One-Shot Underwater 3D Reconstruction

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Motivation

Underwater environments are highly unstructured and limit the availability and effective range of sensors. There are three main problems to solve:

Limited visible range

The visible range is limited in UW environments. It is better to use polarized light or laser.

Time

A full 3D scan takes time. To avoid that, a one-shot reconstruction method is advisable.

Featureless environments

Underwater environments are hard to map. The solution is to use active systems.

Advantages & Limitations

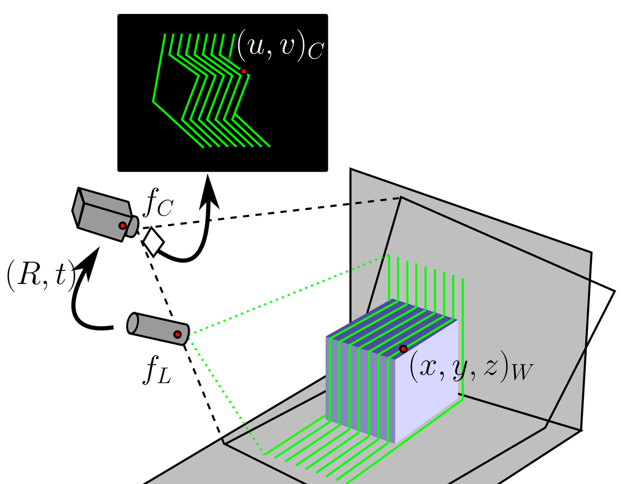
LLS = Laser Light System
SLS = Structured Light System
SV = Stereo Vision

The available sensors in the market suffer from the following drawbacks and advantages.

Technology	Advantages	Drawbacks	Range	Accuracy	Cost
SONAR	Tested	Contrast, echoes	L	$\sim 1\ cm$	€€€
LIDAR	Low Backscatter	Time, Min distance	M-L	$\sim 1\ cm$	€€€
LLS	Low Backscatter	Time, Movement	M	$\sim 1\ mm$	€€
SLS	Reconfigurable	Time, Movement, Backscatter	S-M	$\sim 1\ mm$	€
SV	Reconfigurable	Light, Features	S-M	$\sim 1\ mm$	€

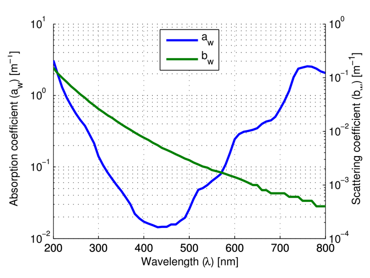
There are few sensors that combine light projection with laser technology, such as our new developed Laser Based Structured Light system.

Design



The sensor is formed by a camera and a green laser. In front of the laser, a Diffractive Optical Element (DOE) modifies the beam shape to a set of parallel lines. These lines are projected on the scene and recovered by the camera.
The laser lines have to be detected in the camera image, its peaks extracted and matched to their corresponding source laser line. Once the relation between a peak pixel and the laser plane is known, the 3D information can be computed by triangulation.

Light Absorption and Scattering



To transmit the maximum light, the addition of these coefficients has to be minimum (450 nm).

$$I = I_0 e^{-(a+b)z}$$

Blue - Green color spectra present a good compromise.

Pipeline

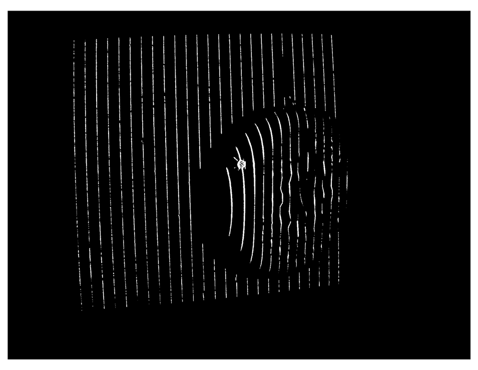
Acquisition

The camera exposure is automatically set so only the central dot of the laser can be saturared.
Geometric and color calibration are performed beforehand with a checkerboard and a white target.
Laser calibration is performed detecting the laser lines at known depths and fitting a plane for each line.

Segmentation

Background illumination is removed by subtracting the red channel to the green channel.
Then, the laser peaks are detected using a weighted mean over 5 pixels of the original image.

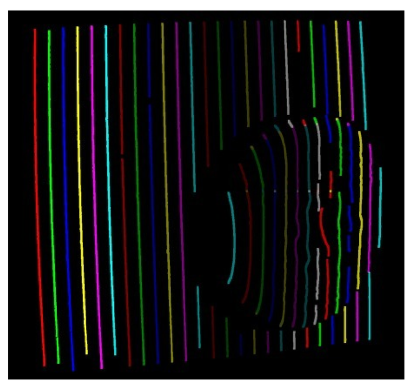
$$\hat{\delta} = \frac{2f(x-2)+f(x-1)+f(x)+f(x+1)+2f(x+2)}{f(x-2)+f(x-1)+f(x)+f(x+1)+f(x+2)}$$



Decoding

Solution of the correspondence problem by a floodfill algorithm.

The floodfill algorithm looks for all pixels in the image which are connected to the start pixels by a path of the target color, and changes them to the replacement color. The start pixels are selected as rows where 25 crossings have been found.



Triangulation

Each 3D point $p(t)$ can be computed by triangulating its corresponding laser plane π_n to the line formed by joining the segmented pixel to the camera focal point, which depends on the scale factor t.

$$\pi_n : \quad Ax + By + Cz + D = 0 \qquad (1)$$

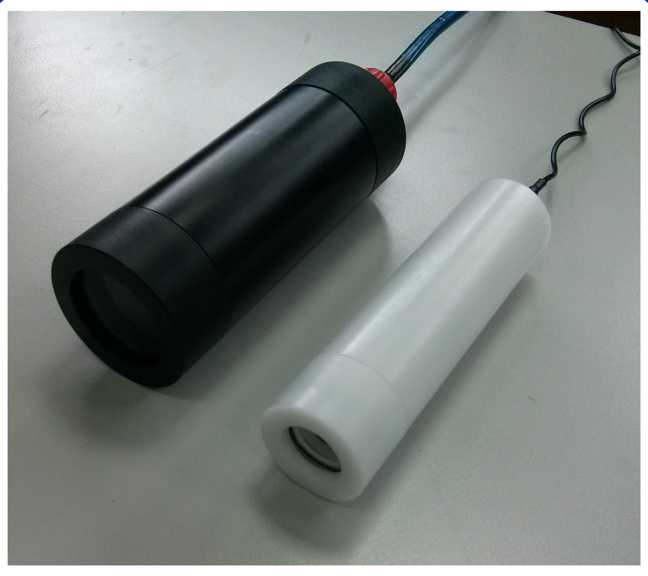
$$p(t) = \left(\frac{u - c_x}{f_x} t, \frac{v - c_y}{f_y} t, t \right) \qquad (2)$$

$$t = \frac{-D}{A\frac{u-c_x}{f_x} + B\frac{v-c_y}{f_y} + C} \qquad (3)$$

where (f_x, fy) is the camera focal length in x and y axes. (c_x, c_y) is the central pixel in the image. (u, v) is the detected laser peak pixel in the image.
Replacing 3 in 2, the 3D coordinates of the point are obtained.

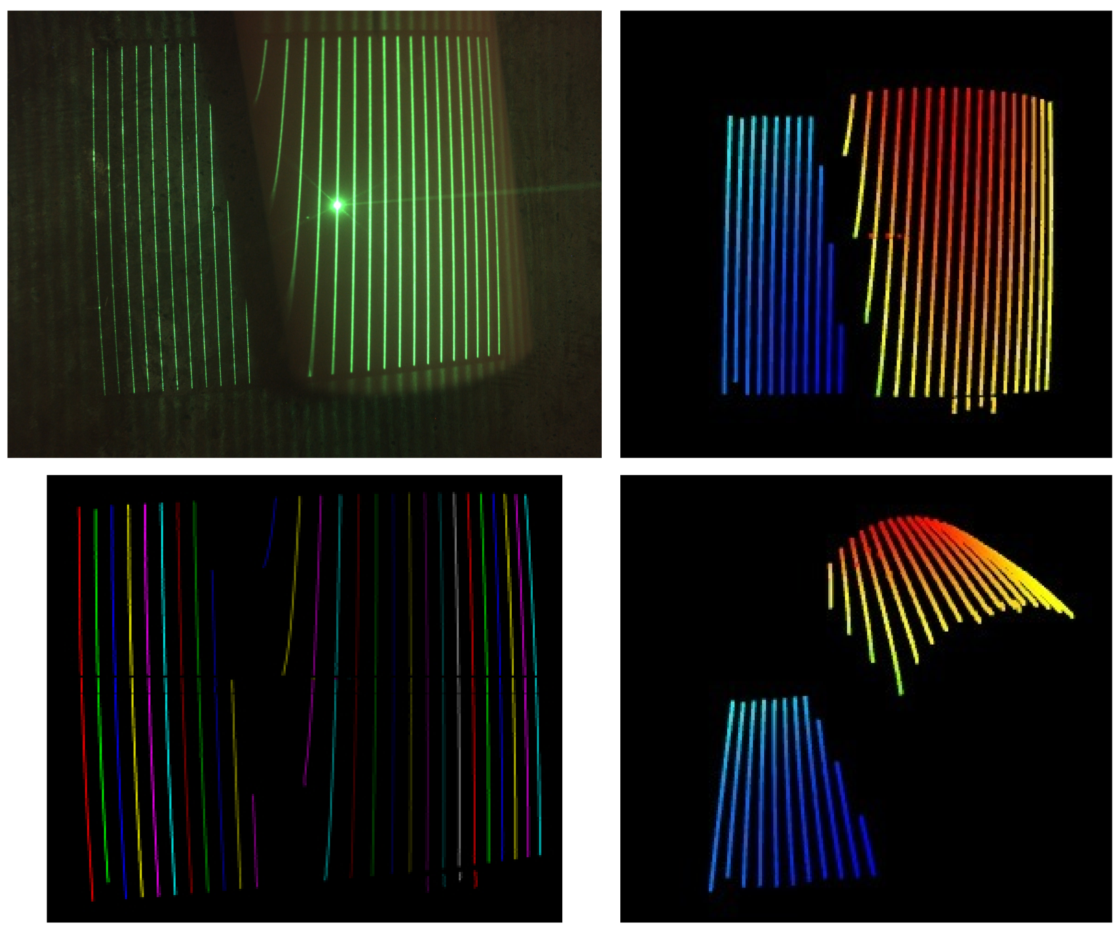
Experimental results

Experimental setup

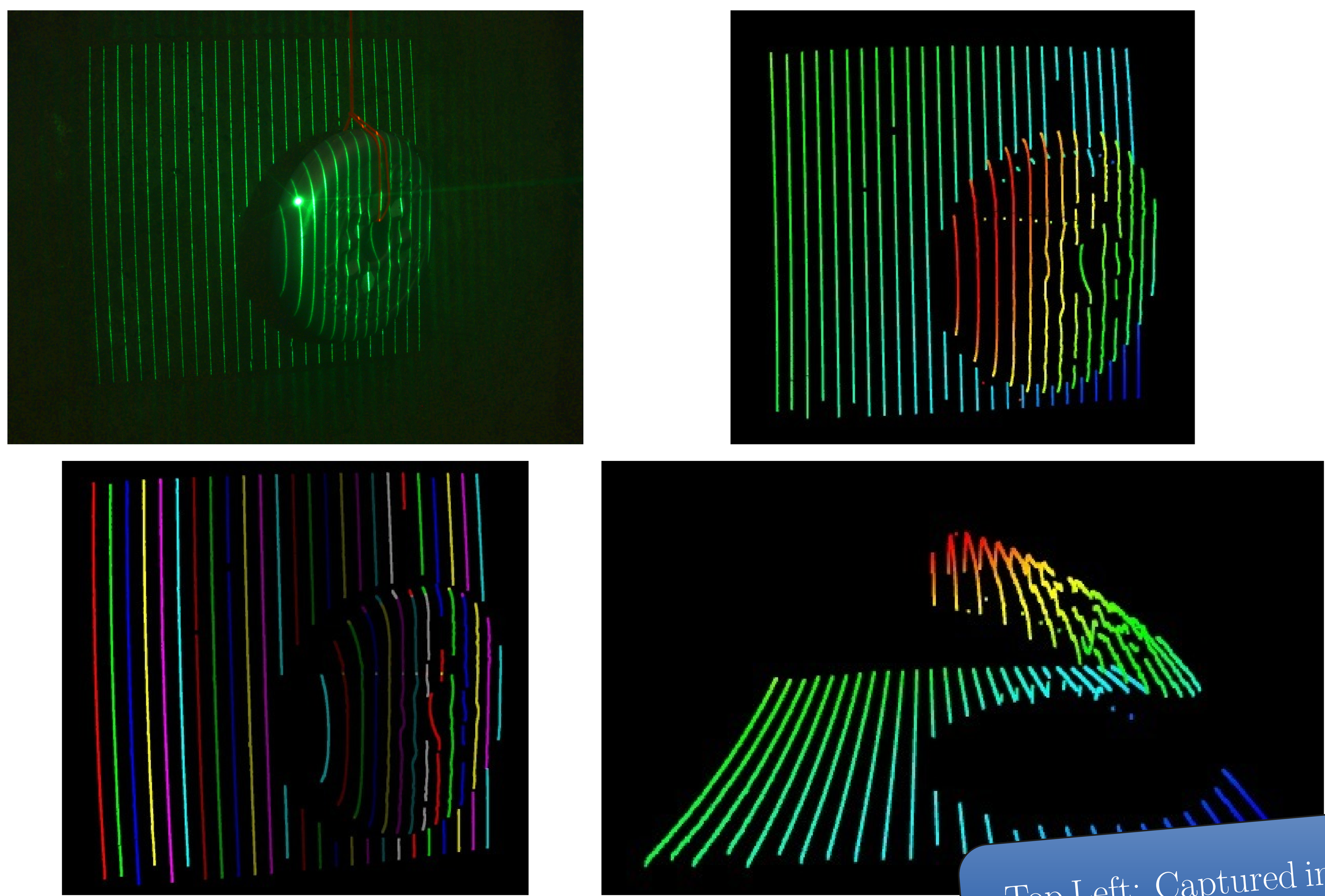


- ▷ 1920 × 1440 px color camera.
- ▷ 532 nm, 5 mW green laser
- ▷ 25 Parallel line DOE

The system has a baseline of 20 cm and it is rated for 200 m.



3D reconstruction of a pipe



3D reconstruction of wheel

Top Left: Captured image
Bottom Left: Decoding
Right: 3D Data

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