Mapping Matters

By Qassim A. Abdullah, Ph.D., PLS, CP**

Your Questions Answered

The layman's perspective on technical theory and practical applications of mapping and GIS

Question: I am a certified photogrammetrist serving as project manager for a roadwork project located in the Canadian North and Northwest Territories, between Inuvik and Tuktoyaktuk. The design engineers are finding differences between their design cross-sections and our lidar data, especially in the river bottoms. Is it possible to obtain accurate lidar readings through rivers and streams? I realize from your May 2003 article that the lidar is light. Would there be refraction after it hits the water surface? Is there any information available pertaining to lidar accuracy for underwater surfaces?

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Dr. Abdullah: If the laser is reaching and reflecting from the bottom of the creek or river, then of course, the light will be refracted through its movement from air to water and again from water to air. Accordingly, the laser ranging will not be accurate until it is corrected for the refraction that the laser goes through when traveling between different media (air and water). The laser ranges should be corrected according to Snell's law, which describes the path that light will take as it passes between two different media, in this case air and water (Figure 1). Snell's law can be represented by the following equation:

$$\frac{\sin \theta 1}{\sin \theta 2} = \frac{\eta 2}{\eta 1}$$

where,

η_1 = refractive index of upper medium
η_2 = refractive index of lower medium
Θ_1 = angle of incident
Θ_2 = angle of refraction

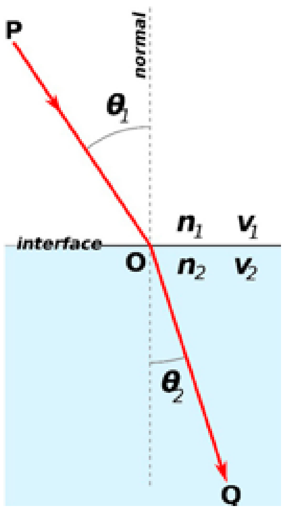

Figure 1. Refraction of light between media with different refraction indices (here $\eta_2 > \eta_1$), image courtesy, http://en.wikipedia.org/wiki/Snell's_law).

Snell's law equation provides us with the direction of the laser pulse within the water column from which the laser ranging correction is derived. The modeling could be complicated or simple due to several reasons, including:

- The laser pulse footprint at the river bed is not a point but a spot a few meters in diameter, in some cases. For the purposes of modeling, a theoretical center (point) of the laser spot on the seafloor is assumed through the assumption that the laser beam has to have a low divergence as it is entering homogenous water. This is the first approximation introduced to the modeling that, as expected, degrades the laser pointing quality.
- Modeling the laser path through different media (water and air) is influenced by the quality and temperature of the water and air that the laser is passing through. Refractive indices of a laser passing through different media are calculated by assuming certain temperature and water/air quality. The computation of the refractive index of water is more complicated as it is a function of laser wavelength, temperature and density of the water column. Here again, there are many assumptions made in modeling the laser path through water, as it is difficult, if not impossible, to predict the actual water temperature and density at different depths of the river during data acquisition.
- Most modeling is based on the assumption that the water surface is smooth and flat, which is not true in most cases, as winds and underwater currents affect the path the laser takes when it hits the water surface and enters the water. Having a model to correct for water dynamics is not a straightforward task without actual field measurements.

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The simple modeling I have used in the past for underwater photogrammetry is given by the following equations:

Apparent object depth = Water level - compiled object elevation

*True object depth = (ηw/ ηa)*apparent object depth*

*True object elevation = Water elevation – {(ηw/ ηa)*apparent object depth}*

where,

η_a = refractive index of air
η_w = refractive index of water

Both values of η_a and η_w vary according to different parameters such as air density and temperature, water density and temperature, whether it is freshwater or seawater, etc.

Table 1. Refractive indices for water with different salinity.

Water Type	Practical Salinity Unit (PSU)	Refractive Index η_w	Refractive angle Θ_2 (degree)
Freshwater	0	1.3354	14.84°
Brackish water	10	1.3387	N/A
Seawater	35	1.3468	14.72°

"Laser ranging will not be accurate until it is corrected for the refraction that the laser goes through when traveling between different media (air and water)."

The tricky part here is figuring out the correct refractive indices of the water and air as the laser changes from one situation to another. Using the model introduced by the International Association for the Properties of Water and Steam, Table 1 contains values that are obtained for green laser assuming 20° C temperature and incident angle ($\Theta 1$) of 20 degrees in different water types.

Based on the above discussions, the discrepancies in the elevation between the lidar data and the cross-section are most likely due to the uncorrected laser path when it went through water. This is especially true for the conventional (topographic) lidar that is used in your project. Lidar systems designed for bathymetric work most likely correct for the refraction that occurs in the water.

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