Effect of Water Property on Depth Measurements by Airborne LiDAR Bathymetry

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ABSTRACT: The returned waveform of airborne LiDAR bathymetry can be used to measure water depth and classify objects. When a laser beam travels into the water, the condition of the surface and the content of the water may cause scattering and absorption to change the route of the laser beam and deteriorate the laser energy, thus affecting the shape and the duration of the received waveform. To gain a deeper insight into how the waveform is affected geometrically as well as radiometrically by water property, this study, taking scattering and absorption effects into consideration, designed a simulator by employing Monte Carlo modeling technique to not only identify the influential factors but also quantify the amount of variation on the waveform. As a result of it, the emphasis on water depth measurement by airborne LiDAR bathymetry can be better placed.

1. Introduction

Airborne LiDAR Bathymetry Systems(ALBS) use laser pulse to detect sea bottom and surface. It can use return waveform to calculate water depth. Return waveform may be influenced by the condition of the surface and the content of the water, because the condition of the surface and the content of the water may cause scattering and absorption to change the route of the laser beam and deteriorate the laser energy. It may cause some errors or even mistakes when calculating water depth.

This study focusses on different water content's influence in waveform and water depth calculating. There are many factors influence water content. The factors which discuss in this study include salinity and suspended sediment. Water surface and bottom are considered as a horizontal plane. There are not considering the influence of surface wave and the absorption of bottom.

This study simulates the route of Airborne LiDAR laser beam traveling in water by Monte Carlo method. Laser beam is seen as that it is composed by many photons carrying energy. By recording every photon's position, length of photon's route and time of photon traveling in water can be estimated. The time and the number of photon back to receiver can be used to draw laser beam return waveform. This study analyses the return waveform received in different water condition and tries to tell the influence of salinity and suspended sediment concentration change in waveform and water depth's calculating.

2. Method

2.1 The Monte Carlo simulation

Monte Carlo simulation is to follow a photon from the light source through all possible events (transmission, absorption, scattering, and reflection) that it may experience until reaching the receiver. Each interaction event is determined by a properly associated probability function and the assigned physical properties of the materials (absorption coefficient, scattering coefficient, scattering phase function, etc.)(Wang et al., 2011). This simulation classifies all interaction events into three groups (water surface, water body, water bottom). The content of the interaction events in these three groups are introduced in following sections, and the photon movement can be seen in Figure.1. The original point (0,0,0) is at transmitter. The vertical way upper transmitter is Z axis. The direction of Y axis is north. The transmitter field of view is set as 5mrad and receiver is set as 21mrad. The position of transmitter and receiver are the same. There are 1000000 photon simulated in this study.

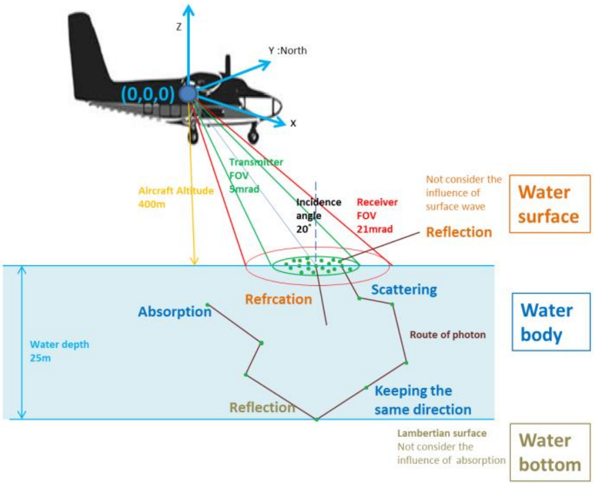


Figure. 1 route of photon and interaction events in water surface, body, and bottom

2.1.1 water surface

In this simulation, transmitter and receiver's aircraft altitudes are set as H=400m. Typical Airborne LiDAR Bathymetry System's aircraft altitudes are in the 200-500 meter range. (Guenther, 2006) The laser pulse scanner nadir angle is set as θ=20˚. The maximum scanner nadir angles in use are 15-22 degrees. (Guenther, 2006) By considering aircraft altitude H, scanner nadir angle θ, and transmitter field of view the position of each photon traveling to water surface can be calculated. When photons travel to water surface, there are two events, reflection or refraction may happen. The way to determine which event would happen to photons is using the Fresnel's Law and generating a random number R1 range from 0 to 1. Comparing the value calculated by Fresnel's Law and R1, which event will happen can be decided.

2.1.2 Water body

ALBS surveyable depth can be greater than 50m in clear water, but the depth can be smaller than 10m in turbid water. (Guenther, 2006) The water depth is set as 10m in this study. The factors influence water content including colored dissolved organic matter (CDOM), phytoplankton, suspended sediment and mineral dissolved in water (salinity). ALBS are mostly used to measure sea water depth. The factors influence sea water the most are water temperature and salinity, but the influence of temperature in refraction is not significant as salinity. This study set the water salinity as 30‰、40‰ under the temperature 20˚ to simulate. The other control variable of water content is suspended sediment. The reason to choose suspended sediment as control variable is that CDOM and phytoplankton concentration change in water is hard to simulate. Suspended sediment can be seen as composite by the same size particles, and changing the concentration as control variable. This study set the suspended sediment concentration as 16mg/l、45mg/l under the particle size 0.048~0.075mm to simulate. Difference depth may result in difference return waveform. This simulation also test the result of the true depth from 10~15m in water salinity as 30‰ and temperature 20˚C, and comparing the depth calculated from return waveform with true depth. The coefficients use in the simulation can be seen in Table.1.

Table.1 The coefficients use in the simulation

	concentration	Refractive index	absorption coefficient , $a\,(m^{-1})$	scattering coefficient , $b\,(m^{-1})$	light velocity in water (km/s)
salinity	30‰	1.34055	0.06625	0.03375	223633.9
	40‰	1.3424	0.066247	0.033753	223325.7
Suspended sediment	0.016g/l	1.344167	0.61	0.51	223032.2
	0.045g/l	1.349909	0.95	0.79	222083.5

There are there events (absorption, scattering, keeping the same direction) may happen when photon travels into water. The way to determine which event will happen to photon is generating a random number R2 and comparing R2 with the value that photon's route length plus absorption and scattering coefficient. The determinant of these three events will continue until photon travel to water bottom or surface. When traveling to surface, the scattering angle will be compared with the critical angle to determine photon will stay in water or back to air.

2.1.3 Water bottom

In this study, the water bottom is seen as Lambertian surface and don't consider the absorption of water bottom, so when photon travels to water bottom, it will be reflected back to water body.

2.2 return waveform and water depth calculating

This study only focuses the influence of different water content, only the length of the route that photon travels in water body will be calculated. Using the light in water velocity can find out the time that photon gets back from water. Photon energy is set as 3.7739×10^{-19} J for each photon in this study, because there is using the light bandwidth 532nm to simulate. Using photon energy and the time it get back, the return waveform can be draw. The unit of time is ns. After drawing return waveform, Time-varied Gain function (TVG) will be used to compensate the loss of energy when laser beam travels in water and enhance the return signal in water bottom. The equation of TVG can be seen in Eq.1.

$$g(t) = (ct/2)^2 e^{\alpha_0 ct}/2 \qquad (1)$$

g(t) is the value of TVG, t means time，c is the velocity of light in water, α_0 is absorption coefficient.(Moszynski, and Stepnowski, 2002) When finding out the value of the second peak in return waveform, water depth D can be calculated by Eq.2.

$$D = \frac{vt}{2}\cos\theta \qquad (2)$$

v is the velocity of light in water, t is the value of the second peak in return waveform, θ the angle of refraction.

3. Result

The return waveform simulated by change the salinity and suspended sediment concentration can be seen in Table.2 and Table.3. The energy distribute by time in return waveform salinity is 30‰ doesn't differ much from the return waveform salinity is 40‰. Two water depth measures by waveform are 10.486m and 10.15m. The difference compare with true water depth are 0.486m and 0.15m. It shows that when water salinity change from 30‰ to 40‰, the measured depth decrease almost 30cm error.

Table.2 The result of changing water salinity

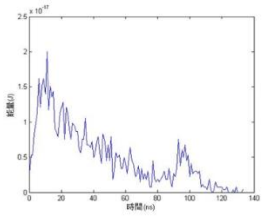
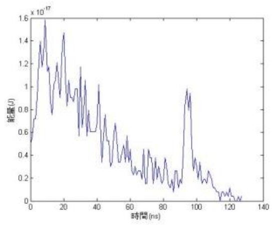
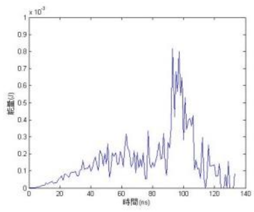
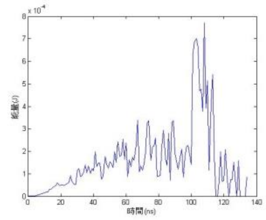
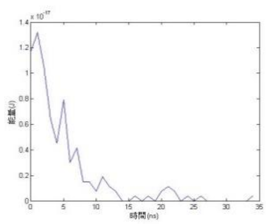
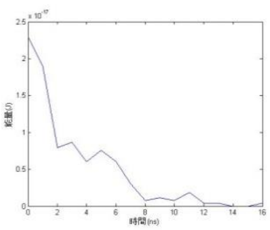
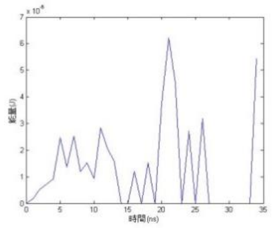
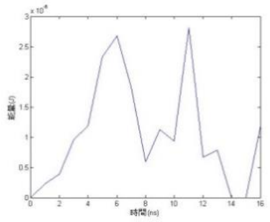
	salinity=30‰	salinity=40‰
Original waveform		
Waveform after TVG		
Measured water depth	10.486m	10.15m

Table.3 are the return waveform of changing water suspended sediment concentration and measured water depth. The energy distribute by time in the return waveform in concentration is 0.045g/l is different from concentration is 0.016g/l. The energy return in the waveform of 0.045g/l is much more than 0.016g/l, but the time range that energy distributes is shorter. Two water depth measures by waveform are 2.13m and 1.15m. The difference compare with true water depth are -7.87m and -8.85m.

Table.3 The result of changing water suspended sediment concentration

	concentration=0.016g/l	concentration=0.045g/l
Original waveform		

Waveform after TVG		
Measured water depth	2.13m	1.15m

The range of the difference of calculated depth and true depth from 10~15m are from 8cm to almost 50cm. It shows that under the water condition that salinity is 30‰ and temperature is 20˚C the depth can measure to 15m with 45.9cm error.

Table.4 The result of changing water suspended sediment concentration

True depth	10	11	12	13	14	15
Calculate depth	10.486	11.351	12.108	13.081	14.054	15.459

Units: meter

4. Conclusion

When salinity increases from 30‰ to 40‰, measured water depth doesn't change much. The measured water depth is around 10m. The difference of water depth of two simulation result is around 30cm. The error doesn't increase with the salinity. When suspended sediment concentration increases from 0.016g/l to 0.045g/l, the depth that laser beam can measure becomes shallower. The depth laser beam can measure is around 1-2m. Most of the energy of laser beam may be loss before it arrives at water bottom (depth=10m), so it can't calculate out the true depth. The measured water depth becomes shallower when suspended sediment concentration increases. The unit of salinity is how much saline matter in 1000 grams water. When salinity increases from 30‰ to 40‰, the error decreases almost 30cm in water depth. When suspended sediment concentration increases from 0.016g/l to 0.045g/l, the error increases almost 1m in water depth. The quantity that suspended sediment concentration increase is smaller than salinity, but the error increase bigger, so comparing the result of changing salinity and suspended sediment concentration, the influence of suspended sediment concentration is bigger than salinity. Under the water condition that salinity is 30‰ and temperature is 20˚C the water depth can measure to 15m with 45.9cm error.

5. Reference

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