A STATE OF ART ON AIRBORNE LIDAR APPLICATION IN HYDROLOGY AND OCEANOGRAPHY: A COMPREHENSIVE OVERVIEW

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ABSTRACT:

Nowadays, lidar has been accepted as one of the important sensors providing accurate and dense 3D point cloud from earth surface terrain and water bathymetry. The basic idea of using lidar stems from the problem of measuring water depth without direct contacting with the water body or without any instrument mounted on the water surface in shallow regions. Bathymetric lidar that uses two different laser beam mounted on a flying aircraft above the water surface has proved to be a good solution. This ability resolves many of the industrial and military needs for accurate and precise geospatial information from water body in shallow area in a very rapid manner. This technology has been used in the cases which would be solved with serious difficulties using alternative solutions. In addition to hydrology and oceanography, there are other important application areas which mainly are urban mapping, forestry, and photogrammetry. In this study, a comprehensive overview to the use of lidar technology in the oceanography and hydrology is discussed. In ocean and hydrography, various subjects are tackled such as: dunes and tidal flats measurement, coastal change and erosion, flood mapping and prediction, snow and ice measurement, water bathymetry in depths up to 70 m. Airborne lidar systems are rapidly developing and expanding in new applications. Integration of lidar with imaging sensors, efficient using of waveform information and better processing algorithms would make a great development in obtaining more realistic and accurate 3D models of the geospatial objects. Maybe in future, more cost effective solutions would attract the users to suite from this technology.

1. INTRODUCTION

Currently lidar technology has been operational used in different applications by many organizations and industries. In some specific cases, using traditional methods would take a lot of time and cost from the customers to fulfill their needs. For instance, many hydrography and oceanography organizations need bathymetric maps for near coastline area. Using echo-sounders would be dangerous, not accurate enough in shallow waters, time consuming, and do not give a continuous water depth. Alternatively, using bathymetric lidar provide accurate, continuous, fast depth information from a large region. There is no need to contact directly with the water body and this ability resolves many of the industrial and military needs for accurate and precise geospatial information from water body in shallow area in a very rapid manner. In this study, a comprehensive overview to the use of lidar technology in the oceanography and hydrology is discussed and various subjects are tackled such as: dunes and tidal flats measurement, coastal change and erosion, flood mapping and prediction, snow and ice measurement, water bathymetry in depths up to 70 m.

2. LIDAR APPLICATIONS IN HYDROLOGY AND OCEANOGRAPHY

Water hydrology modeling and watershed management is based on constant monitoring of the water volume over a long time for modeling water dynamic behavior. Flood prediction and flood extend modeling is one of the most important issues in the watershed management and usually the primary interest would be coastal area and rivers hydrodynamic modeling especially in the event of the flood. Remote sensing technology provides a highly fast and rich source of data for the above mentioned modeling which was lacking by other type of sources like ground based methods. Previously due to the lack of information, there was not good correlation between reality and hydrodynamic models and also the models were not complete enough. With the presence of Remote Sensing sensors huge amount of data in short period of time is available for the hydrologists and there is need to investigate the different available RS data and their suitability. River and coastal monitoring and modeling task require 3D information about a) Coast or river bottom depth, b) coast or river surface and banks topography (in the lowest water level), c) Vegetation height, d) Man-made objects near to the coast or river, e) All the objects that might have effect on the water current.

A number of RS sensors have the potential of providing the data for the required mentioned factors and will be investigated in the following judgment which is more a personal opinion. Airborne multispectral images is capable of the recording the backscattered sun beam from the river bottom surface. This gives the possibility of indirect estimation of the water depth through a regression model between image recorded radiation and the in situ control information for validation of the model. The practical models have shown that airborne optical multispectral passive sensors demonstrate the depth measurements up to 6 meters with 50 cm accuracy. One should consider that data collected over turbid water and cloudy or wavy areas makes these sensors inefficient. Automatically for water depth more than 6 meters, the water clarity is not enough for accurate depth measurement. For depth more than 6 meters, other bathymetric sensors are used like radar images, Hyperspectral airborne images, and Lidar. Vogelzang (Vogelzang et al., 1994) proposed depth extraction from radar intensity image using an numerical image inversion method based on the fact that the water surface waves in low wind condition is affected by the bottom topography which higher magnitude surface waves result in high intensities and consequently lower depth for that point relative to the adjacent topography. He has reported an error order of 1 meter at an average depth of 22. Radar sensors have the advantages of data collection over night and also turbid water depth computation. Hyperspectral airborne images like: Compact airborne spectrographic imager (CASI), Airborne visible-infrared imaging spectrometer (AVIRS), Advanced airborne hyperspectral imaging systems (AAHIS) and Digital airborne scanner (DIAS) are mostly used in biological investigations (coral mapping, chlorophyll estimation, identification of other marine vegetation, water temperature) and there are some activities on bathymetry information extraction from CASI data. CASI sensor has the ability to acquire 288 bands and gives the ability to the user to select the bands which are suitable for the bathymetric information extraction for a particular area of interest. Choosing the right wavelength makes it possible to calculate regression between depth and reflectance for clear and turbid water. But due to the confusing effect of variable depth on bottom reflectance, the computed depth measurements have limited accuracy of order 1 meter for up to the depth of 22 meter, which does not satisfy bathymetry depth measurement standards. For deeper water, lidar sensors not only have the ability to measure the deepness down to two or three times the Secchi depth at 532 nm (equals to approximately 50 meters in clear water) but also have higher spatial resolution, below surface object detection larger than 1×1 m2, high data acquisition rate per m2, acquires direct 3D position and need less data post processing and rapidly is available on the emergency situations. The planimetric and vertical accuracy of Lidar sensor is dependent on the flying height. Currently Lidar data accuracy satisfies the bathymetric standards. Detection of the zero depth which is river banks and its displacement are very time consuming and expensive task by traditional hydrographic methods and can be detected by Lidar sensors more rapidly with lower costs. For the second factor which was coast or river surface and banks topography, only photogrammetry stereo images and Lidar sensor are capable of the topography extraction and the remaining sensors produce 2D data. A comparison between Lidar and photogrammetry is demonstrated by Lane (Lane et al., 2003). He has given more priority to the photogrammetric approach in the flood extent extraction comparing to the Lidar sensor. But if one could focus on his results, it would be apparent that: 1) For flood extents, there is negligible difference between accuracy of data derived by Lidar and photogrammetry, 2) Photogrammetric method has problems for the water surface topography but against to this Lidar is capable of supporting those kind of information and also for large flood extends, photogrammetric approach needs a lot time for the data processing but Lidar data can be delivered to the user very rapidly on emergency needs. Bates (Bates et al., 2002) and Cobby (Cobby et al., 2001) have done investigations on vegetation height extraction near from Lidar data to improve flood modeling which can not be detected by other remote sensing sensors. Pereira (Pereira et al., 1999) recommends using Lidar sensor instead of photogrammetric image due to its rapid and cheaper product. Man-mage objects like, bridge and building are particularly favored because provide a tool for Lidar calibration providing a check for horizontal and vertical alignment.

Ackermann (1999) gives an overview to present status and future expectations of airborne laser scanners. Baltsavias (1999a, b) discuss the basic formulas and existing systems and Wehr and Lohr (1999) presents an introduction and overview to airborne laser scanners. Mohammadzadeh et al. (2006) gives a brief review to the some of the exiting research works in different applications of lidar technology. Hydrographic Lidar calculates the water body depth in shallow rivers and coastal areas using the time difference of blue-green channel and infrared channel reflected from the sea bottom and the water surface respectively. Schmugge et al. (2002) has made a brief survey on the past remote sensing solutions used in hydrological problems. Cunningham et al. (1998) and Irish et al. (2000) give a good overview on the airborne Lidar hydrography program. Among all the operating hydrographic Lidar sensors SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) is an airborne Lidar system in the world that collects both hydrographical topographical measurement in a single survey (Guenther et al., 2000). Before flight, some calibration processes are carried out by the instrument designing company and therefore some researchers have focused their research on fundamental aspects such as: laser scanner calibration (Adams, 2000) and (Wagner et al., 2006), accuracy improvement (Latypov, 2002), strip adjustment (Bretar et al., 2004), noise reduction of lidar signal (Fang and Huang, 2004), lidar backscatter modeling (Fochesatto et al., 2004), lidar beam alignment (Latypov, 2005), and stability of laser swath width (Luzum et al., 2005). Also there are other calibration activities needed to be performed before the flight starts in the field. The position shift among laser scanner, GPS and IMU should be measured accurately to apply the spatial shift among them. Also scan rate, GPS/IMU data acquisition rates are not the same and should be synchronized. The maximum detectable depth by laser scanner is varying according to the water turbidity and small particles in the water. The white calibration disk should be used to calibrate the laser backscatter from different depth of the water body. Scan rate, flight height, flight lines, designing control points to mount GPS instruments and project cost should be determined before performing flight over the region of interest. During the flight, the human expert should check the overall accuracy of the data to avoid large and unexpected systematic errors. The coverage between acquired data should be monitored to avoid data gaps. Afterwards all the acquired data should be processed simultaneously to convert raw data set to LAS or ASCII format readable by lidar processing software. The primary effort in all the hydrographic applications is transformation of the Lidar point cloud into a desired projection system. Outliers can be filtered out to have more realistic dataset. Then advanced image processing algorithms are applied according to the user needs and application nature. The intensity information is interpolated or in some cases is estimated using other source of data to produce raster image. The use of intensity derived image and optical images makes it possible to better recognition of the outlines of the coastline and nearby standing objects. Various approaches are developed in each specific hydrographic and oceanographic case to obtain required value added information such as: rapid high-density measurements of the coastal zone (Saye et al., 2005); track movements of sand placed for beach nourishment (Shrestha et al., 2005); reveal linkages between changes in offshore bathymetry and shape of the shoreline (Thoma et al., 2005); flood prediction (Webster et al., 2004); water surface (Hwang et al., 2000) and bottom reconstruction in bathymetric lidar (Pillai and Antoniou, 1997) ; coast or river surface and banks topography (Bates et al., 2003), (Charlton et al., 2003); Vegetation height (Bates et al., 2002), (Mason et al., 2003), (Cobby et al., 2003), and (Cobby et al., 2001); effect of man-made objects on tidal rivers (Gilvear et al., 2004); tidal channels geomorphology (Lohani and Mason, 2001). In the following part a synthesized discussion around important exiting problems in lidar data processing and possible solutions will be discussed.

As DTM extraction is the most popular and main fundamental process in most of the application, so it is always important to seek for new accurate and precise methods for DTM production from Lidar data. Still there are some errors in almost all of the DTM calculation approaches which need to be investigated that affect the calculated height the objects above the terrain surface in the normalized DSM. Appropriate interpolation method should be chosen for surface reconstruction: Gridding or Tinning. The surface reconstructed by grid method, passes from all the points and resulting surface is smooth. TIN interpolation method is unreliable in sparse and missing data cases. Most of the current methodologies outlook is applying an isolate treatment of the Lidar data but there are some tendencies for the utilization of the structure based methodologies sensitive to the shape and neighborhood orientation of the locally adjacent points around the point of interest like 3D fuzzy-morphology algorithms. In forest application only single coniferous trees have been extracted that have more regular and simple shape for modeling. Better regression models with dynamic parameters considering topographic relation of the trees should be proposed for tree canopy extraction of different type. As objects are vague and represented as cloud point in Lidar range data, fuzzy and neural network approaches are well suited for this kind of data. For example, for roads, a fuzzy reasoning system can be established in a way that if the points' heights are near to the DTM and have gentle slope and same intensity in the optical image then pixels are attributed as road. As another example, a neural based system could be trained to identify different trees shape. Newly there are some efforts on finding a direct relation between acquired optical image and the corresponding Lidar data to avoid resampling which affects the shape of the trees and objects. Future works would concentrate on evolving available statistical information and multi-source information into the decision-supported classification algorithms. The effective use of Lidar intensity data has not been established yet and as mentioned before it is limited in classification or matching process of Lidar data and optical images. As the Lidar intensity data is more representing the surface characteristics, it can be used along with optical data for better object classification. In more technical sentence, the result of the classification of Lidar data and optical data is not the same and a well-defined reasoning system is required to do an intelligent overlapping process for object extraction. Absolute orientation of low cost photogrammetric data using the automatically extracted 3D linear features from the Lidar intensity data could be another interesting topic which opens a new horizon on robust true ortho-photo generation in flood mapping or determining coastline border accurately. In 3D man-made object's surface reconstruction especially in building extraction, which are built close enough to the water bodies, still there are unsolved problems. In bathymetric Lidar, water surface and bottom reconstruction are the most important concerns and a lot of efforts have been done to achieve higher accuracy and better spatial resolution. Still there are some uncertainties related to penetration depth of the laser beam, GPS/INS systematic errors, atmospheric effect, ground control point errors, foot print size, mission planning, processing of data and etc. and those need more investigations. Still coastal shoreline monitoring is not completely solved. Water body dynamic movements are simulated according to the acquired Lidar data for the prediction purpose of the water flows. Reliable Lidar data and better prediction models are required for improved results. Finally some important recommendation and future works are expressed by the authors as follows:

1. For better waterfront detection, it is better to use ground data and non-ground data together, as sometimes there are misclassified.
2. Proposing a method for better differentiating of ground returns from building or vegetation and from atmospheric aerosol for better overall accuracy.
3. Providing better visualization tool for better detection of outlier of Lidar data and the ability of using video images simultaneously.
4. Calibrating of Lidar data during the flight by some ground calibration targets due to varying conditions of the environment and internal calibration drift of the laser scanner components.
5. Providing advanced feature extraction methods for discrimination of abrupt elevation changes like: water front, sea wall, cliffs, and coastal dunes.
6. Integration and fusion of Lidar sensor with other type of images especially CASI images.
7. Designing an improved automatic methodology for GIS data-base updating using extracted features from the Lidar data to facilitate the time-consuming task of manual editing.
8. Investigation on the accurate water surface wave extraction especially in shallow areas to achieve better estimation of the depth and laser beam traveling path in the water body. One should consider the tidal effects on surface waves. Also distance between laser shots must be less than half of the surface wave height.
9. Using the slope information of the adjacent topography of the river to use it as estimation parameters for river bathymetry and water height in very shallow area.
10. Comparing depth derived from the Lidar data with other accurate data like echo sounder data to study the possible systematic errors or fusion of the data.
11. Studying the errors caused by the projection transformations applied on the Lidar data.

3. CONCLUSIONS

Airborne lidar systems are rapidly developing and expanding in new applications. In this report, we focused on different applications of Lidar sensor in hydrology and oceanography especially for the river and watershed management. A good comparison has been demonstrated among all the available sensors and Lidar sensor seems to be an efficient sensor for this purpose. This shows that Lidar sensor provides efficient, rapid, and low cost tool for hydrological application, especially for coastal and river water management. But still there are some weaknesses on the Lidar data segmentation, visualization, very shallow depth measurement, water wave estimation and etc. Integration of lidar with imaging sensors and better processing algorithms would make a great development in obtaining more realistic and accurate 3D models of the geospatial objects. Please note that the above discussed issues are more the authors personal point of view.

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