Title	Thesis proposal
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Evaluation of Image Filtering Techniques for 3D Laser Triangulation

1. Context

3D Laser Triangulation is a non-contact method to measure the height profile of an object by analyzing the deformation of laser line on a 2D image. shows a simplified laser-based triangulation system.

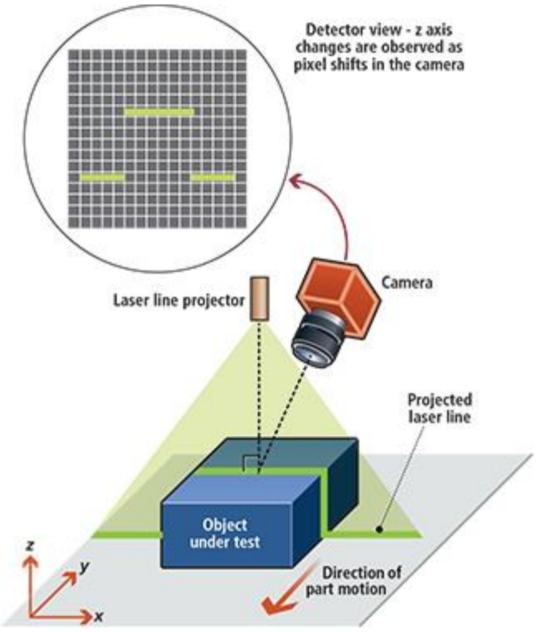

Figure 1 - Simplified laser triangulation system.

In 3D Laser Triangulation, a narrow band of light projected onto a 3D surface produces a line of illumination that will appear distorted from an observation perspective other than that of the projector.

Analysis of the shape of these line images can then be used to achieve an accurate geometric reconstruction of the object's surface shape [Understanding laser-based 3D triangulation methods, Vision Systems Design, 2015].

For an accurate height measurement, the key issue is to define precisely the position of a projected laser line on a 2D image. Peak Detection, Maximum Detection, and Center of Gravity are popular

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algorithms to extract the laser line position. However, none of these algorithms are robust to artefacts commonly present in images containing light pattern projections. The most common of these artefacts are Laser Speckles (Figure 3).

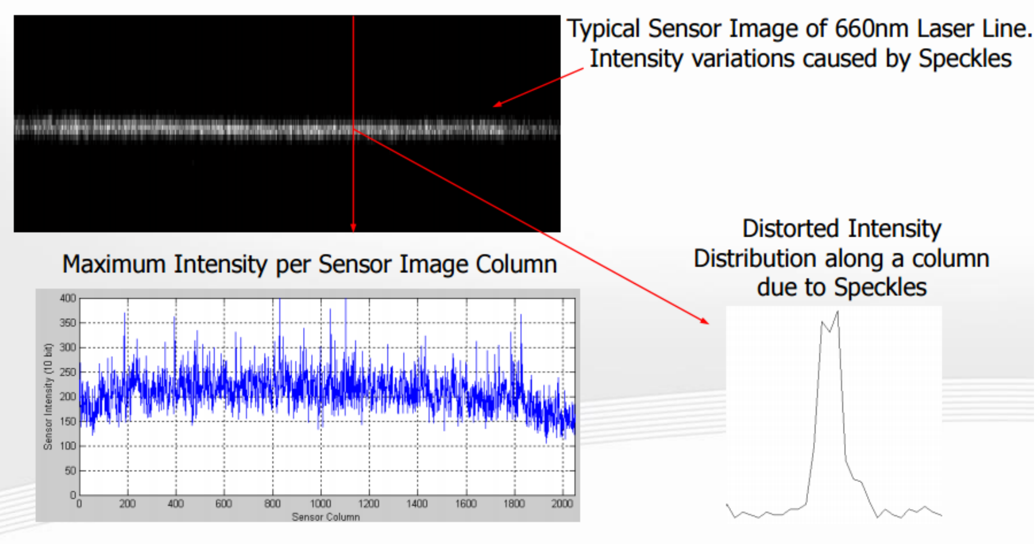

Figure 2 – Noise due to Laser Speckles Phenomenon.

2. Objective

The objective of the present proposal is to explore different 2D image filtering techniques in order to improve accuracy of the laser line extraction. The study could start with a revision of line extraction algorithms, evaluating the advantages and drawbacks of each method considering different scenarios, e.g., coherent line projector with different wave lengths, non-coherent line projectors, reflectance of the projected line on different materials, etc. This revision could be followed by an analysis of the State of the Art filtering techniques targeting similar problems. A classification of these techniques in terms of efficiency, computational performance, and computational complexity could be interesting to help choosing the filters that are better fitted to industrial applications. The software implementation of the chosen filters followed by an analysis of their results on real images acquired in our 3D Optical Laboratory will give the main results of this work. Extensions of this work regarding other applications that could take advantage of these filters could also be interesting. For instance, QR code extraction could also be improved by suppressing artefacts similar to the ones present in line projection images.

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3. Appendix

Laser Line Extraction Algorithms

A Laser Line Extraction (LLE) algorithm is required to create a **heightmap** based on a sequence of profiles of the object captured by the camera sensor.

The objective of an LLE algorithm is to estimate the position where a laser line horizontally crosses a Region of Interest (ROI). The detection can be done by analyzing each column of a frame individually.

An LLE algorithm typically outputs a data array containing the vertical position of a detected laser line along of a ROI, i.e., each computed ROI produces a single data array. Figure 3 illustrates the heightmap generation.

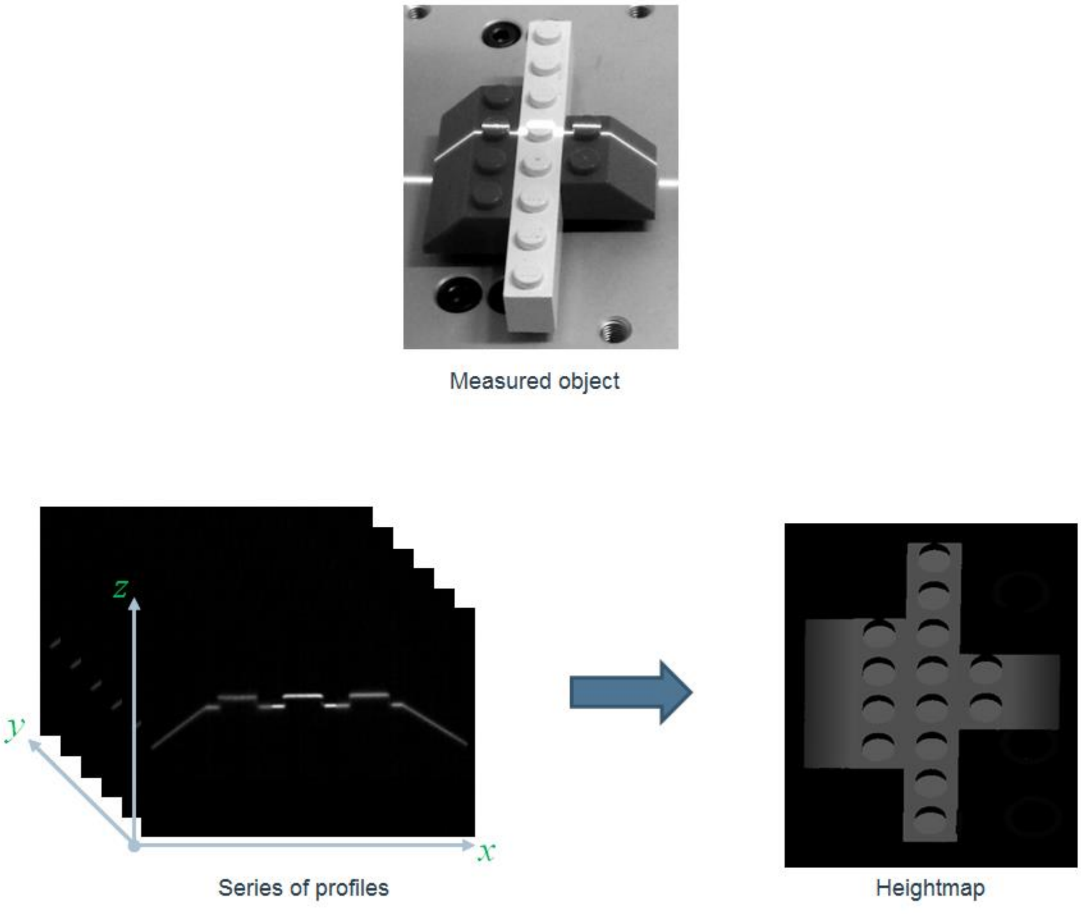

Figure 3 - Heightmap generation.

Maximum Detection and **Peak Detection** LLE algorithms are described hereafter.

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Maximum Detection

The **Maximum Detection** algorithm analyzes all pixels in a column in order to determine which one has the maximum value. Figure 4 shows the laser line position on a given ROI column.

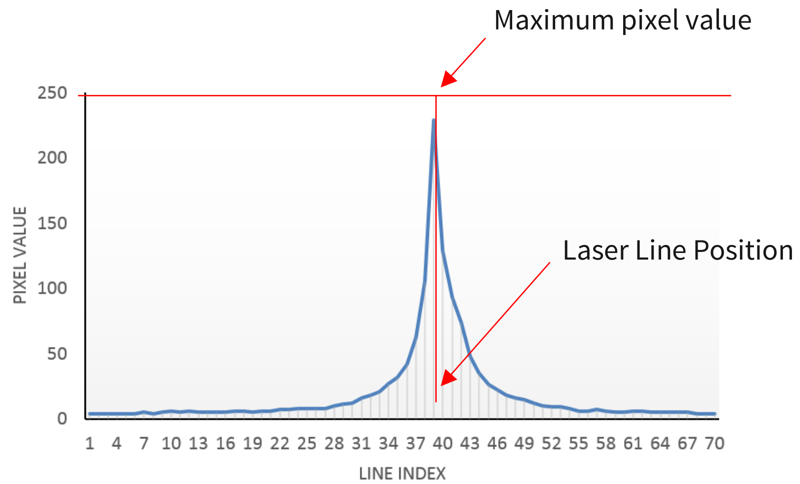

Figure 4 - Maximum Detection on a ROI profile.

It is also desirable to include in the processing chain a **Low-Pass Filter** to reduce the high frequency variations in the image and a **Threshold** to eliminate the background noise from the sensor.

When a maximum value is detected in more than one pixel on a given ROI column, the Maximum Detection algorithm will indicate the position of the one that correspond to the highest height.

Peak Detection

The **Peak Detection** algorithm relies on a discrete simplification of the first derivative function.

$$\frac{df}{dx} = f(x+1) - f(x-1) = f'(x)$$

The $f'(x)$ outputs the slope of a given $f'(x)$ along the x (Figure 5).

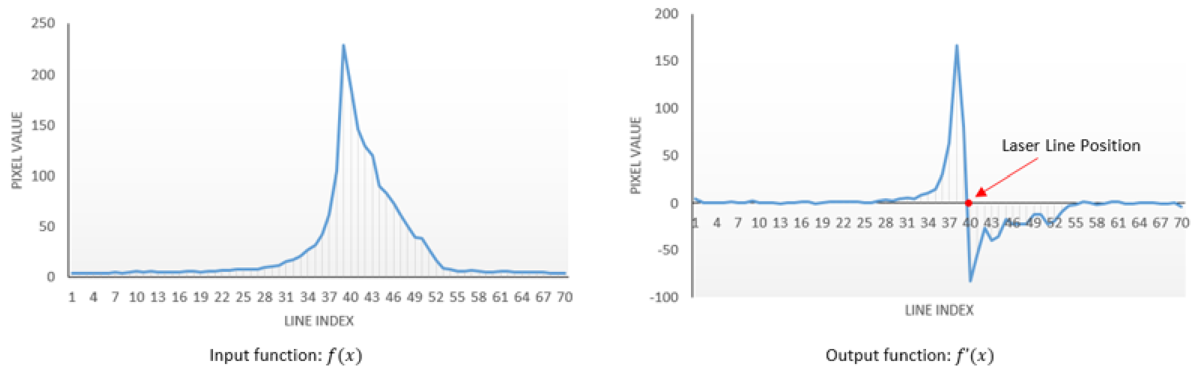

Figure 5 - f(x) and f'(x) plots.

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We can detect the position where $f'(x)$changes its signal and, based on the two-point form line equation:

$$x = \frac{x_1 y_2 - x_2 y_1}{y_2 - y_1}$$

Where (x_1, y_1) and (x_2, y_2) are two points on the line with $x_2 \neq x_1$, we obtain the following equation for $y = 0$:

$$x = \frac{x_1 y_2 - x_2 y_1}{y_2 - y_1}$$

When more than on peak are detected on a given ROI column, the Peak Detection algorithm will indicate the position of the one where the corresponding $f(x)$ pixel has the highest value. If more than one corresponding $f(x)$ pixel have the same condition (highest value), then the position equivalent to the highest height will be indicated.

4. References

- **Novel Bayesian Multiscale Method for Speckle Removal in Medical Ultrasound Images**, IEEE Transactions on Medical Imaging, 2001.
- **Evaluation of denoising algorithms applied to the reduction of speckle in digital holography**, 23rd European Signal Processing Conference (EUSIPCO), 2015.
- **3D scanning using multibeam laser**, Master Thesis - Technical University of Denmark, 2005.

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