develops a solution for the standard bathymetry algorithm to determine the depths in clean water. The previous algorithm obtains water depths of less than 10-15 m, while the transformation algorithm can obtain depths in 25 m of clean water.

Said (2017), explains in his article the development of the acquisition of bathymetric data through the satellite-derived bathymetry technique (SDB).

It is a spatial acquisition technique that extracts bathymetric data from high-resolution multispectral satellite images for various purposes and recently it has been considered as a promising new technology in the hydrographic surveying industry.

However, all the previous investigations still have room for improvement, since they have not yet been able to completely measure the depths in bodies of water and for now only measurements are made in bodies of water of greater depths. For this reason, the present work has the design of an interface in Matlab for the measurement of depths in water bodies and the use of algorithms such as NDVI, NDWI, NDSI and satellite-derived bathymetry mentioned by McFEETERS (1996), which makes a great contribution to the state of the art.

Methodology

Satellite images of the LandSat 8 satellite platform available from the United States Geological Survey (USGS) were acquired, between 2015 and 2018, the downloaded images correspond to the different bands shown in Table 1 for the Landsat 8 satellite system, downloaded images from (USGS-US Geological Survey).

LANSAT 8		
Bands	Bandwidth (μ*m*)	Resolution
Band 1 Coastal	0.43 a 0.45	30
Band 2 Blue	0.45 a 0.51	30
Band 3 Green	0.53 a 0.59	30
Band 4 Red	0.64 a 0.67	30
Band 5 NIR	0.85 a 0.88	30
Band 6 SWIR1	1.57 a 1.65	30
Band 7 SWIR2	2.11 a 2.29	30
Band 8 Pan	0.50 a 0.68	15
Band 9 Cirrus	1.36 a 1.38	30
Band 10 TIRS 1	10.6 a 11.19	100
Band 11 TIR 2	11.5 a 12.51	100

Table 1 Bands of LANDSAT 8 Markham

The files downloaded from the USGS consist of a total of 11 bands, each with a different bandwidth and spatial resolution. They also have a metadata file, which contains information necessary for the systematic and practical search of data files, and also explains the essential characteristics of the data to be processed as radiance and reflectance, as well as the position of the sun during capture of the images.

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The block diagram of Figure 1 describes the methodology used in this investigation.

1. Multispectral images

As a first step, we have the acquisition of multispectral images; this is where we get all the bands necessary to develop the established algorithm.

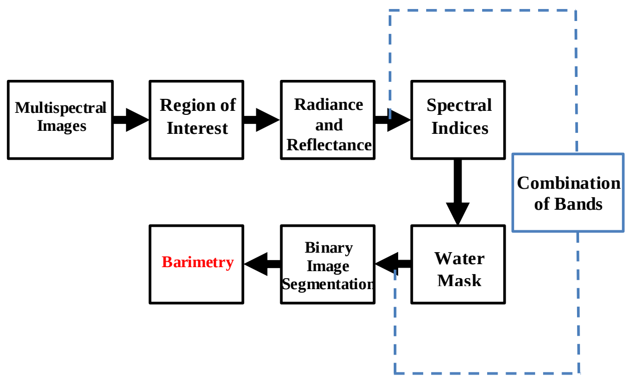

Figure 1 General block diagram

2. Region of interest

The second step is to choose or select the region of interest in which the bathymetry will be used as mentioned in Gonzalez (2007).

3. Radiance and Reflectance

The third step is to apply the radiance and reflectance equations to each of the bands. This is with the intention of calibrating the digital levels of the pixels from the metadata information, which represent the data of the multispectral images, as I investigated (Chavez, 2010).

4. Spectral Indices

The fourth step is to generate the spectral indices (NDWI, NDVI and NDSI) from the calibration of the reflectance of each of the bands.

The NDWI index (Normalized Difference Water Index) has been widely used for the remote detection of bodies of water as the study by (Gao, 1996). The NDWI can improve water information effectively in most cases. It is sensitive to built-up land and often results in overestimated bodies of water, Szabó (2016).

The NDWI is expressed as follows according to McFEETERS (1996).

$$NDWI = \frac{G-NIR}{G+NIR} \quad (1)$$

In equation 1, G is the reflectance in the visible green channel, which is Landsat band 3, and NIR is the near infrared channel spectral reflectance is Landsat band 5.

Probably the most used index to assess the state of the vegetation is NDVI (Normalized Difference Vegetation Index) which is defined as shown below:

$$NDVI = \frac{NIR-R}{NIR+R} \quad (2)$$

In equation 2, R is the reflectance in the visible red channel, which is Landsat band 4, and NIR is the near infrared channel spectral reflectance and is Landsat band 5.

The Normalized Difference Snow Index (NDSI) is a normalized proportion of the reflectance difference in these bands that takes advantage of the exclusive signature and spectral differences to identify snow from surrounding features including clouds. The equation for the NDSI is:

$$NDSI = \frac{G-SWIR}{G+SWIR} \quad (3)$$

In equation 3, G is the reflectance in the green channel of the visible one, which is Landsat band 3, and SWIR is the spectral reflectance of the middle infrared channel and is Landsat band 6.

5. Water Mask

The spectral indexes are not good water discriminators, for that reason a water mask is created due to the need to extract the bodies of water from the scene, as in Edrosa (2014).

To improve their discrimination of coverings with different reflective behaviors, such as those of vegetation, soil and water, an auxiliary RGB image called "NDXI" or "Image of indexes" was constructed. The generation and application of a permanent water mask is due to the need to extract with it the bodies of water that have a spatially stable distribution over time, and thus we are able to observe the data set only with water.

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The methodology of Figure 2 reduced the volume of information, and discriminated the coverage mentioned.

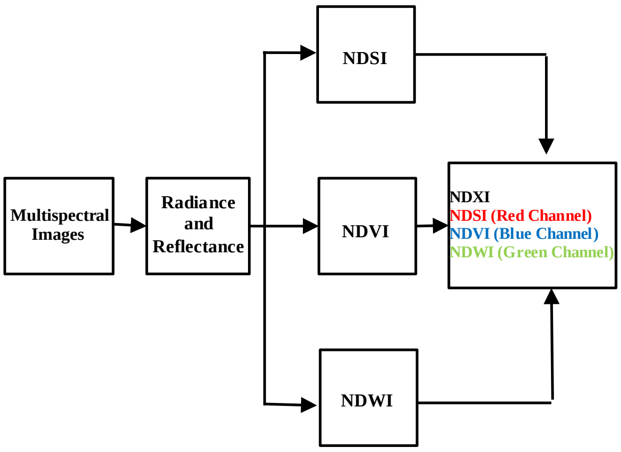

Figure 2 Generation of water masks through spectral indexes

The use of the NDXI image helped to identify the coverage of interest (in this case "water" and "no water") by means of a composite analysis of optical interpretation plus an analysis of the spectral responses of the indices.

6. Binary Image Segmentation

The next step is, from the water mask, to generate a grayscale image as to create a binary image of it, this in order to have only two values: one will represent the areas with water (white, value of one) and the other will be areas that are not water (black, value of zero).

7. Bathymetry

Finally, the next step is to obtain the water depth of any scene through bathymetry. The model developed by Stumpf (2003) applies the fundamental principle that each band has a different level of water body absorption. The different level of absorption conceptually will generate the relationship between bands and this relationship will change simultaneously when the depth is modified. Theoretically, when the ratio increases the depth will also increase. The band with a higher level of absorption will decrease continuously when the depth increases.

According to Stumpf (2003), this logarithmic ratio model is more robust and has demonstrated a more accurate depth estimate especially for shallow habitats with low reflectance.

$$z = m_1 \left(\frac{ln\left(L_{obs}(Band_{blue})\right)}{ln\left(L_{obs}(Band_{green})\right)} \right) - m_0 \qquad (4)$$

Equation 4, helps to obtain the absolute bathymetry for the whole image as mentioned both in (El-Sayed, 2018) and in (Said, Mahmud & Hasan, 2017). Where L_{obs} are the radiance bands, m_1 and m_0 are tunable constants to transform linearly (i.e. scale and displacement). The algorithm results in a plotted depth.

Since with the logarithm the maximum and minimum values of the function become distant, it was decided to maintain the function in a linear manner, so that the depth range is wide to detect areas of low and high depth in the same scenario.

Figure 3 represents the first of three interfaces, which executes the Satellite Derived Bathymetry algorithm in such a way that it shows the levels of water bodies within the scene.

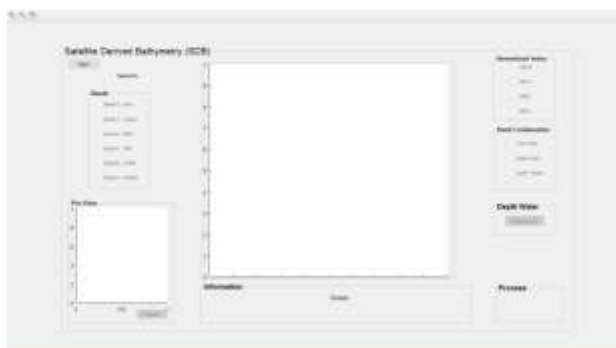

Figure 3 Main bathymetry interface

The interface has a single screen in which the user will choose the path where the images downloaded from USGS with their metadata file are saved. When selecting the file, the program will generate an RGB image so that the user can have a better interaction and choose the ROI (region of interest). In the interface the user can choose to observe each band individually from 2 to 7, visualize the spectral indexes, a combination of bands or see the result of the Satellite Derivative Bathymetry algorithm.

Figure 4 Comparative interface of depth levels

The interface of Figure 4 has a screen divided into two sections, each calculating the Satellite Derivative Bathymetry algorithm. It is divided into two sections to make a comparison between images of the same region, but with different temporal resolution, this to see the changes that were in the depth of the bodies of water.

Figure 5 Flood estimation interface

The interface of Figure 5 has a screen divided into two sections. The reason for the division is to estimate the behavior of a flood.

The interface can work with two scenarios of different temporal resolution or with the same image, since in the process a message will appear to create synthetic images. Similarly, a message will appear saying that there is no flood or a message that says the percentage of flooding within the scene.

Results and Interface

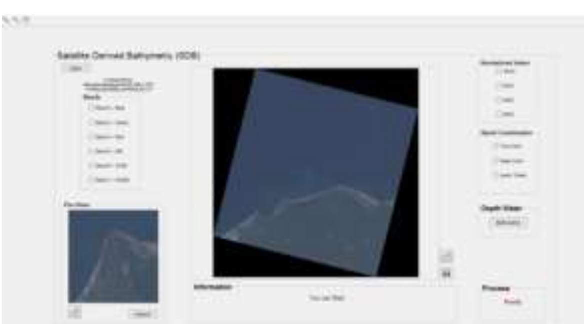

Figure 6 Result of the flood estimation interface

Figure 6 refers to the display of the first interface when the user has selected multispectral images. The RGB image of the original area is displayed in the main window. The region of interest that the user selected is shown in the left side of the lower corner of the window.

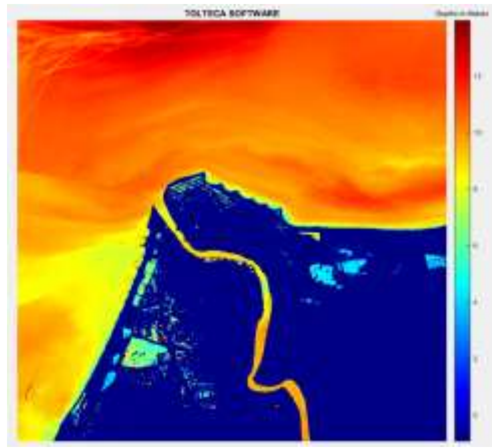

Figure 7 First bathymetry result

Figure 7 shows the final result of the SDB algorithm for the first interface where the ROI image is displayed after preprocessing, processing and having completed the bathymetry equation. The colors within the image show the depth value of each pixel of water and these can be compared in the bar on the right side, which will show the values that those colors will have reflected in meters.

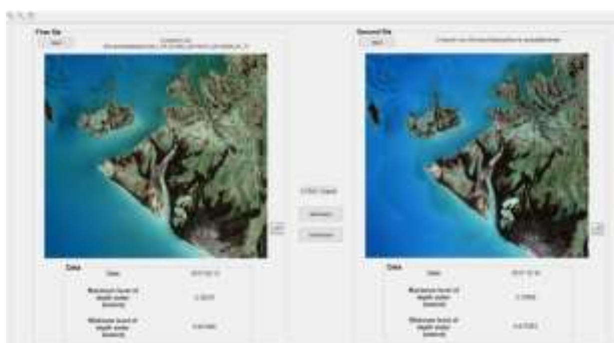

Figure 8 Result of the interface, comparison of depth levels

Figure 8 shows the second interface when the user selected the ROI. In the interface the user will select two multispectral image files, which should have the same spatial resolution but different temporal resolution.

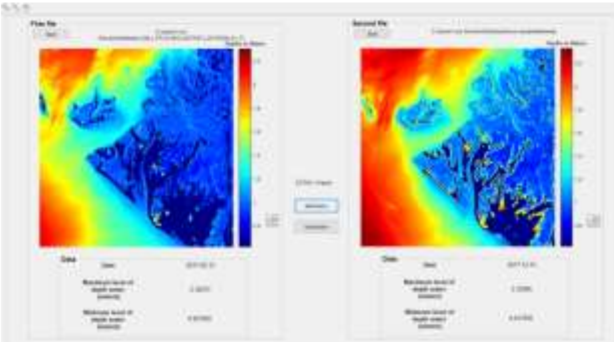

Figure 9 First bathymetry result

Figure 9 shows the images after applying the SDB algorithm in each scene. In each section we have a bar that says the depth value of each color within each file. In the lower part, the maximum and minimum water depth values in each scene appear, in addition to the date they were acquired.

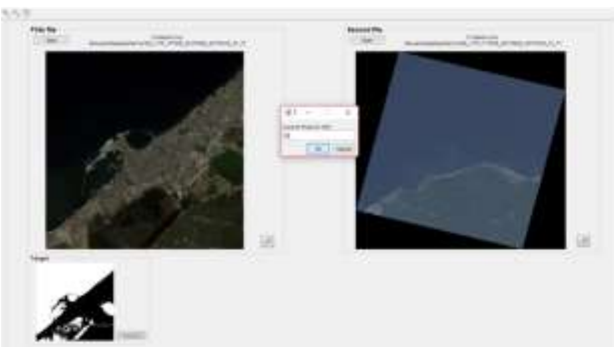

Figure 10 Result of the flood estimation interface

Figure 10 shows how the flood estimation interface is presented from multispectral images. The interface will serve to show a possible behavior of the propagation of water in a flood, we can work with images of different temporal resolution or with the same package of multispectral image files since it is possible to create a synthetic image for its operation.

Figure 11 First result of a flood simulation

Figure 11 shows the process of developing a synthetic image for the visualization of a possible flood behavior. The user has the possibility to make a real comparison between two images with different resolution in which there is one with flood or to be able to create a synthetic image and simulate a flood.

In both ways, the two images will be compared and in order to have a better visualization of the flooded areas they will be painted with a color to highlight the areas vulnerable to flooding.

Conclusions

The use of the standardized spectral indices that were described in the paper provides information for the segmentation of areas of water and vegetation with greater ease. From the segmentation it is easier to perform the calculations of depth levels only in areas of interest, without the need of mapping the entire image. It should be noted that there are multiple variants of the indexes, so each one can provide different benefits over certain images.

The bathymetry algorithm produces visible results very similar to those shown by the different articles reviewed and added as references in the document. For this, relevant adjustments of the parameters for the proposed equations must be made, since in the absence of suitable adjustments they will show results that are not appropriate to what we are looking for. One of the simplest ways to determine the parameters is the use of the linear regression method, in order to determine more precisely if the modifications are the best, a comparison with a gold model (multispectral image with data measured in situ) is required, having the depths of certain bodies of water.

With the designs of the interfaces for bathymetry, it became more user-friendly, since it will be easier to modify variables to the user’s liking and visualize the results in a better way.

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