UltraDepth: Exposing High-Resolution Texture from Depth Cameras

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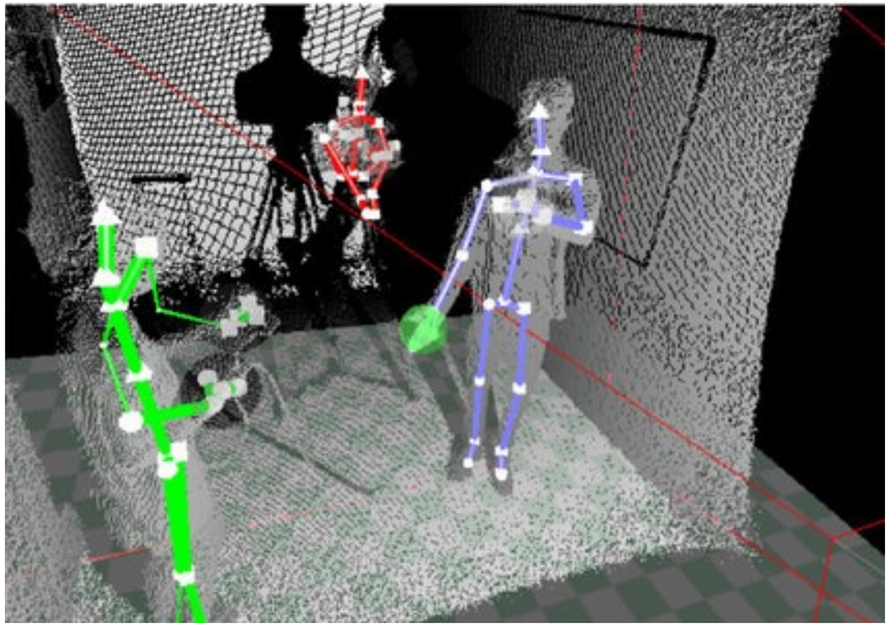
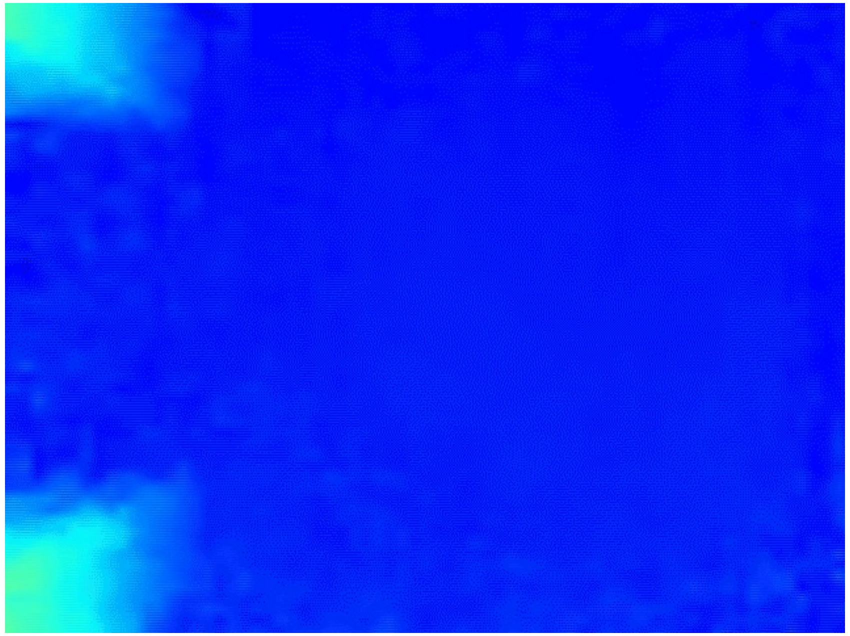
ToF Camera: Applications

With RGB



Skeleton tracking

ToF only



People counting & surveillance

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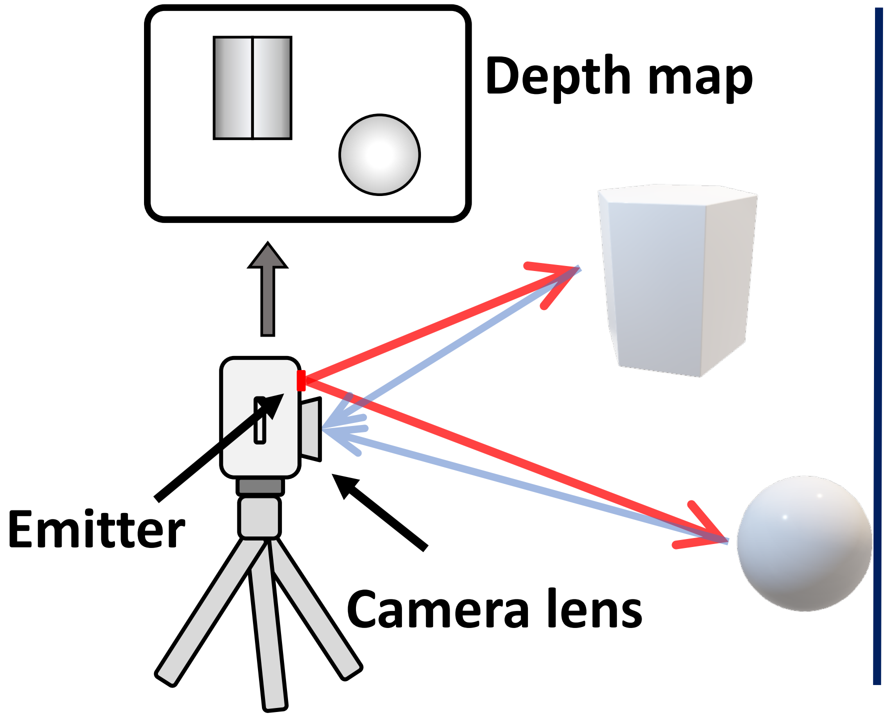
ToF Camera: Principle



$$\text{distance} = \frac{S_2}{S_1 + S_2} \cdot \frac{cT}{2}$$

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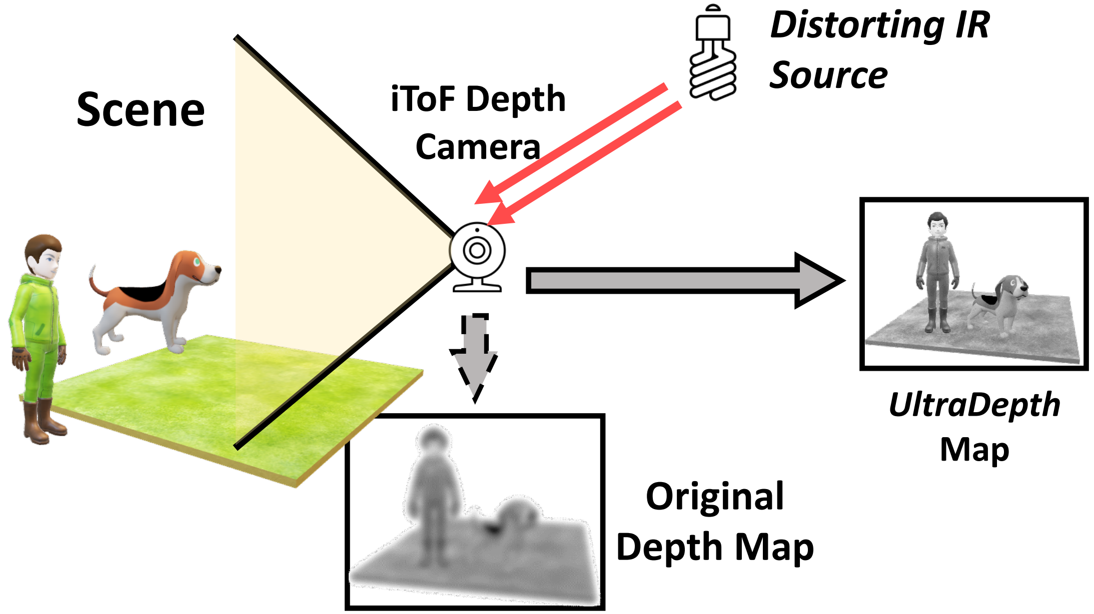
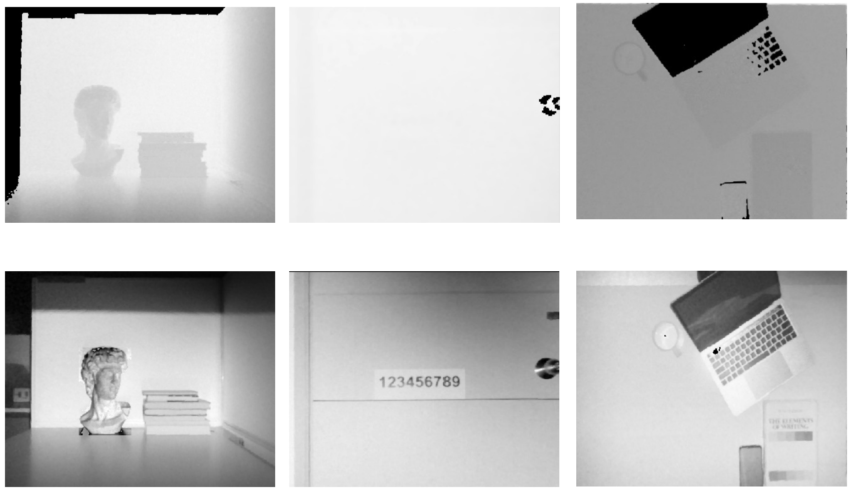
UltraDepth: System Overview





- *UltraDepth* is designed to expose high-resolution texture from the depth maps
- *UltraDepth* is realized by introducing distorting IR source

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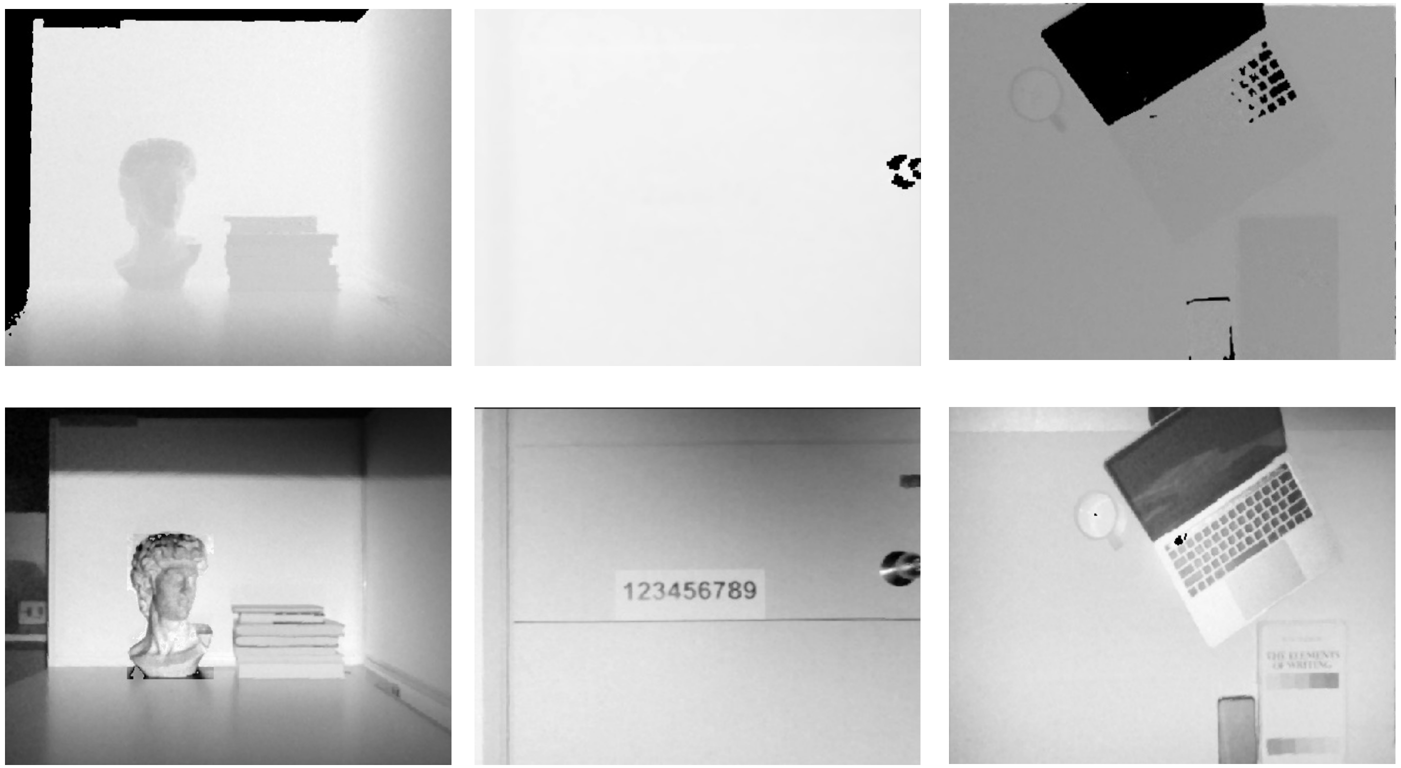
UltraDepth: System Overview

Ordinary depth map

***UltraDepth* map**



- Augment depth-based applications
- Launch privacy attacks to ToF cameras

UltraDepth: Key Idea

- By introducing a distorting IR source, the distance measurements are changed.

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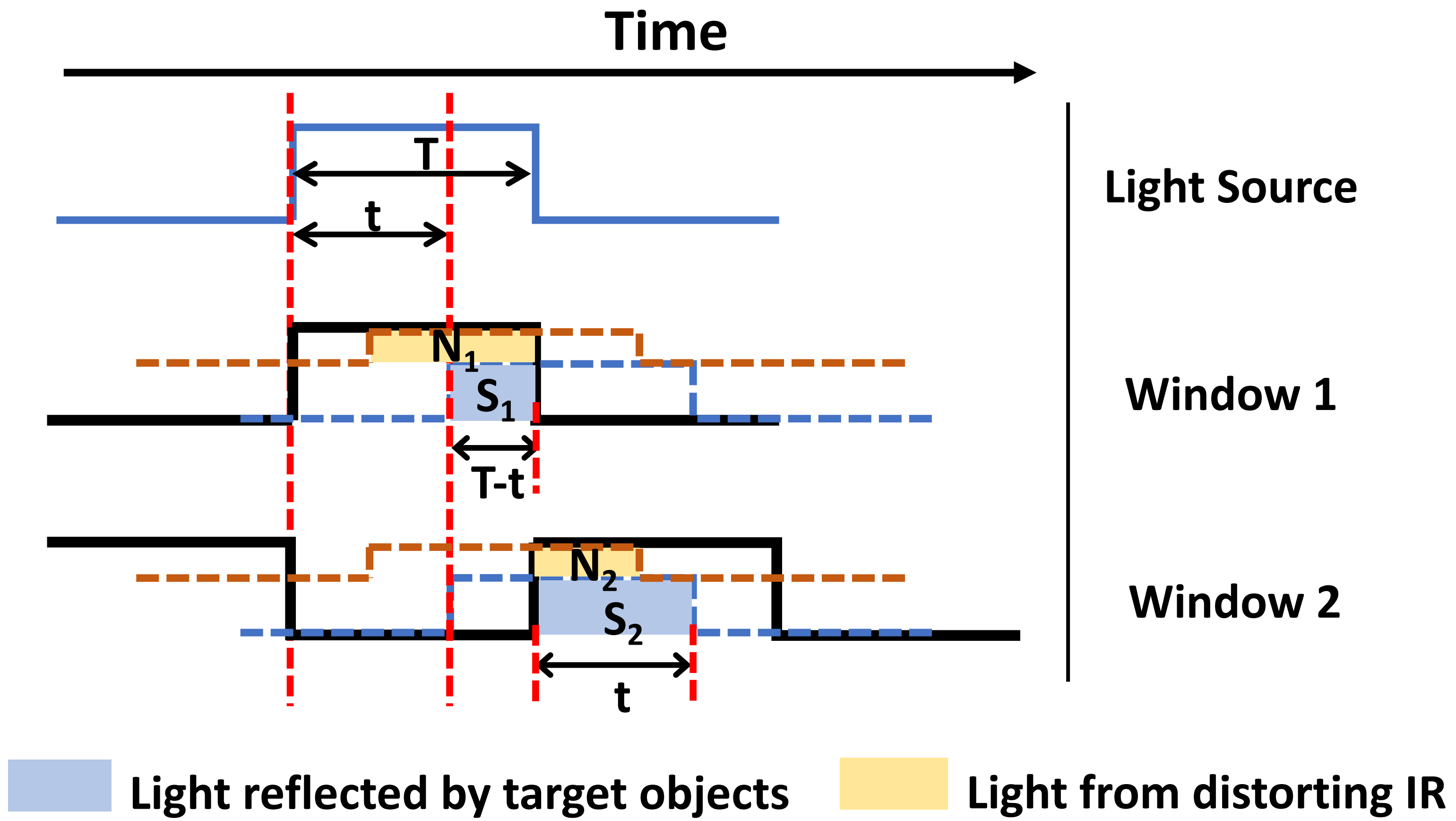
UltraDepth: Analysis on Distorting IR



The real distance is:

$$d = \frac{S_2}{S_1 + S_2} \times \frac{cT}{2}$$

The measured distance is:

$$\tilde{d} = \frac{S_2 + N_2}{S_1 + S_2 + N_1 + N_2} \times \frac{cT}{2}$$

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UltraDepth: Analysis on Distorting IR

The measured distance is:

$$\widetilde{d} = \frac{S_2 + N_2}{S_1 + S_2 + N_1 + N_2} \times \frac{cT}{2} \Longrightarrow \widetilde{d} = \left[1 - \frac{[(N_1 + N_2)d - N_2 D]d}{ET + (N_1 + N_2)d^2}\right] \times d$$

$d > \frac{N_2}{N_1+N_2} D$, the measured distance will be smaller than the real one.

(*d* is the real distance, *D* is the range of measurement)

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UltraDepth: Analysis on Distorting IR

The measured distance is:

$$\widetilde{d} = \frac{S_2 + N_2}{S_1 + S_2 + N_1 + N_2} \times \frac{cT}{2} \Longrightarrow \widetilde{d} = \left[1 - \frac{[(N_1 + N_2)d - N_2 D]d}{ET + (N_1 + N_2)d^2}\right] \times d$$

$E = E_0 \alpha \cos\theta / (8d^2)$, determines how distorted the distance measurement.

(E_0 is a constant, α is the reflectivity of objects, θ is the angle of incidence)

UltraDepth: Exposing Textures in Depth maps

For two points A and B, with:

- The same distance & distorting IR.
- Different reflectivity and angle of incidence.

$$\tilde{d} = \left[1 - \frac{[(N_1 + N_2)d - N_2 D]d}{ET + (N_1 + N_2)d^2}\right] \times d$$

⇓

Different distance measurement.

⇓

The distance measurement is distorted according to the reflectivity and angle of incidence, which are texture-related.

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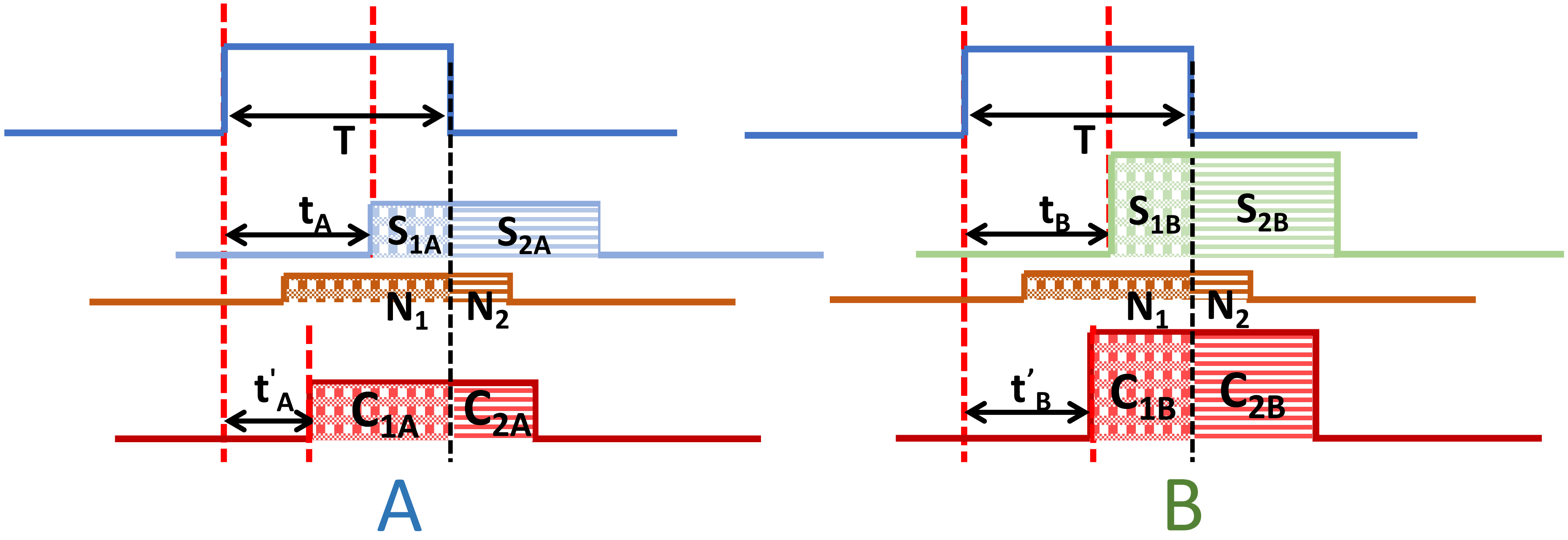
UltraDepth: Exposing Textures in Depth maps

From a diagrammatic perspective:



$$t_A = \frac{S_{2A}}{S_{1A} + S_{2A}} = \frac{S_{2B}}{S_{1B} + S_{2B}} = t_B \qquad t_A' = \frac{C_{2A}}{C_{1A} + C_{2A}} \neq \frac{C_{2B}}{C_{1B} + C_{2B}} = t_B'$$

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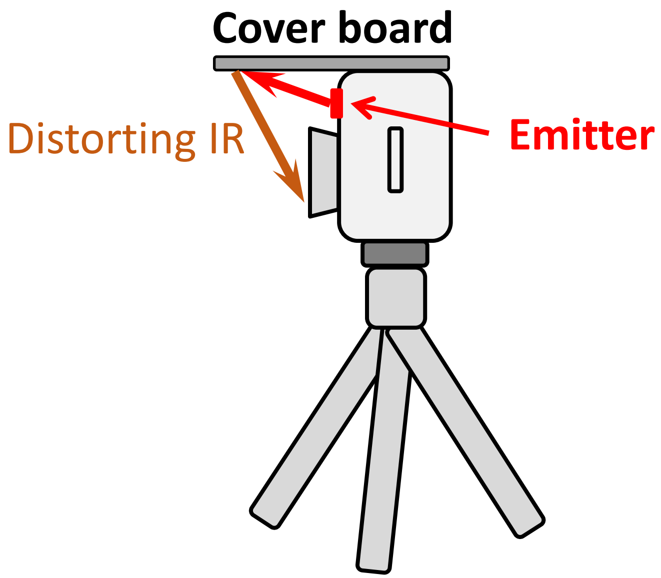
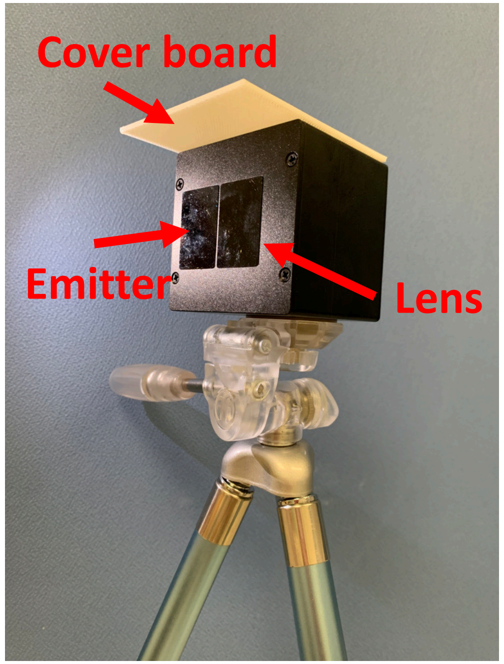
UltraDepth: Reflection Implementation



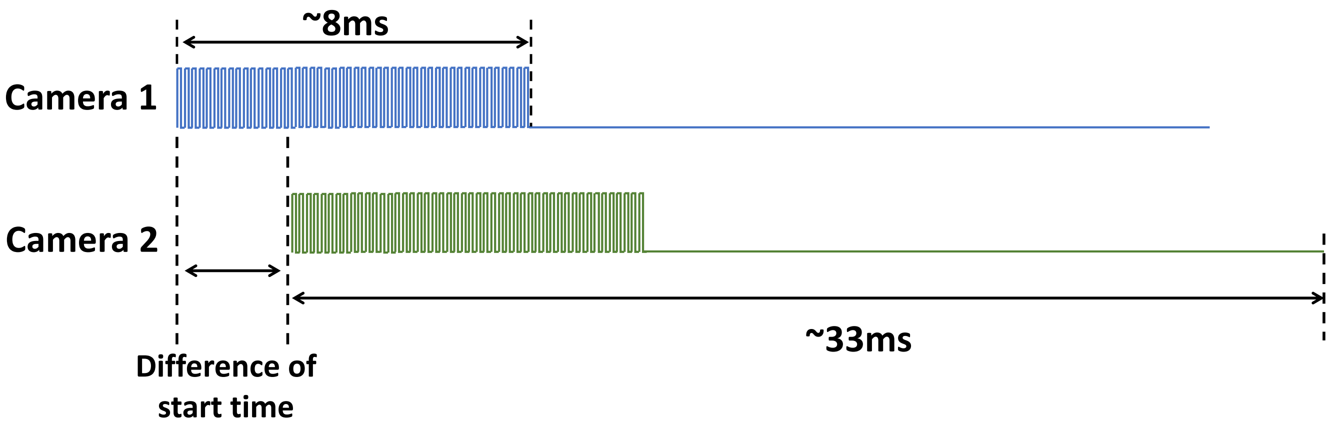


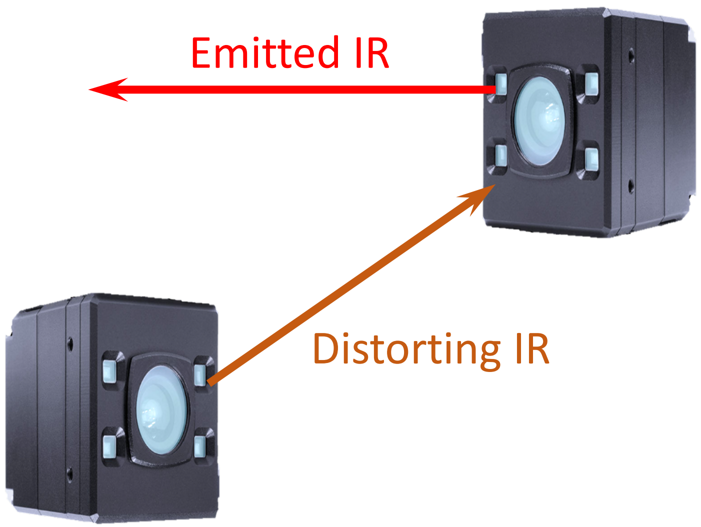
- Part of the emitted IR is reflected by the cover board and serves as distorting IR.
- The material of cover board is not strictly limited. Common objects like walls, furniture can also work.

UltraDepth: External IR-based Implementation

- To use another ToF camera with the same model as distorting IR source.

- Objective: To align the emission time of the two cameras.





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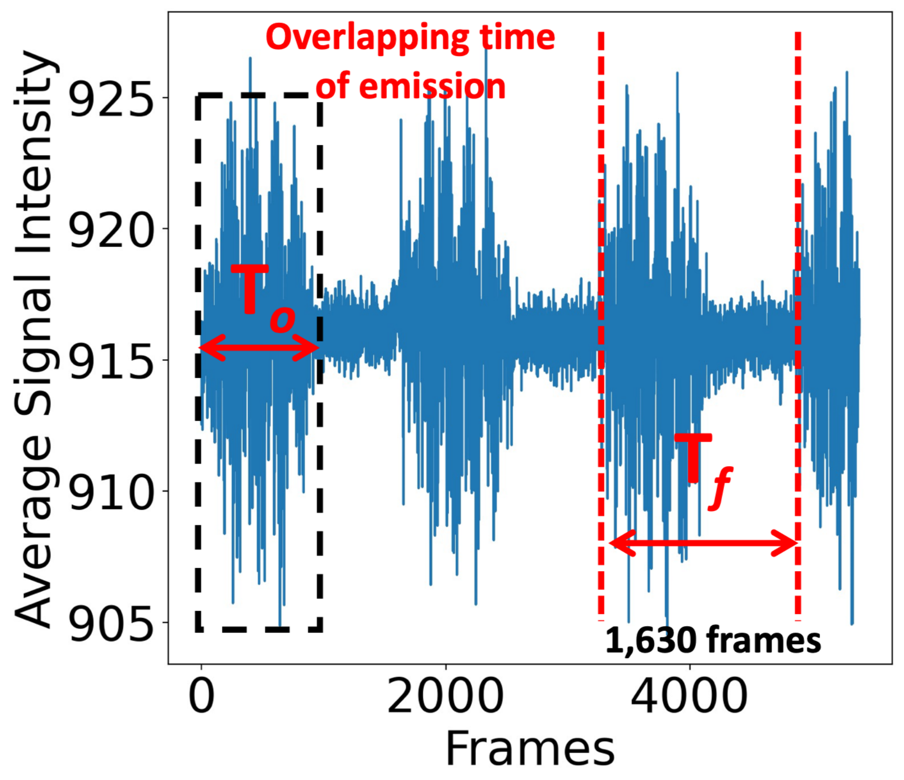
UltraDepth: External IR-based Implementation

- Observation: Emission time of different cameras are slightly different.



- From the view of the attacking camera, the received signal fluctuates periodically.
- The attacking camera only needs to adjust its emission time periodically.

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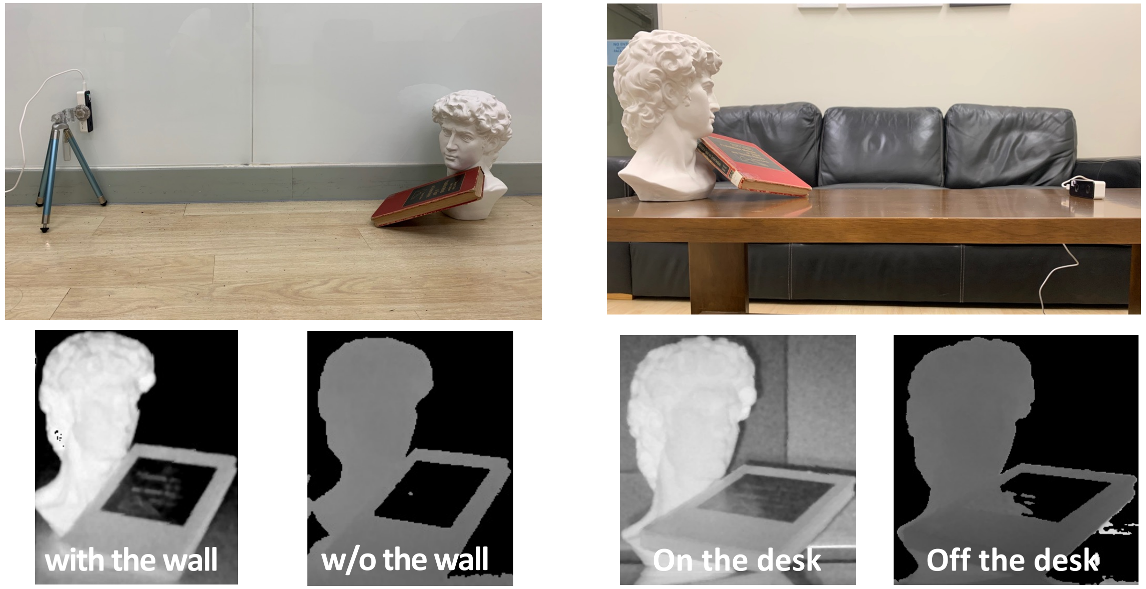
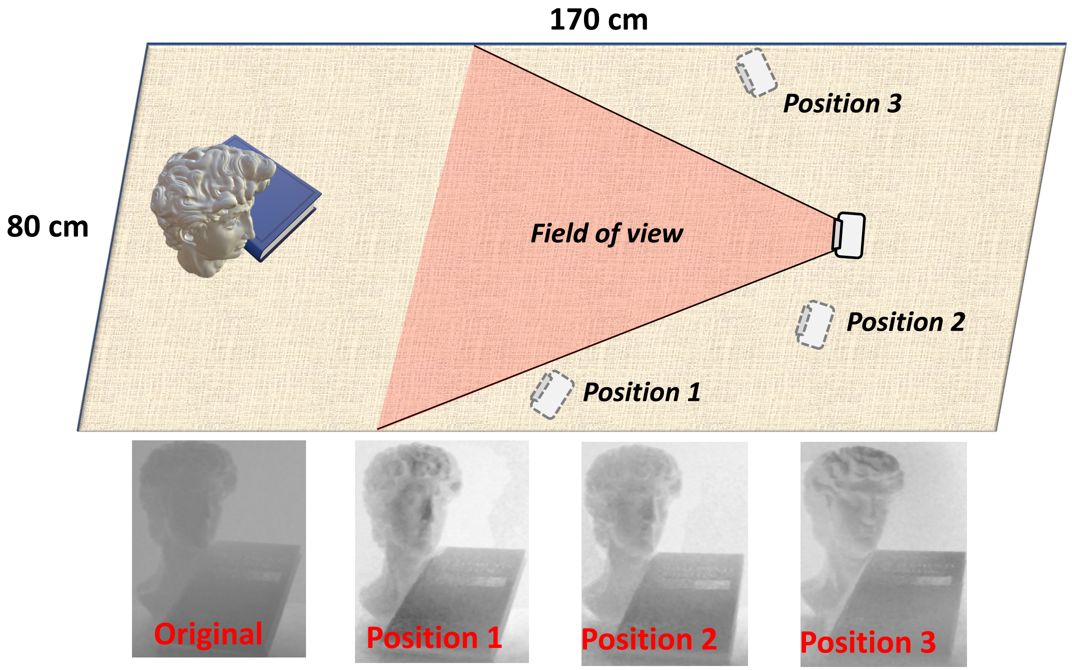
Experiments: Feasibility Study

➢ Feasibility Study



Reflection-based *UltraDepth* is easy to be realized.



External IR-based *UltraDepth* is robust to different positions.

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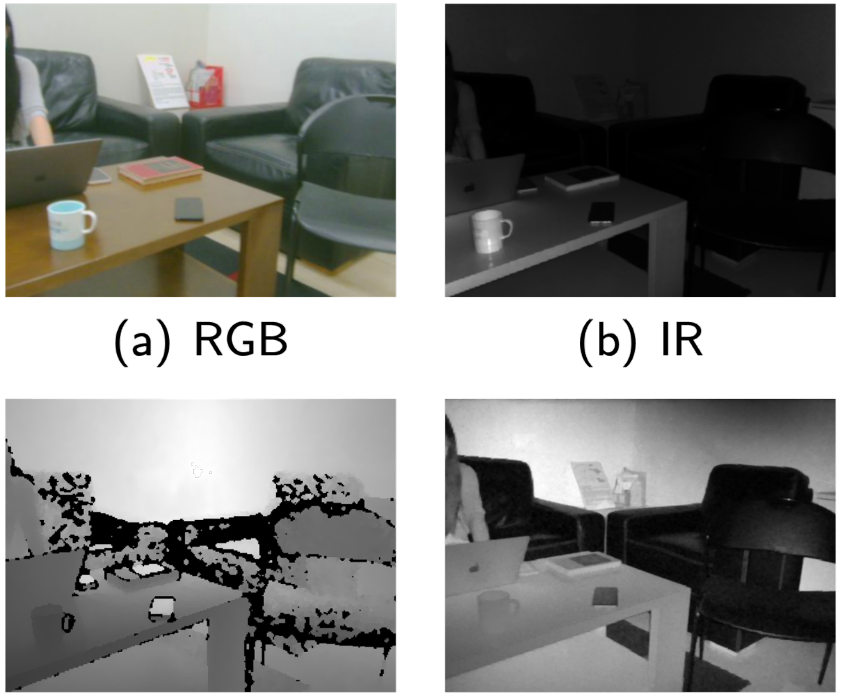
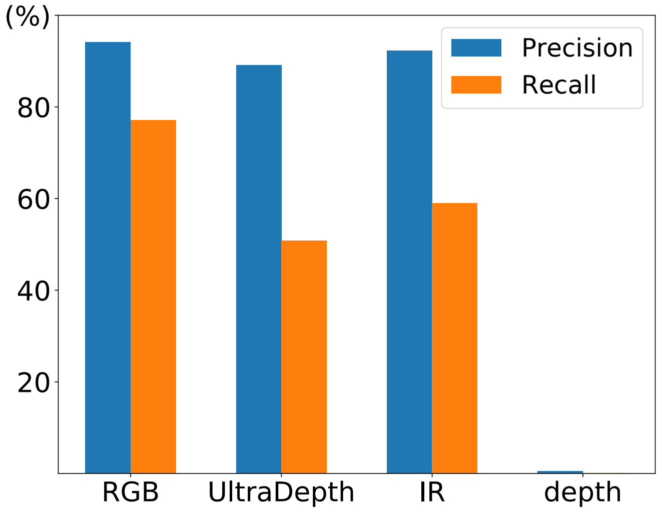
Experiments: Object Detection

➢ RGB, IR, Depth map and *UltraDepth* are packed together to record the same scene for the object detection task.



(a) RGB (b) IR

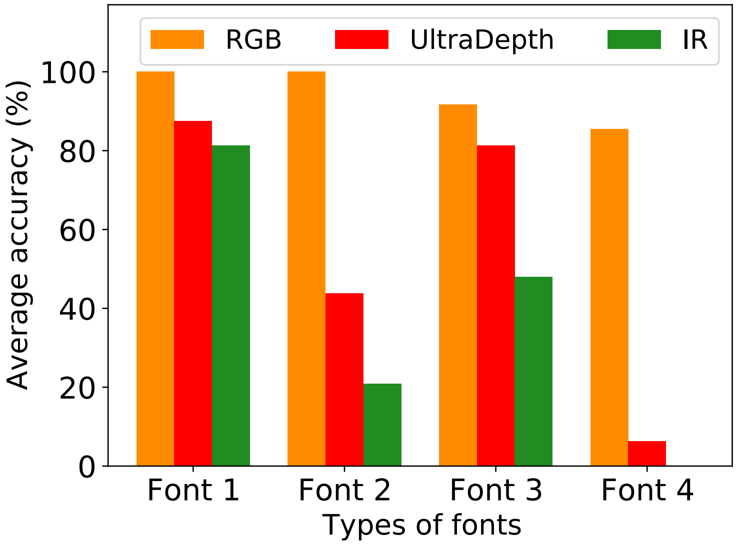
(c) Depth map (d) *UltraDepth* map



The performance of *UltraDepth* is close to RGB and IR images, and far exceeds depth maps.

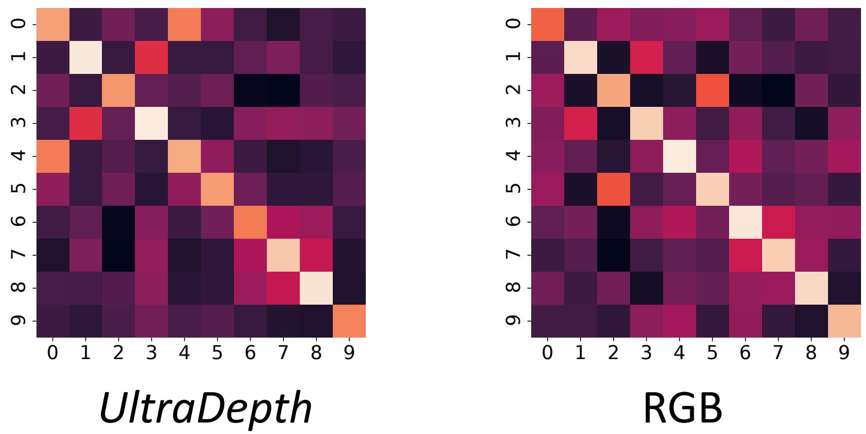
Experiments: Character & Face Recognition

- Character recognition



- *UltraDepth* outperforms IR images.

- Face recognition



- Heatmaps showing the feature similarity of faces from 10 volunteers.
- *UltraDepth* achieves 99.334% accuracy of classification

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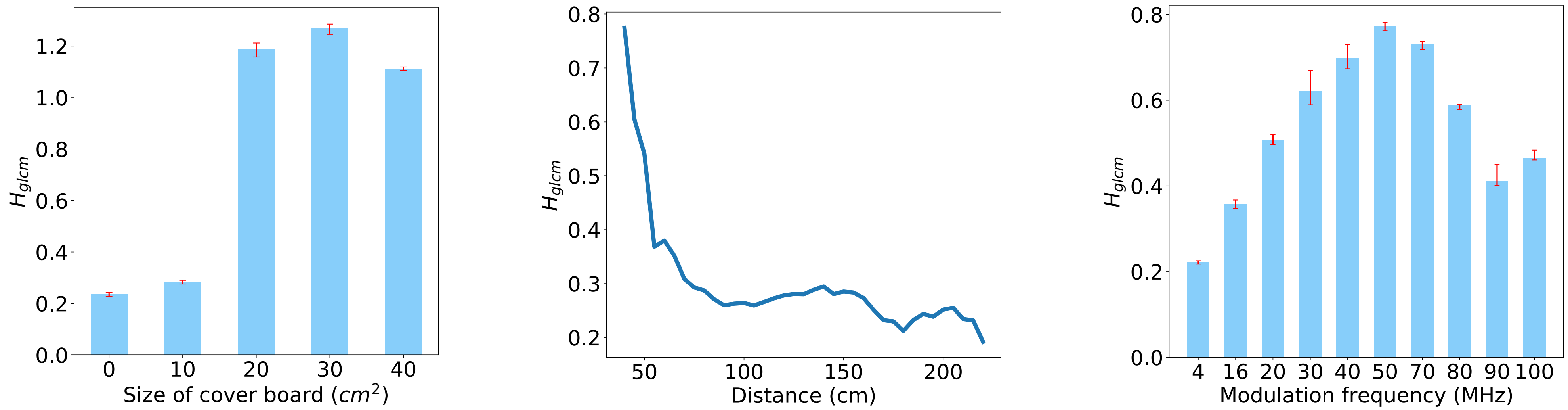
Experiments: The Impact of Key Factors

- Metric to measure the level of texture exposure:

$$H_{glcm} = -\sum_{i=0}^{h-1}\sum_{j=0}^{w-1} p(i,j)\log_b p(i,j)$$

Here, *p(i,j)* is the *(i,j)*th element of the gray level co-occurrence matrix (GLCM).



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Conclusion

➢ *UltraDepth*: Exposing high-resolution texture from depth cameras.

- Provide an in-depth analysis on the texture exposure mechanism of depth cameras.

- Propose two practical implementations for *UltraDepth*.

Thanks!

- *UltraDepth*: Exposing High-resolution Texture from Depth Cameras

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