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Evaluation of different water surface ranging technologies for lightweight UAVs

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1. Background and Motivation

Surface water is one of the components of the water cycle that is essential to all life on Earth. It includes streams (from large rivers to small creeks), reservoirs, lakes, canals, ponds and freshwater wetlands. Knowledge of the spatial and temporal variability of open water surfaces is often limited. The measurements required to understand the variability of open water surfaces include the elevation of the water surface of wetlands, rivers, lakes, reservoirs (h), the temporal and spatial derivatives ($\partial h/\partial t$, $\partial h/\partial x$) and the surface water area extent (Alsdorf et al., 2007) . Ground-based measurements of water level in terrestrial water bodies are restricted to the networks of measuring stations. However the global decline in the number of measuring stations, due to both political and economic issues, is making water resource management problematic (Lawford et al., 2013) . Furthermore, the understanding of flood processes and of the interaction between floodplains and rivers is limited by the lack of water measurements in floodplain areas and across river courses. For this reason, the objective of remote sensing hydrology is to retrieve these hydraulic variables from spaceborne platforms. However, there is no technology that can singularly supply these hydraulic measurements, needed to accurately model the water cycle, with both high temporal and spatial resolution. Indeed, although precision altimetry missions, such as Ocean Surface Topography Mission (OSTM), provide a better understanding of sea level changes, coarse resolution and low coverage of space-borne missions have several limitations in assessing the water level of terrestrial surface water bodies and its variation with time and space. To overcome these limitations, the forthcoming Surface Water and Ocean Topography (SWOT) satellite mission , which is planned to be launched in 2020, will combine the concept of WATER (Water and Terrestrial Elevation Recovery) and the

Hydrosphere Mapper missions in order to integrate land hydrology and oceanography (Durand et al., 2010). However, UAV monitoring has the potential to fill the gap between the low coverage of ground-based stations and the coarse spatial resolution of satellite missions, which are generally characterized by physical limits in accuracy. Developing light sensors, able to accurately measure water level, would open up for the possibility of exploiting the advantages of remote sensing from Unmanned Aerial Vehicles (UAVs): high spatial accuracy and coverage, quick turn-around time and flexibility of the payload. Moreover, small UAVs (frequently payload less than 1.5 kg) are generally not regulated as strictly as larger UAVs, this allows for more flexible operations and shorter response times. From this standpoint, our research focuses on retrieving the orthometric height of water surfaces using sensors that comply with the weight constraint of lightweight UAVs.

2. Methodology

Given the weight constraint, the need of accuracy and a reasonable price necessary for more flexible operations, we tested three sensors already available on the market (a sonar, a radar and a time-of-flight laser) and a laser-based technology recently developed at the Technical University of Denmark (Reyna Gutierrez, 2013). This laser prototype consists of two laser pointers and a live MOS sensor. The laser pointers are two 100 mW laser diodes with an emitted wavelength of 532 nm. The live MOS sensor is derived from a commercial digital camera. The current design of the developed distance-meter involves the digital camera mounted at the center of an aluminum frame with laser pointers located along the aluminum bar at selected distances. The measurement of the distance to water surface is carried out by illuminating the water surface with the laser pointers and taking a picture of the illuminated water surface. When light emitted by laser pointers hits the water surface, dots are formed at the contact spot on water surface. Due to the scattering processing of water surface, the reflected radiation is sensed by the sensor of the camera and thus it is possible to estimate the range to water surface. The geometrical configuration of the camera is shown in Figure 1. The range distance H can be computed by measuring the angle θ^1 at which light enters the camera and by knowing the distance A between the laser source and the camera, i.e. $H=A/\tan(\theta^1)$. The angular measurements of θ^1 is obtained as the number of pixels from the center of the image to the recorded laser dots in the image. Therefore, a calibration procedure to convert from pixel units to angular units has to be performed. The advantage of having two laser pointers instead of one is an improvement of the error assessment. The measured distance integrated with the accurate vertical and horizontal position retrieved by RTK GPS makes possible the estimation of the orthometric height of the water surface.

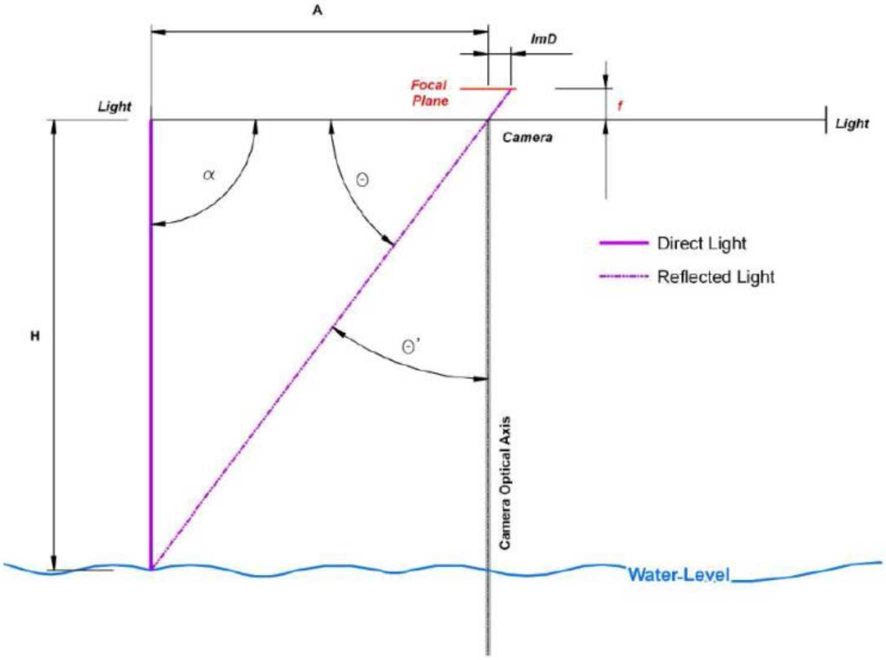

Figure 1, geometrical configuration of the laser based-prototype (Reyna Gutierrez, 2013). A is the distance between the center of the camera and the laser pointer, H is the distance from the camera (and from the laser pointers in case of horizontal frame) to water surface, ImD is the distance from the center of the image to the recorded light source, f is the focal length.

Conversely, the radar, which is originally developed for car industry, consists of a 77 GHz radar sensor with a mechanically scanning antenna. It measures range to targets in one measuring cycle due basis of FMCW (Frequency Modulated Continuous Wave) with a sampling frequency of 15 measurements per second. Assuming that removing white noise it is possible to improve the accuracy, the radar will be tested by taking measurements for a few seconds (around 10) and then calculating a weighted average. Through this averaging process, an accuracy of few centimeters will be achievable, although the resolution of the radar is 0.1 m. The sonar is a 42kHz ultrasonic sensor (6Hz reading rate) with internal temperature compensation, noise tolerance and clutter rejection. The time of flight (TOF) laser is a distance-meter using red-visible light. The expected accuracy, beam divergence and the maximum range for the four sensors are shown in Table 1.

Sensor:	**Accuracy**	**Beam Divergence**	**Maximum range**
Sonar	1-5 cm	Around 30 cm at 10 m	10 m
Radar	1.5% distance far field 3-10 cm close up range	0.1° far field, 2°close-up range	200 m far field, 60 m close-up range
Time of flight (TOF) laser	Water surface doesn't exhibit sufficient reflection of light	5.5 x 4.5 mm at aperture, beam divergence 0.3 mrad	50 m
Laser based prototype developed at DTU	5-10 cm	Mostly depending on the distance between each laser pointer and the optical camera	20 m

Table 1, expected accuracy, beam divergence and maximum range for the four different water level rangers

As it can be seen from Table 1, the sonar is the most accurate instrument with an accuracy of few centimeters, whereas the laser prototype ensures an accuracy of 5-10 cm in a measuring range of 20 m and the radar has an accuracy around 3-10 cm. The Time Of Flight (TOF) laser does not show satisfactory results because the water surface does not exhibit sufficient reflection of light to have a correct measurements. However, also beam divergence and maximum measuring range must be considered since the sensors will be implemented on UAVs that are supposed to fly a few meters above water surface, in particular above vegetation canopy to avoid that the GPS signal is lost on board the UAV. From this point of view the sonar is able to measure up to 10 m range with a reduced beam divergence (around 30 cm), whilst the radar measures up to 60 m with 2° beam divergence in close-up range. In contrast, the laser prototype is expected to have low beam divergence (mainly depending on the distance between the laser pointers) and a measuring range up to 20 m.

3. Results

We will report results of ranging experiments for different water conditions in terms of different measuring ranges, water turbidity, waviness and natural illumination. The sensors will be tested from different ranges because the atmosphere scatters, adsorbs and transmits electromagnetic radiation and this this affects the measurements retrieved by the laser-based prototype, the radar and the TOF laser. Moreover, atmospheric conditions also affect the accuracy of the sonar since it influences sound waves properties and speed, which are mainly disturbed by changes in temperature profile. Water turbidity influences the scattering process because Mie scattering tends to be less significant (with respect to Rayleigh scattering) when water is clear. Furthermore, waviness is one of the key factor affecting measurement of the laser prototype, because reflections from the water surface will be intermittent and several acquisitions will be required. In this case, the possibility to have successful measurements depends on the exposure time of the camera. Moreover, water waviness also affects measurements from the radar, sonar and the TOF laser causing additional noise and disturbance. Lastly, natural illumination strongly reduces the possibility of the live MOS sensor to record the laser dots on water surface, in particular in the case of sun glint. Therefore, the four sensors will be cross-compared in order to evaluate which is the best technology to retrieve water level from UAVs in different environmental conditions.

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