Shape from Thermal Radiation: Passive Ranging Using Multi-spectral LWIR Measurements

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Project page

Introduction: Challenge

Is passive ranging possible using a single thermal camera?

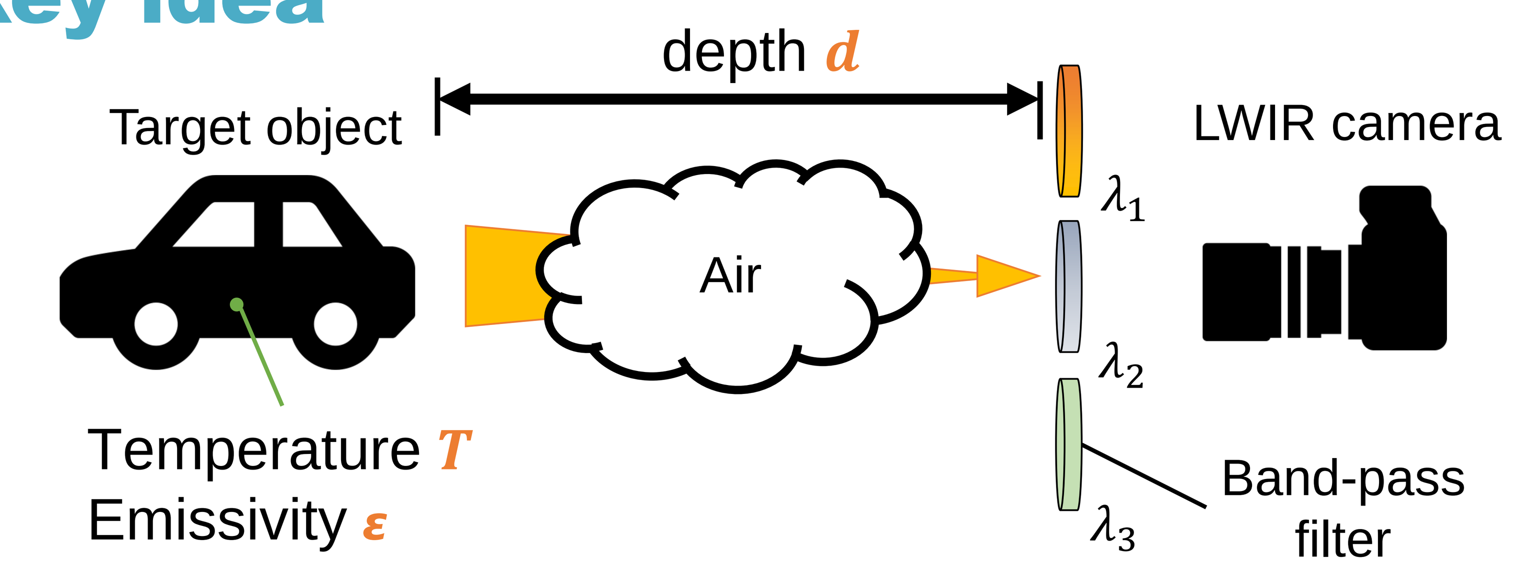
- We propose *a novel depth sensing technique* refer to physics-based cues, long wavelength infrared (LWIR).
- The proposed method is the first attempt to prove that LWIR is useful for depth sensing.

Advantages

Our method overcomes many weakness of conventional methods.

	Stereo cameras	Structured light	LiDAR	*Ours*
Dark scene	Impossible	Possible	Possible	***Possible***
Texture independence	No	Yes	Yes	***Yes***
Far range	Baseline	Impossible	Possible	***Possible***
Outdoor	Possible	Difficult	Possible	***Possible***
Risk of interfering	Low	High	High	***Low***
Stealth measurement	Yes	No	No	***Yes***

Key idea



- The main idea is *modeling LWIR light attenuation* through the air.
- Multi-spectral observation enables estimate *not only depth but also temperature and emissivity*.

Assumptions

- The attenuating spectrum of the air is known.
- Emissivity of the target is not wavelength-dependent in LWIR.
- The target object does not reflect LWIR light from any other heat source.

Method

- **Thermal radiation theory**

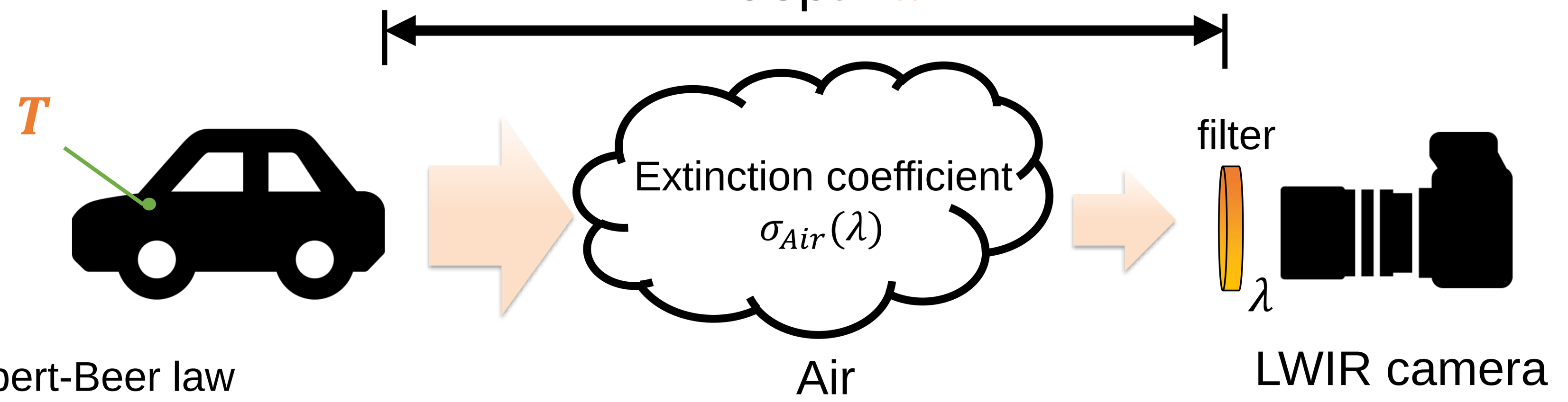
All objects radiate LWIR light according to Planck's law, depending on their temperature and emissivity.

Planck's law

$$M_e(\lambda;T) = \frac{2\pi hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$$

- **Light attenuation and imaging model**

Lambert-Beer law expresses transmission of the air.
By using a filter, attenuated LWIR light at a specific wavelength can be observed.



Lambert-Beer law
(Air attenuation model)

$$I(\lambda) = i(\lambda)e^{-\sigma_{Air}(\lambda)d}$$

Imaging model

$$I(\lambda) = \varepsilon M_e(\lambda;T)e^{-\sigma_{Air}(\lambda)d}$$

Three unknowns

- **Estimate depth**

To estimate unknowns, we use three equations with different wavelengths.
Using filters enables to multi-spectral observation.
The depth can be derived from the *difference in extinction coefficient at different wavelengths*.

$$\begin{cases} I(\lambda_1) = \varepsilon M_e(\lambda_1;T)e^{-\sigma_{Air}(\lambda_1)d} \\ I(\lambda_2) = \varepsilon M_e(\lambda_2;T)e^{-\sigma_{Air}(\lambda_2)d} \\ I(\lambda_3) = \varepsilon M_e(\lambda_3;T)e^{-\sigma_{Air}(\lambda_3)d} \end{cases}$$

Solve unknowns

1, Deriving T: Find T that satisfies this equation.

$$\frac{1}{\sigma_{Air}(\lambda_2)-\sigma_{Air}(\lambda_1)}\ln\left(\frac{I(\lambda_1)M_e(\lambda_2;T)}{I(\lambda_2)M_e(\lambda_1;T)}\right) = \frac{1}{\sigma_{Air}(\lambda_3)-\sigma_{Air}(\lambda_1)}\ln\left(\frac{I(\lambda_1)M_e(\lambda_3;T)}{I(\lambda_3)M_e(\lambda_1;T)}\right)$$

2, Deriving d: substitute T.

$$\frac{1}{\sigma_{Air}(\lambda_2)-\sigma_{Air}(\lambda_1)}\ln\left(\frac{I(\lambda_1)M_e(\lambda_2;T)}{I(\lambda_2)M_e(\lambda_1;T)}\right)$$

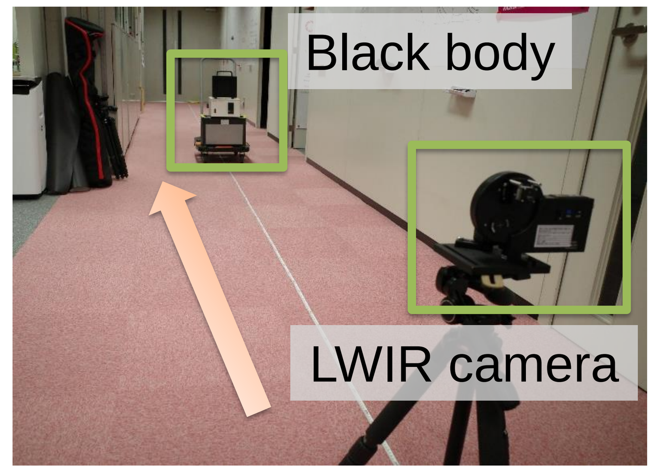
3, Deriving ε : substitute T and d.

$$\varepsilon = \frac{I(\lambda_1)}{M_e(\lambda_1;T)e^{-\sigma_{Air}(\lambda_1)d}}$$

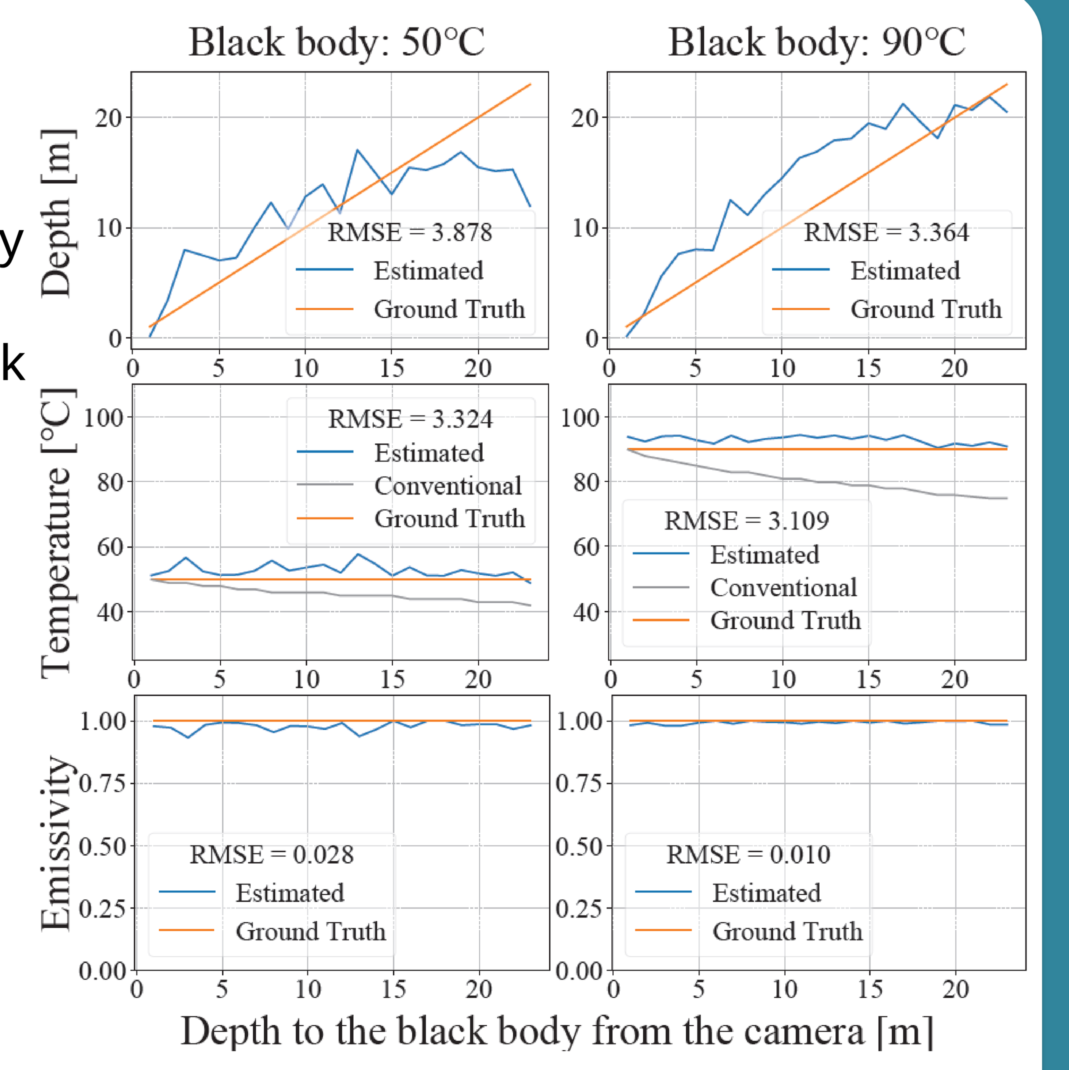
Experiments

1. Black body target

Measure a black body, which is moved away from the camera, every 1 m.
Estimate the each unknowns when the black body is set to 50℃ and 90℃.

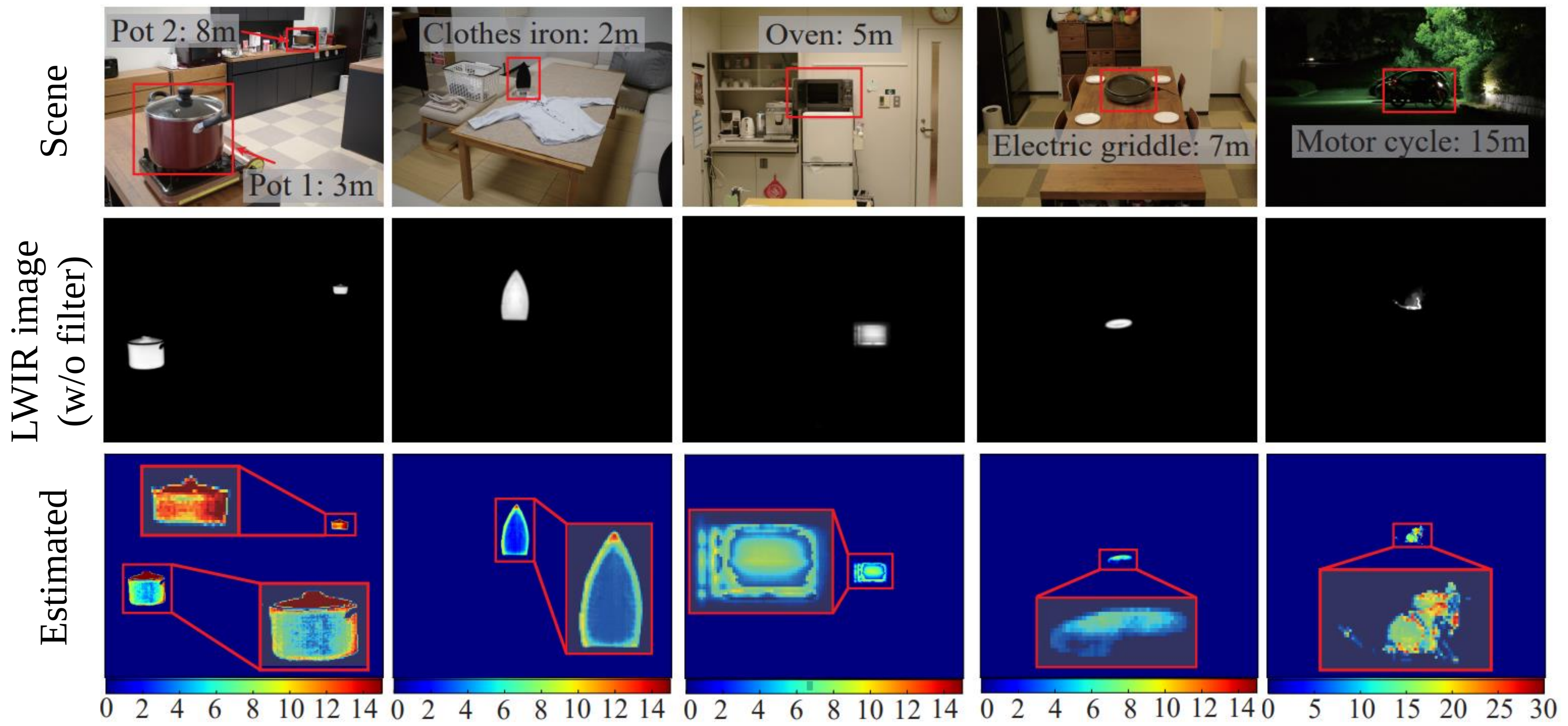


Black body
A device with emissivity ≈ 1 can control the temperature.



All unknowns are estimated *roughly correct* compared to Ground Truth.

2. Practical target



The results suggest that the proposed method can be *adapted to real-world environments*.

Conclusion

- We propose a novel and unique depth sensing approach using an LWIR camera.
  - Estimating not only depth but also temperature and emissivity.
- We demonstrate the effectiveness in real-world experiments.
- This is first attempt. We expect our findings will be improved to practical level.