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Acoustic side-scan on enclosed underwater environment

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***Abstract*— This paper brief introduces a ray tracing based mapping strategy that gathers the bottom information of an unknown enclosed water pond. This is done by an autonomous underwater vehicle, which equipped with acoustic transducer, performing acoustic Side-scans. The consequence of the mapping is a point cloud data.**

I. INTRODUCTION

Nowadays more and more industrial processes take place on liquid based environment, those industrial processes included but not limited to the undersea oil pipeline leakage detection, spent nuclear fuel storage pond monitoring, and chemical reagent synthesis in large-scale vessels. Unfortunately most of such processes take placed on risky and cluttered underwater environment they are difficult to access and monitor. Moreover, some environments pose additional hazards. For example, the spent nuclear fuel storage pond, it contains high radioactive metals such as Uranium and Plutonium [1] which are hazardous to human health, so such place is nearly impossible for human to work with even wearing a protection suite. In such circumstances, small-scale mobile underwater robots (micro-autonomous underwater vehicle or µAUV) could potentially be used to replace human to monitor the radiation level and explore the unknown underwater environment.

Underwater autonomous navigation is an important research topic in underwater robotics, whose purpose is to allow the robot to navigate and deploy safely from the starting position to the target position. A typical offline navigation process for a swimming pool sized underwater environment (nuclear storage pond) constitutes of 3 main procedures: environment mapping, occupancy map establishing, and path planning. Among them the environment mapping is the preliminary step, because the following procedures are relying on the data obtained by the environment mapping. In order to gather the bottom layout of the enclosed underwater environment, the acoustic side-scan is introduced. Other approaches such as Lidar or Radar are hard to implement in a cluttered underwater environment and too expensive or the instruments not fit to a small size AUV.

II. METHOD

Acoustic side-scan uses sonar devices that produce a conical beam downward to the pond bottom with a wide beam angle perpendicular to the path of the sensor through the water to measure the depth of the bottom [2] [3]. In practice, µAUV will project a vertical beam from a plane with specified height toward an area by high-frequency acoustic pulse emission in order to capture depth information about the corresponding bottom surface. The movement plane is set above clutters and sampled in a uniformly spaced 2d grid (see Figure 1). The µAUV will move to each grid and measure the depth of the current grid by the received pulse that reflected off from the object's top surface. A routine of this survey is shown in Figure 2. The result of an aerial survey is an array of tuples, whose components are measurement positions and its corresponding height. This dense elevation point data is called "point cloud". See Figure 3 for the input and output of this method.

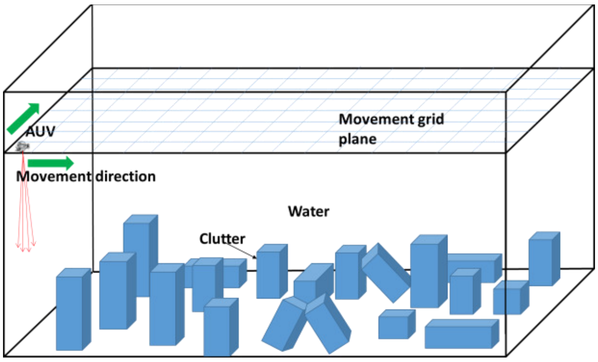

Figure 1: Regular grid acoustic side-scan

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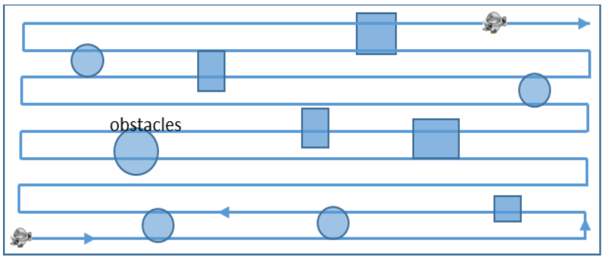

Figure 2: Scan itinerary

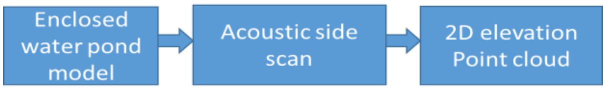

Figure 3: Diagram of input and output

The acoustic Side-scan is carried out by acoustic sensors which rely on modulating surface acoustic waves to sense a physical object. These devices transduce electrical signals to acoustic waves, receive reflected waves, and convert received waves back to electrical signal [4]. During the wave propagation, acoustic waves will be reflected, refracted, or attenuated by the medium. For the depth measurement the reflection is the main concern. In terms of analysis, the form of wave in depth measurement is not convenient, but the characteristic of the wave is approximate to a ray, so the ray tracing algorithm is introduced [5]. The acoustic wave propagations are regarded as rays, and the conical beam is constituted of finite number of rays. The depth can be calculated by knowing the time interval between the transmitted signal and received signal and the propagation speed of the acoustic ray.

The main problem is finding the correct signal (ray) from the received signal spectrum. Because there are unwanted signals and background noises in the received signal spectrum. The background noise includes reflections from small objects, reflections of sidelobes or part of reverberation (especially in shallow waters), the unwanted signal includes later reflections (signal that have multiple times of reflections) and diffuse reflections (signal that scatters in all direction when hits an object). Therefore, the useful signal is the normal reflection of the emitted ray, because a receiver and a transmitter combined in one device (transceiver), so the only first order specular reflection can be received is the normal reflection. Theoretically, it is reflected off the nearest obstacles and has the highest remaining energy [5]. Based on this property, 2 key factors can be used to estimate the normal reflection: time of flight (TOF) and response energy level. In the impulse response in time domain, the normal reflection signal is the pulse with the highest energy response and the shortest TOF. Once the TOF of the desired signal is known, the depth is given by the equation:

$$Depth = v * \frac{t}{2}$$

Where v is the speed of sound in water and t is the time of fight of the normal reflection signal.

For a horizontal surface, the transceiver will always receive the normal reflection signals. However, for the case of inclined surface, it is possible that normal reflection signal do not exist (no ray is perpendicular to the inclined surface see Figure 3.a). The way to address this problem is to propose a wide projection beam angle and ensure there is normal reflection. See Figure 3.b.

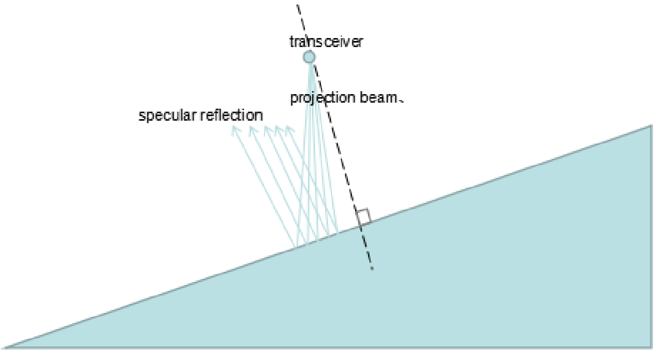

Figure 3(a): Small beam without normal reflection

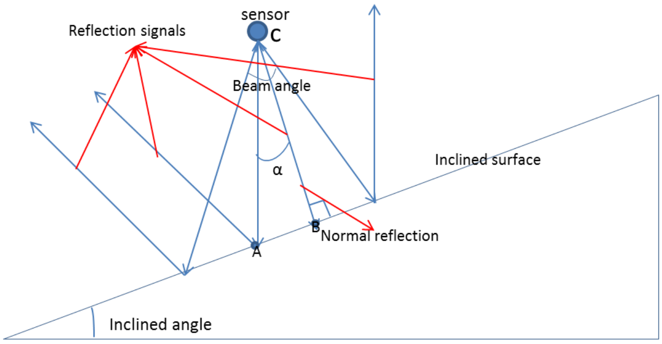

Figure 3(b): Wide Beam with normal reflection

III. RESULTS

A. *Depth measurement simulation*

There is a MATLAB model to illustrate how the depth can be calculated from received impulse response. See Figure 4(a): a scan above an obstacle. Assume this scanning beam is consisted of 21 rays (the beam angle is 20 degree, one ray for 1 increment degree). Assume each ray carried the same amount of energy (150 units), once the ray hit objects, its energy will be dissipated, assume the remaining energy of specular reflection signal is 50% of the total energy, and remaining energy of each diffuse reflection signal is 5% of the total energy. The corresponding energy impulse response of each received ray in time domain is shown in Figure 4(b). The signal that is useful to depth measurement is the first pulse, because it has the shortest TOF and highest impulse response, so it is the normal reflection ray. The TOF of this signal is 0.00696s; the depth can be calculated is 0.00696*1450/2=5.04657m.

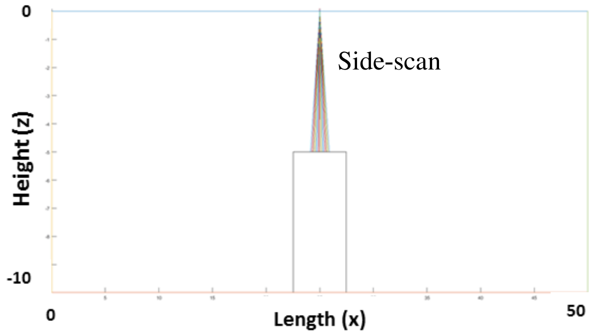

Figure 4(a): Acoustic scan with 20 degree beam angle

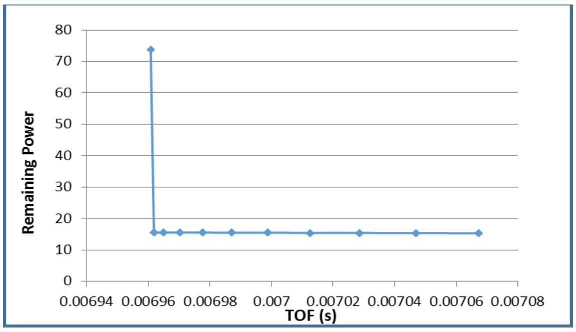

Figure 4(b): Energy impulse response of each received ray

B. *Well-organised modern nuclear storage pond*

The used nuclear fuel containers in modern storage pond are well-organised and regularly placed. They are equipped with storage racks designed to hold each container. An example of a modern nuclear storage pond is shown in Figure 5(a) and its geometry representation is shown in Figure 5(b).

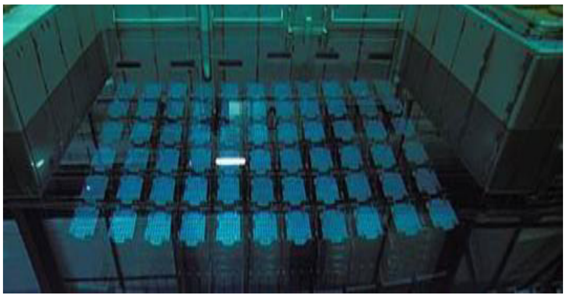

Figure 5(a): True pond

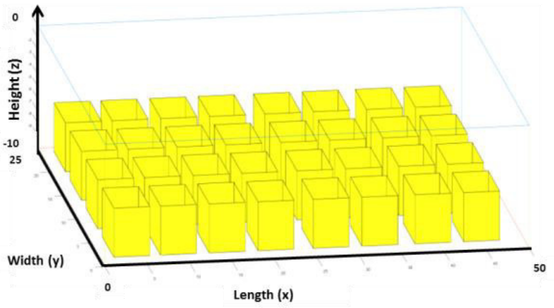

Figure 5(b) MATLAB pond model

Assume the pond is a 50m*25m swimming pool sized enclosure with a depth of 10m. Assume the side-scan sampling resolution is 0.5m*0.5m, the obtained point cloud data and its' corresponding surface plot are shown Figure 6(a) and 6(b) respectively.

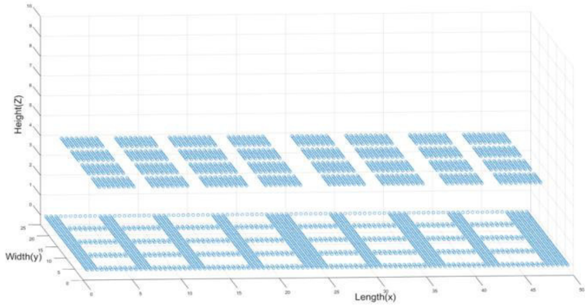

Figure 6(a): Point cloud model

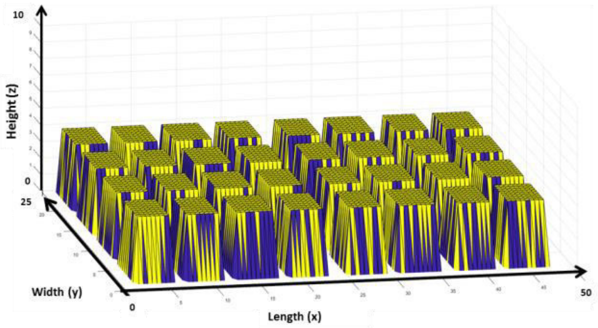

Figure 6(b): Surface plot

The surface plot is a MATLAB function which creates a continuous surface based on the obtained discrete sampling points. This simulation shows an image of what information is obtained by acoustic side-scans.

IV. CONCLUSION

Ray tracing based acoustic side-scan will follow the proposed route to measure the elevation of each measurement point. The consequence of the whole pond survey is a matrix of tuples (x, y, z coordinates) of the pond's bottom environment. This data is the 2D projection of the 3D clutter on to the measurement plane. This is a preliminary step of offline underwater navigation of µAUV. The scanning process must be performed on-line, while path planning might be performed off-line. The gathered point cloud data will be further processed with point interpolation to construct a 3D point cloud model (fill the gap between the ground and the top surface of measured objects), and then convert it to an occupancy grid map. Once competed, path planning algorithms can be applied to the reconstructed occupancy grid map in order to plan a collision free path.

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