Monitoring the failure of fluvial dikes using a Kinect sensor

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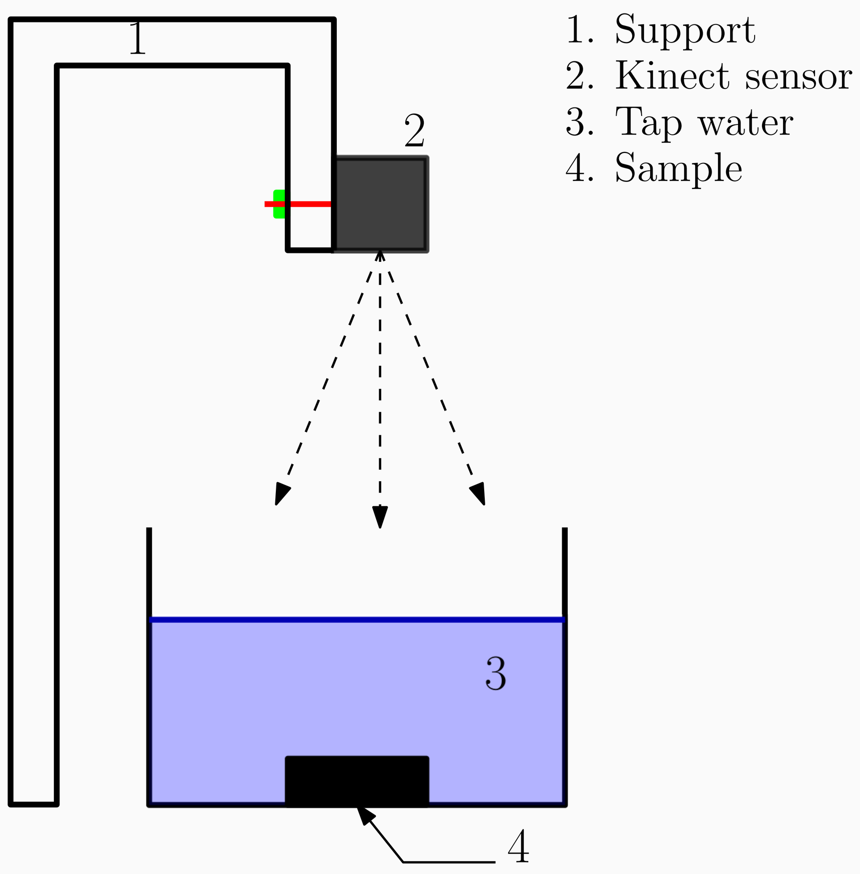
Objective

Assess the ability of the low-cost widely-available Kinect depth sensor to monitor the geometry of a model of a failing fluvial dike. Highlight possible limitations.

Experimental setup and coding requirements

- Interfacing Kinect sensor with C#(less freedom w.r.t. libfreekinect2 but easier);
- Correction algorithm for refraction and Time-of-Flight (ToF) offset.

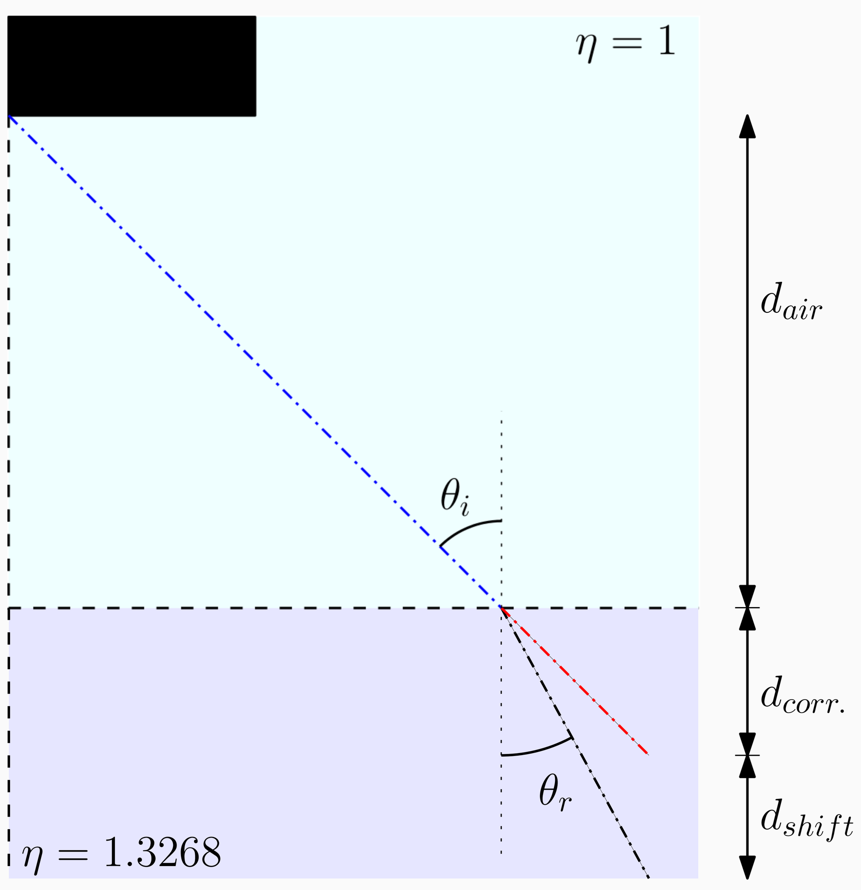


Correction algorithm

- First problem: ToF offset due to multiple media.

$$t_{\text{pix.}} = d_{\text{pix.}}/c_{\text{air}}$$
$$t_{\text{air}} = \color{red}{d_{\text{air}}}\color{black}/c_{\text{air}}$$
$$c_{\text{w}} = c_{\text{air}}/n(\text{w,20°C,830 nm})$$
$$t_{\text{w}} = t_{\text{pix.}} - t_{\text{air}}$$
$$\Rightarrow d_{\text{corr.}} = t_{\text{w}} \cdot c_{\text{w}}$$

- Second problem: refraction due to interface between two media.



Using the law of sines:

$$d_{\text{shift}} = \frac{d_{\text{corr.}}}{\sin(\frac{\pi}{2} - \theta_i)} \cdot \frac{\sin(\theta_i - \theta_r)}{\sin(\theta_r)}$$
$$\Rightarrow d_{\text{pix.,corr.}} = d_{\text{pix.}} - d_{\text{shift}}$$

- Third problem: find the angle of incidence. Multi-step approach:
  - Calibrate the sensor using 3 distortion coefficients, focal lengths and principal points.
  - Compute real x and y coordinates, z being the value of each pixel (uncorrected).
  - Transform the Cartesian (x, y, z) system to a spherical system (ρ, θ, ϕ).
  - Compute θ_r with Snell's law.
  - Compute successively, for each pixel: $d_{\text{corr.}}$, d_{shift} and $d_{\text{pix.,corr.}}$ which is the final depth value after correction.

Results

To evaluate the influence of water depth and material, measures were done with 2 materials. The measured depth is reported as a function of water depth.

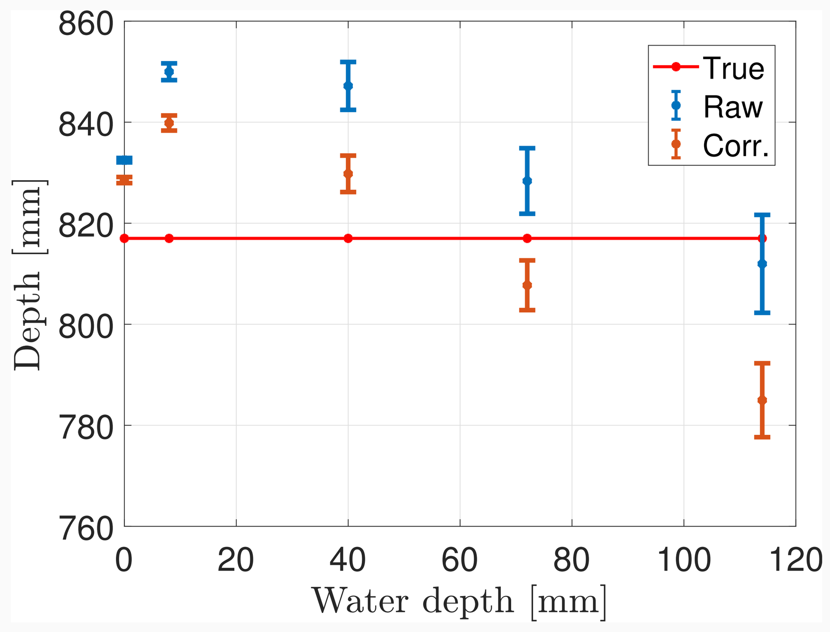


Figure: Painted Metal (P. M.).

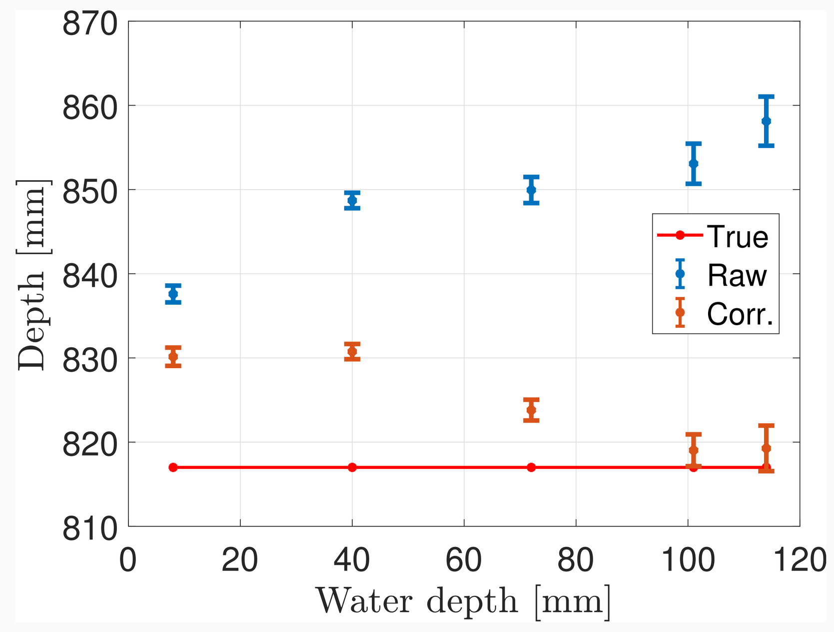


Figure: Non-Painted Metal (N.-P. M.).

Limitations

- A fraction of the depth pixels have a zero value, depending on the material:

N.-P. M.	0.384/8	0.319/40	0.188/72	0.106/101	0.106/114
P. M.	0.123/0	0.0458/8	0.0456/40	0.0565/72	0.0497/114

Table: Fraction of zero-valued pixels (%) / water depth [mm].

This is explained by reflection on the material (lowered by painting) and too low distance between the Kinect and the sample. Water depth is a key factor.

Untackled sources of error

- Temperature dependence of the depth map, spurious results in the vicinity of sharp corners, assessment of the behaviour of gravels and wood.

Future work

- Use two Kinects $(1, 2)$ to get rid of the knowledge of d_{air}:
  - $\theta_{i,1}$, $\theta_{i,2}$, $\theta_{r,1}$, $\theta_{r,2}$ are known

$$\Rightarrow f_j(\theta_{r,j}, \theta_{i,j}) = \frac{\sin(\theta_{i,j} - \theta_{r,j})}{\sin(\frac{\pi}{2} - \theta_{i,j})\sin(\theta_{r,j})};$$

  - Assuming $d_{\text{air},1} = d_{\text{air},2} = d_{\text{air}}$, one gets:

$$d_{\text{pix.},1} - d_{\text{shift},1} = d_{\text{pix.},2} - d_{\text{shift},2}$$
$$\Leftrightarrow d_{\text{air}}(f_1 - f_2) = d_{\text{pix.},2}(n - f_2) - d_{\text{pix.},1}(n - f_1)$$

The initial correction algorithm can then be applied. A new acquisition software must be implemented, ensuring the two Kinects never probe simultaneously to avoid interference.

Conclusion

The implemented algorithm shown the possibility of correcting refraction- and ToF-induced errors in a satisfactory extend. The painting of metal surfaces decreases the amount of zero-valued pixels, but the corrected results are less satisfactory. The developed method requires the knowledge of the thickness of the air layer separating the Kinect from the free-surface. A method was proposed to overcome this problem.