CAN ASTER-DATA BE USED FOR BATHYMETRIC MAPPING OF CORAL REEFS IN THE RED SEA USING DIGITAL PHOTOGRAFMETRY?

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ABSTRACT

Coral reefs are main contributors to the national income of many developing countries. As they are experiencing more and more stress due to inappropriate human actions and global change, they need to be studied in order to monitor them and preserve them for the future. Bathymetric mapping of coral reefs has always experienced difficulties. Due to their rather shallow depth and/or often remote location in the middle of the ocean, they are not always suitable for standard bathymetric sounding campaigns. Here remote sensing can bring a solution. Different methods have been developed to derive bathymetric information out of remote sensing data. Some methods are based on information gathered by active sensors, e.g. LIDAR; others are based on the different attenuation coefficients of sequencing wavelengths detected by multispectral passive sensors. The aim of this research paper is to examine the possibilities to map bathy-metry of coral reefs using digital photogrammetric processing of stereoscopic ASTER-images. Through-water photogrammetry has already been used for subaqueous mapping, for example by Westaway et al. (2001) and Butler et al. (2002) in close-range river bed surveys using mounted photogrammetric cameras. Due to the refraction of the light on the water surface, calculated depths tend to be underestimated in comparison with the true depth. Westaway et al. (2001) have developed a refraction correction algorithm to deal with this problem. The ASTER stereoscopic data have already proven its usefulness in generating terrestrial DEM’s using the digital photogrammetrical software package VIRTUOZO 3.2. Due to the fact that stereoscopic ASTER – images are only made in the infrared, its application in bathymetric mapping is limited to the upper meters of the reefs. As study area the coral reefs surrounding Big Gifun Island off shore Hurghada (Egypt), are selected. First a DEM is generated in the conventional way. The strict use of absolute ground control points that lay under the water surface, has been proven to be beneficial for the accuracy of the depth estimations. Unfortunately, due to refraction at the air/water interface, an additional shift in X and Y then occurs. Some errors are also occurring after match editing which are distorting the calculated depths. Afterwards the correction algorithm for the two media problem developed by Westaway et al. (2001) has been applied. Although the first, preliminary result presented here, is still subject to some errors, general trends in reef topography can already be noticed. It can be concluded that it is possible to estimate depth of the coral reefs using digital photogrammetry and ASTER data. Further investigation is required for the need of additional adaptation of the refraction correction algorithm to use with ASTER data and the remaining problems with geometric accuracy and the match editing procedure.

1 INTRODUCTION

Coral reefs are not only very interesting ecological formations characterised by a high biodiversity, they are also very important economic resources. As coral reefs are mainly situated in tropical and subtropical regions, they are often main contributors to the national income of developing countries.
Nowadays coral reefs are experiencing more and more stress due to irresponsible human actions and global change. Therefore reefs need to be studied in order to monitor them and preserve them for the future.

One of the elements that form the base for a coral reef monitoring program is a bathymetric map indicating on which depth the corals are situated. Mapping bathymetry of coral reefs has always been a challenge for scientists. Due to the rather shallow depth and/or their often remote location in the middle of an ocean, conventional echo sounding methods are usually inappropriate. Here remote sensing can bring the solution. Many studies have proven already the usefulness of remote sensing for studying coral reefs. Satellite images are used to derive information about the location of the coral reefs (X-, Y- and Z-coordinates), their geomorphology and their condition. Secondly, remote sensing can contribute in monitoring the physical and/or chemical conditions of the seas and oceans where the coral reefs occur.

Different methods have been developed to derive bathymetric information out of remote sensing data. Some methods are using active remote sensing, e.g. LIDAR, to measure depths; others are estimating depth values for coral reefs using passive remote sensing. Most of the conventional methods for mapping bathymetry are based on the correlation between depth and the spectral reflectance measured by the satellite sensor (Benny & Dawson, 1988; Jupp, 1988; Ji et al., 1992; Green et al., 2000; Lyzenga, 1978; Van Hengel & Spitzer, 1991; Vanderstraete et al., 2002; among many others). In this method a lot of additional depth measurements are necessary to make an estimation of depth based on these measured reflectances.

The method presented in this paper uses digital photogrammetry in combination with stereoscopic satellite data registered by the ASTER sensor in order to derive information on depth of the reefs. This offers a reasonably cheap and quick solution for mapping bathymetry in developing countries.

Westaway et al. (2001) and Butler et al. (2002) have already investigated the possibilities of what they called ‘through-water’ digital photogrammetry with close range cameras for applications in shallow gravel-bed rivers. We want to investigate whether the conclusions of Westaway et al. (2001) and Butler et al. (2002) can be extrapolated to calculate coastal depths using satellite derived ASTER-images.

The main problem with ‘two-media’ photogrammetry is the refraction of the light ray when passing through the air/water interface (Figure 1). The rays of light are shifted according to Snellius’ law of refraction:

$$\sin (i) = n \sin (r) \quad (1)$$

With $i$ the angle of incidence of the light ray, $r$ the refraction angle of the light after passing the air/water interface and $n$ the refractive index of the water. For our case where the received ray of light at the sensor is concerned, $i$ can be seen as the angle of emittance at the sea surface.

As can be seen in Figure 1, this refraction is causing an error in depth estimation. It has been demonstrated by Butler et al. (2002) that due to refraction, a point $p$ on the bottom, is viewed as point $p_a$ by the sensor meaning that the apparent surface lays at a shallower depth than the true depth. A refraction correction algorithm has been developed by Westaway et al. (2001) to deal with this error. The basic idea is to derive true depth, $h$, out of the apparent depth, $h_a$, calculated using a common digital photogrammetric software program like VIRTUOZO 3.2. Based on the geometry of Figure 1, the true, $h$, and apparent, $h_a$, depth of water can be expressed in terms of the angles of refracted and incident light (Westaway et al., 2001):

$$h = x / \tan (r) \quad (2)$$
$$h_a = x / \tan (i) \quad (3)$$

Substituting the unknown $x$-value in formula (2) gives:

$$h = (h_a \tan (i)) / \tan (r) \quad (4)$$

or, after deriving $r$ out of formula (1):

$$h = (h_a \tan (i)) / \tan (i/n) \quad (5)$$
Meaning that, provided the angle of incidence, \( i \), is known, the true water depth can be calculated from the apparent water depth (Westaway et al., 2001).

Figure 1: Refraction of the light at the air/water interface and its effect on depth observation by a sensor (after: Butler et al., 2002)

2 METHODOLOGY

2.1 Study area

As study area the coral reefs near Hurghada (Egypt) (27°14’N 33°54’E), situated in the northern part of the Red Sea, are selected (Figure 2). The coral reefs are located in a unique environmental setting: the enclosed Red Sea is completely surrounded by deserts, has almost no water input from rivers and hence very stable physical characteristics such as salinity, temperature and water quality. Although the coral reefs are not under great natural threat, they are suffering from the negative effects of booming tourism and urban coastal development projects mainly for tourist accommodation and in support of the relocation policy executed by the Egyptian government.

2.2 Data sources

2.2.1 Satellite data

An ASTER-image dating from March 21\textsuperscript{st}, 2001, (ID: SC:AST_L1B.002:20002782671) is used for this study. The ASTER satellite is equipped with 2 telescopes that are configured to take stereo-images. These 2 telescopes (bands 3n and 3b) register near-infrared light. Due to this, estimates of depth are restricted to the upper meters of the coral reefs as infrared wavelengths are strongly absorbed by the water. One telescope (3n) is looking at nadir, the other one (3b) looks backwards with an angle of 27.60° compared to the downward looking sensor (Aster Users Guide, 2001). Both images forming a stereo-pair, are pre-processed in such a way that the contrast for both land and sea is optimised in order to get maximum relative orientation point recognition in the VIRTUOZO 3.2 relative orientation module.
2.2.2 Field data

During two field campaigns from August 25th, till August 31st, 2001 and from March 28th, until April 4th, 2002, 420 depth measurements were taken in the surroundings of Hurghada. X- and Y-coordinates were measured using a GPS in the UTM 36 – WGS84 coordinate system. Depth values were derived using hand-held sonar (Manta Dive Ray DR-100) with an accuracy of 0.3m above and 1.0m below 10m.

Unfortunately these depth points are not recognizable on the ASTER-scenes, so they can’t be used as absolute ground control points. Based on these depth values and a LANDSAT7 ETM+ data, using the method of Jupp (1988), a bathymetric map has been calculated (Vanderstraete et al., 2002). On the ASTER-scenes 22 points are selected of which the depth is derived from this bathymetric map. A minimum of six of these points is needed for absolute orientation of the stereo-model.

2.3 DEM extraction

2.3.1 Creating a DEM in VIRTUOZO3.2

Two main problems occur with digital ‘through-water’ photogrammetry.

First, the refraction of the rays of light at the air/water interface will cause deviations in the apparent X-, Y- and Z-location of the bottom compared to the real seafloor (Butler et al., 2002). To deal with this problem, Butler et al. (2002) have selected control points that lie above the surface. They have stated that the use of underwater control points is not improving the final result. If ground control points on land are used in VIRTUOZO 3.2 unrealistic depth values, in the order of several tens of meters above and below sea level, are calculated. So, contradicting to their findings, we conclude that the strict use of ground control points that lay under the water surface is beneficial for DEM accuracy. Out of the total of 22 defined absolute ground control points, 6 are selected for absolute orientation of the stereo model. But as already mentioned by Butler et al. (2002) the use of subaqueous points generates an additional shift in the X- and Y-coordinates, so additional corrections should be implied. This will involve additional transformation of the data set that will introduce new uncertainty.

Second, the surface reflection will have a negative effect on the stereomatching algorithms used in digital photogrammetry (Butler et al., 2002). To minimise the effect of surface reflection, areas where no reflection of the seabed is supposed to be detected by the sensor, are masked (Westaway et al.,
The setting angle between the nadir and backward telescope is designed to be 27.60°. But due to the curvature of the earth surface, this results in an angle of 30.96° between the nadir and backward direction at an observing point on the earth surface (ASTER User’s Guide, 2001).

The correction has to be made for both images and the estimate of \( h \) and an average of both calculated depth corrections will give the final resulting depth value for the corrected DEM (Butler et al., 2002).

So, using formula (5), with known angle of incidence, \( i \), for both telescopes and the refraction index, \( n \), of the Red Sea water, corrected depth, \( h \), can be estimated.

According to Jerlov (1976), regional variations in temperature and salinity of the seawater can be neglected, so the refraction index of the seawater of the Red Sea is set to the standard value of 1.340.

Based on the setting of the at nadir sensor of the ASTER sensor -near-vertical viewing angle and high flying altitude relative to water depth- the simpler correction algorithm proposed by Westaway et al. (2000) (Westaway et al., 2001) will be used for the correction of the nadir sensor.

This formula is:

\[
h_1 = n \times h_a \quad (6)
\]

with: \( n = 1.340 \) (Jerlov, 1976)

giving: \( h_1 = 1.340 \times h_a \quad (7)\)

For the backward looking telescope, \( i \) and \( n \) are known, so an adapted correction algorithm is derived out of formula (5) to calculate true depth from the apparent depth derived in VIRTUOZO 3.2:
\[ h_2 = \left( \frac{\tan(i)}{\tan(i/n)} \right) h_a \]  
(8)

with \( i = 30.96^\circ \) (Aster User’s Guide, 2001), this results in:

\[ h_2 = 1.41 * h_a \]  
(9)

An average correction between both images gives us the final correction algorithm:

\[ h = \frac{h_1 + h_2}{2} \]  
(10)

giving:

\[ h = 1.38 * h_a \]  
(11)

This algorithm has been applied after the DEM is created in VIRTUOZO 3.2.

### 3 RESULTS

After the DEM has been created in VIRTUOZO 3.2, the DEM with a resolution of 15m, is imported in the ILWIS 3.0 software package where the adapted correction algorithm is applied. The lack of data in the south-eastern corner of the DEM is due to an error in format-conversion.

![Figure 4: Resulting bathymetric map of the coral reefs surrounding Big Giftn Island after applying the adapted refraction correction algorithm. A vector map showing the coastlines is overlaid on the DEM.](image)

### 4 DISCUSSION

Generally, this first preliminary result of a bathymetric map made with digital photogrammetry and the use of ASTER images is very promising. It illustrates the possibility for detecting depth variations on the coral reefs. In the result (Figure 4) topographic changes of the reef surface can be noticed. Though local deviations are occurring, relative realistic depth values, generally between 0.5 and – 3m, are calculated. The problem with the accuracy in the result is most probably consequence of the lack of true absolute ground control points that are directly measured on the field. It has been proven very difficult to recognize exact point locations at sea visible on the ASTER-images and vice versa.

Another remaining problem is the shift in X and Y in the absolute orientation due to the use of subaqueous ground control points. An additional transformation of the data would solve this.

As can be seen on Figure 4 there is still a problem with the image matching over deep water, although these areas have been masked out in the match edit module of VIRTUOZO 3.2. At the edges of the study area ‘pits’ and ‘mountains’ are created that truncate the calculated values over the coral reefs. Further research is needed in the match edit procedure to find a solution for this.

Finally if these problems can be dealt with, the method will generate results that are equal or even better in comparison with the results obtained with methods based on multispectral remote sensing.
data. Certainly the upper few meters of the coral reefs, the area where the ASTER-images record information, is often a problematic area for other methods.

5 CONCLUSIONS

Although this first preliminary result is still subject to some errors and local deviations, it can be concluded that the possibility to estimate depth of the coral reefs using digital photogrammetry and ASTER data is promising. Further investigation is required for the need of additional adaptation of the refraction correction algorithm to use with ASTER data and the remaining problems with geometric accuracy and the match editing procedure.

REFERENCES