HADAR

Heat-Assisted Detection And Ranging: **Part I**

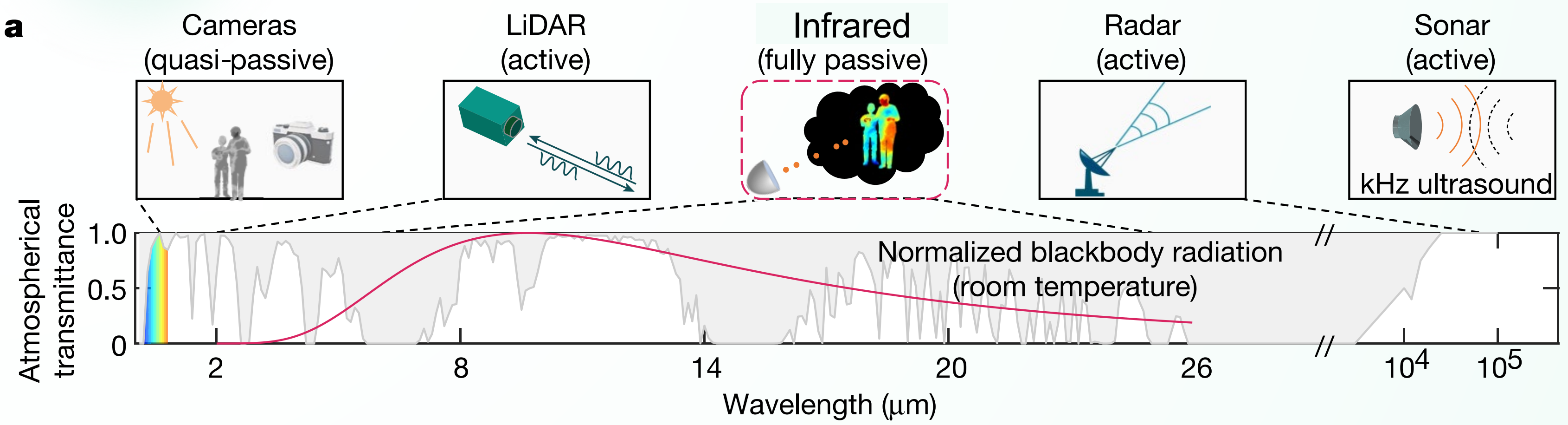
Yimian Dai
PCALab, NJUST

[1] Bao, F., Wang, X., Sureshbabu, S.H. *et al.* Heat-assisted detection and ranging. *Nature* **619**, 743–748 (2023).

Contents

1 Amazing Breakthrough

1 Imaging



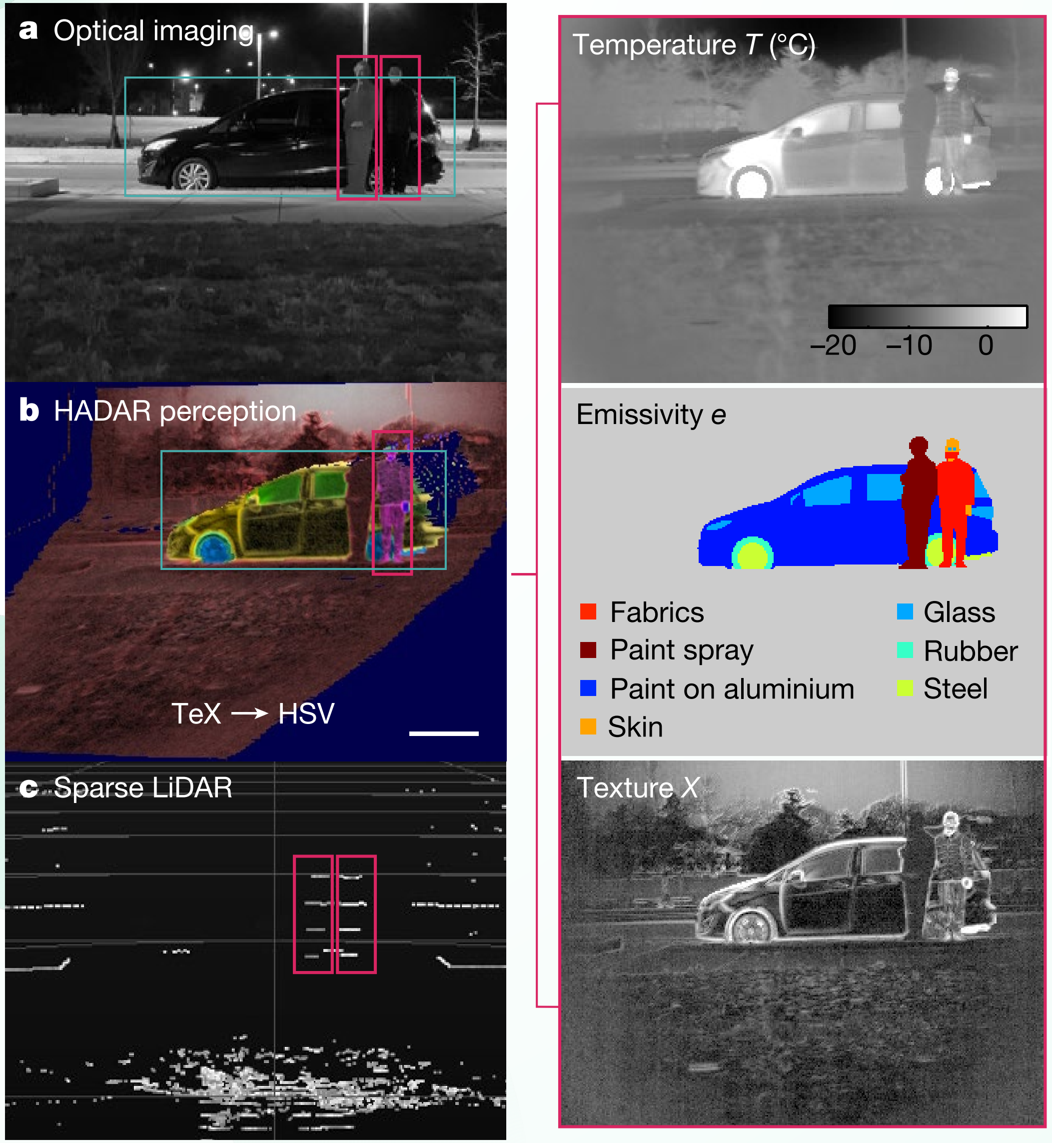
Imaging Mode		Pro.	Con.
Active Imaging	LiDAR	Day and Night	Self Safety Pedestrian Safety
	Radar		
	Sonar		
Passive Imaging	Visible	Texture, Color, Cheap	Needs Lighting
	Thermal IR	Day and **Night**	w/o Texture, Color
	HADAR	Day and **Night** Texture, Material, Temperature, Depth	Expensive

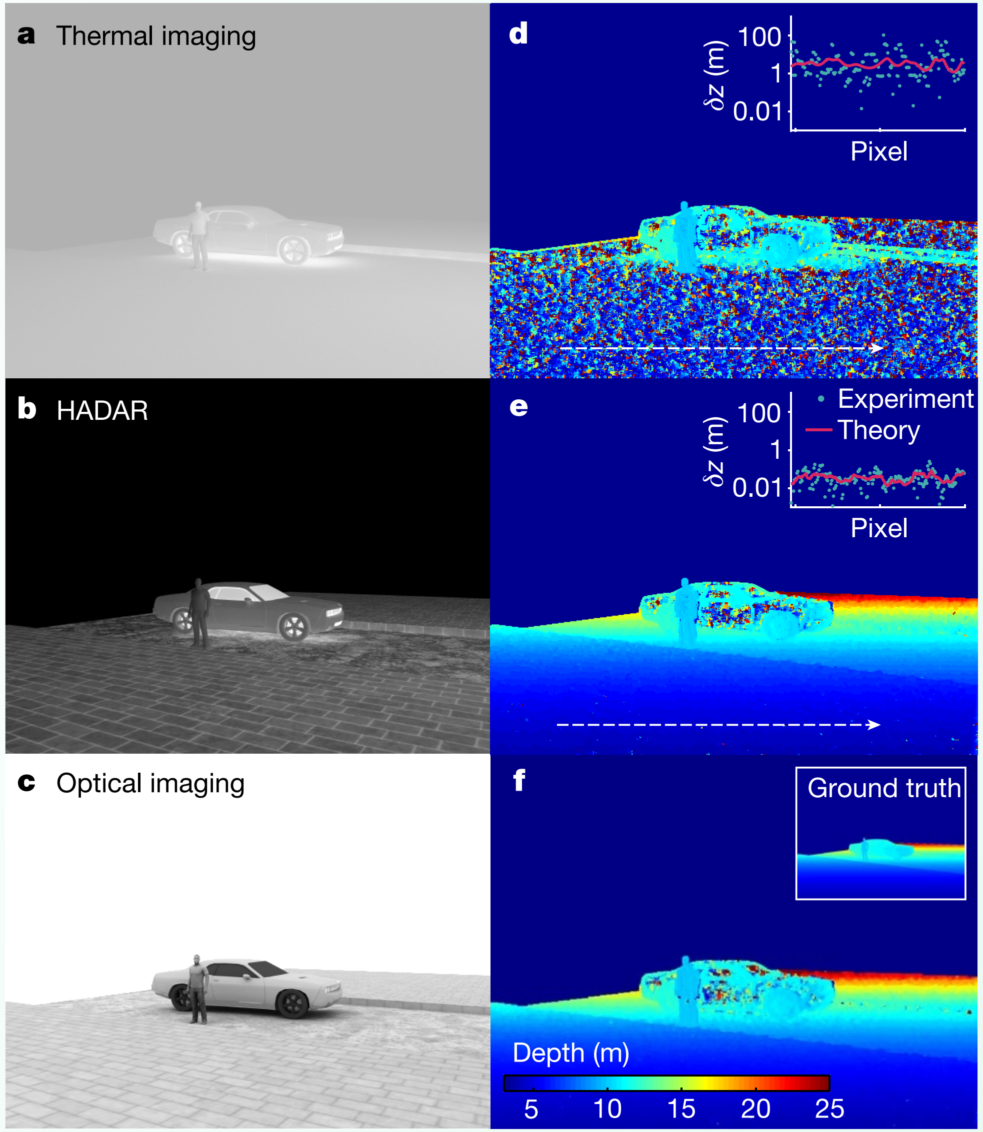
RGB

IR

HADAR

1 Breakthrough

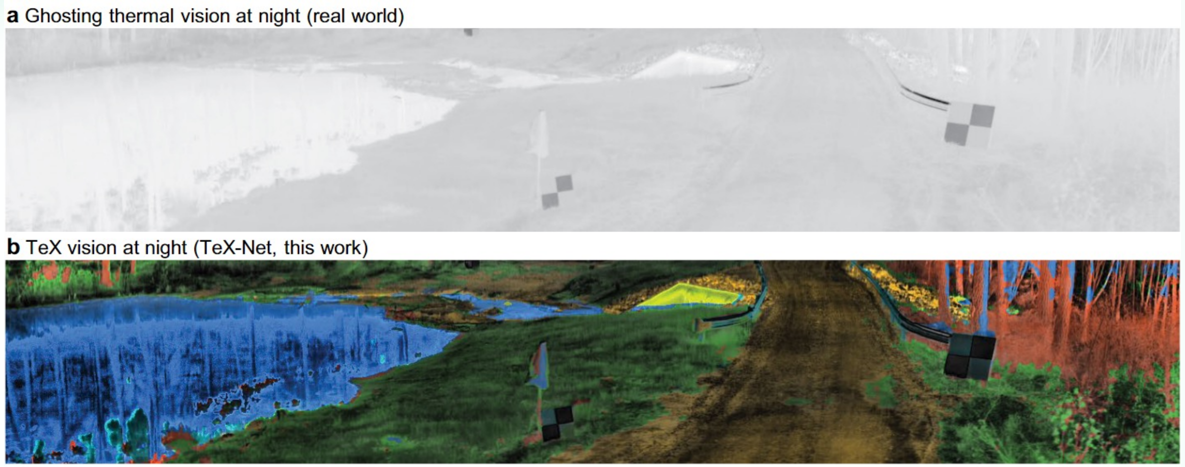




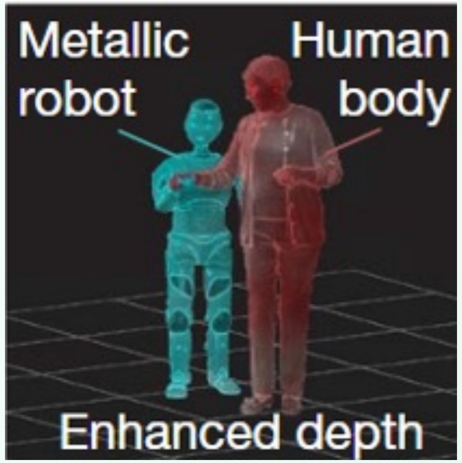
1 Breakthrough

IR

HADAR



IR



HADAR

Main Contribution:

1. Overcoming the **ghosting effect**, it can perceive **temperature**, **material**, **texture**, and **depth** in the dark. ✓
2. Constructing the HADAR estimation theory
    1. Overcoming the photon noise limitation of the lens
    2. Providing the information-theoretic limits of HADAR performance

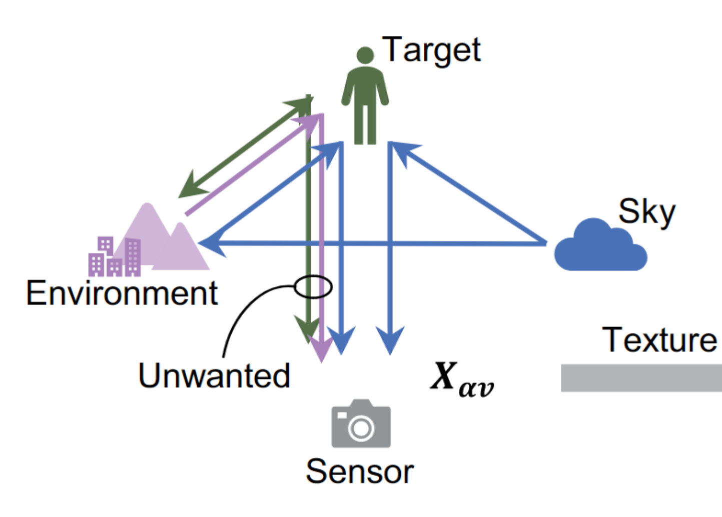
2 Thermal Infrared Signal Model

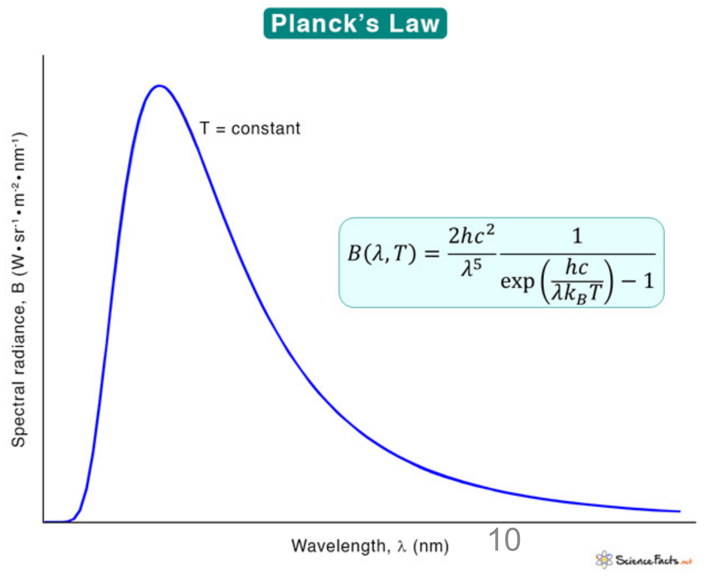
2 Thermal Infrared Signal

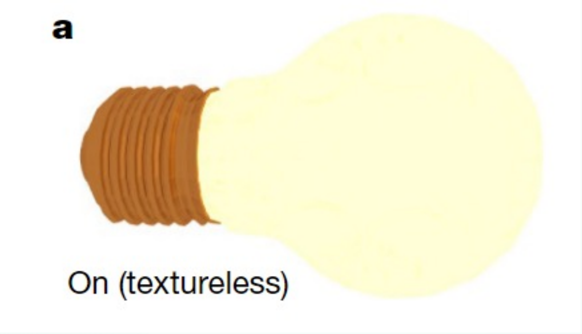
The infrared signal $S_{\alpha\nu}$ received by sensor from object α:

$$S_{\alpha\nu} = \underbrace{e_{\alpha\nu} B_\nu(T_\alpha)}_{\text{w/o Texture}} + \underbrace{[1 - e_{\alpha\nu}] X_{\alpha\nu}}_{\text{w/ Texture}} \quad (1)$$

- ν: wave number, describing the frequency of a wave
- $e_{\alpha\nu} \in [0, 1]$: emissivity, depending on glossiness, roughness, and reflectivity
- T_α: temperature
- $B_\nu(T_\alpha)$: blackbody radiation, governed by Planck's law



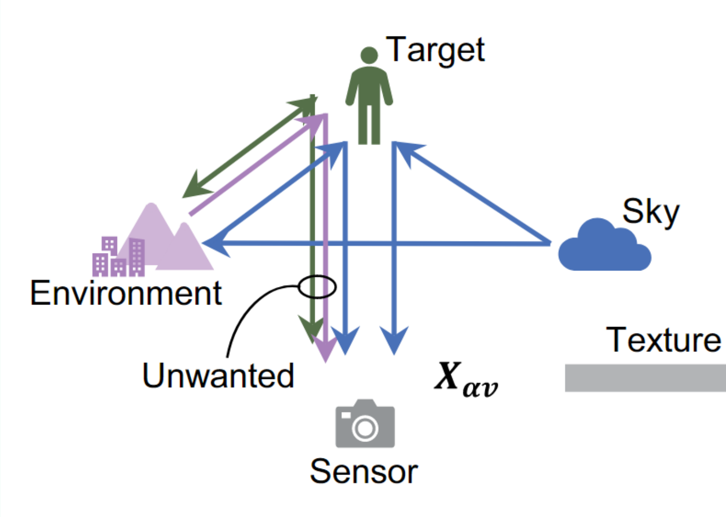




2 Thermal Infrared Signal

The infrared signal $S_{\alpha\nu}$ received by sensor from object α:

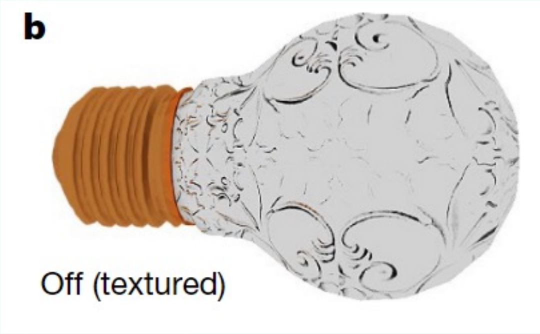
$$S_{\alpha\nu} = \underbrace{e_{\alpha\nu} B_\nu(T_\alpha)}_{\text{w/o Texture}} + \underbrace{[1 - e_{\alpha\nu}] X_{\alpha\nu}}_{\text{w/ Texture}} \quad (1)$$



Texture, reflecting radiation from **environmental object** β:

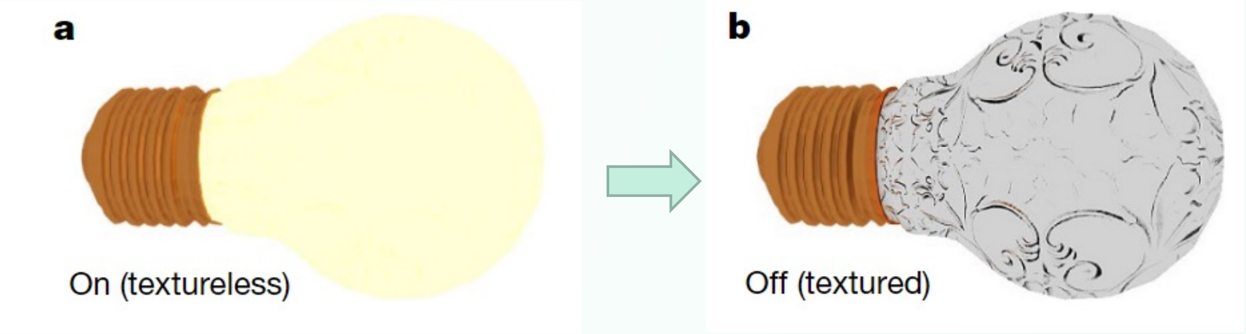
$$X_{\alpha\nu} = \sum_{\beta \neq \alpha} V_{\alpha\beta} S_{\beta\nu} \quad (2)$$

- $V_{\alpha\beta}$: thermal lighting factor, quantifying the proportion of radiation scattered from β to α and then scattered again to the sensor

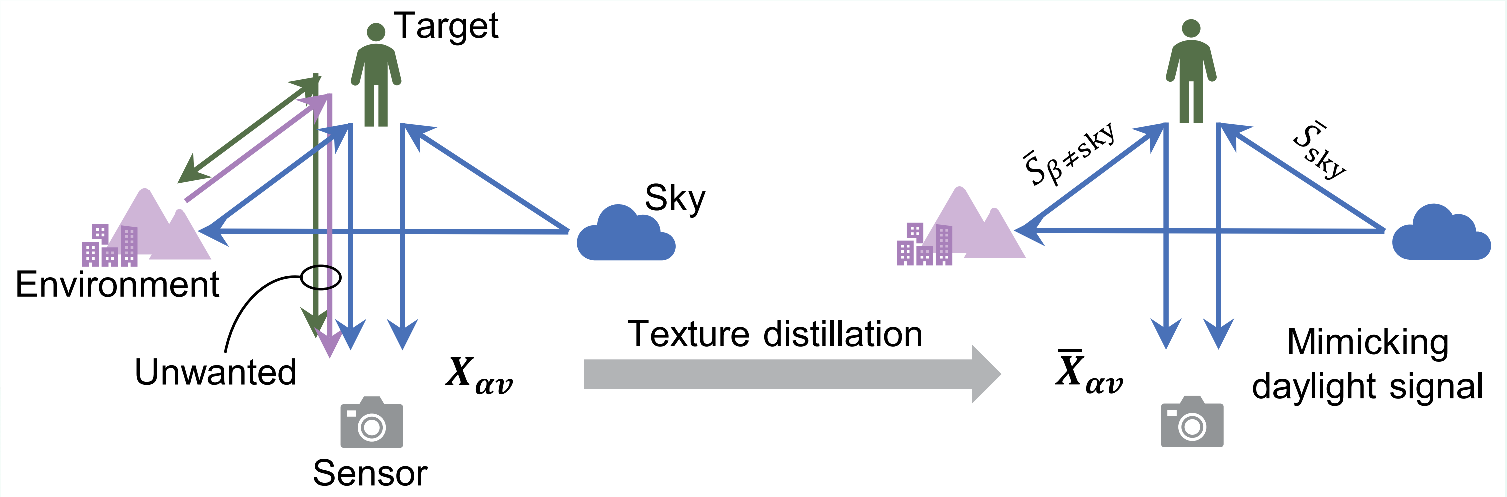


3 Research Goals and Challenges

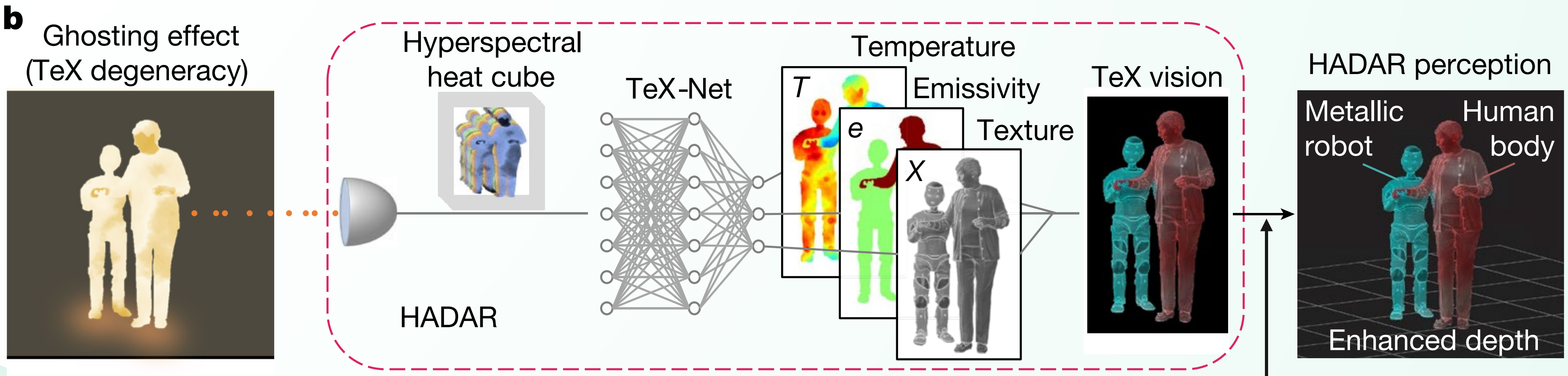
3 Research Goals



Texture Distillation: $S_{\alpha v} = \cancel{e_{\alpha v} B_v(T_\alpha)} + [1 - e_{\alpha v}]X_{\alpha v}$



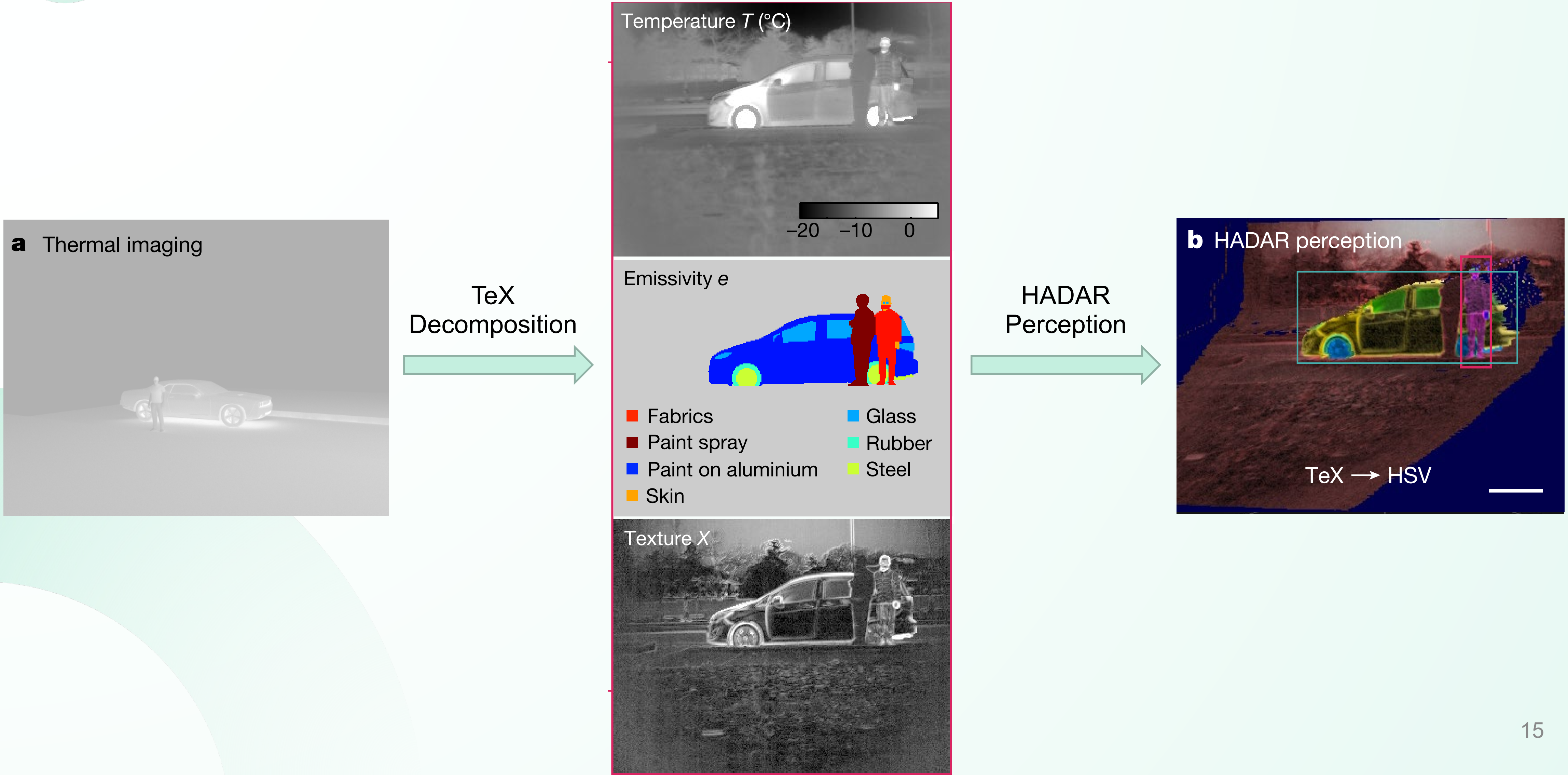
3 Research Goals



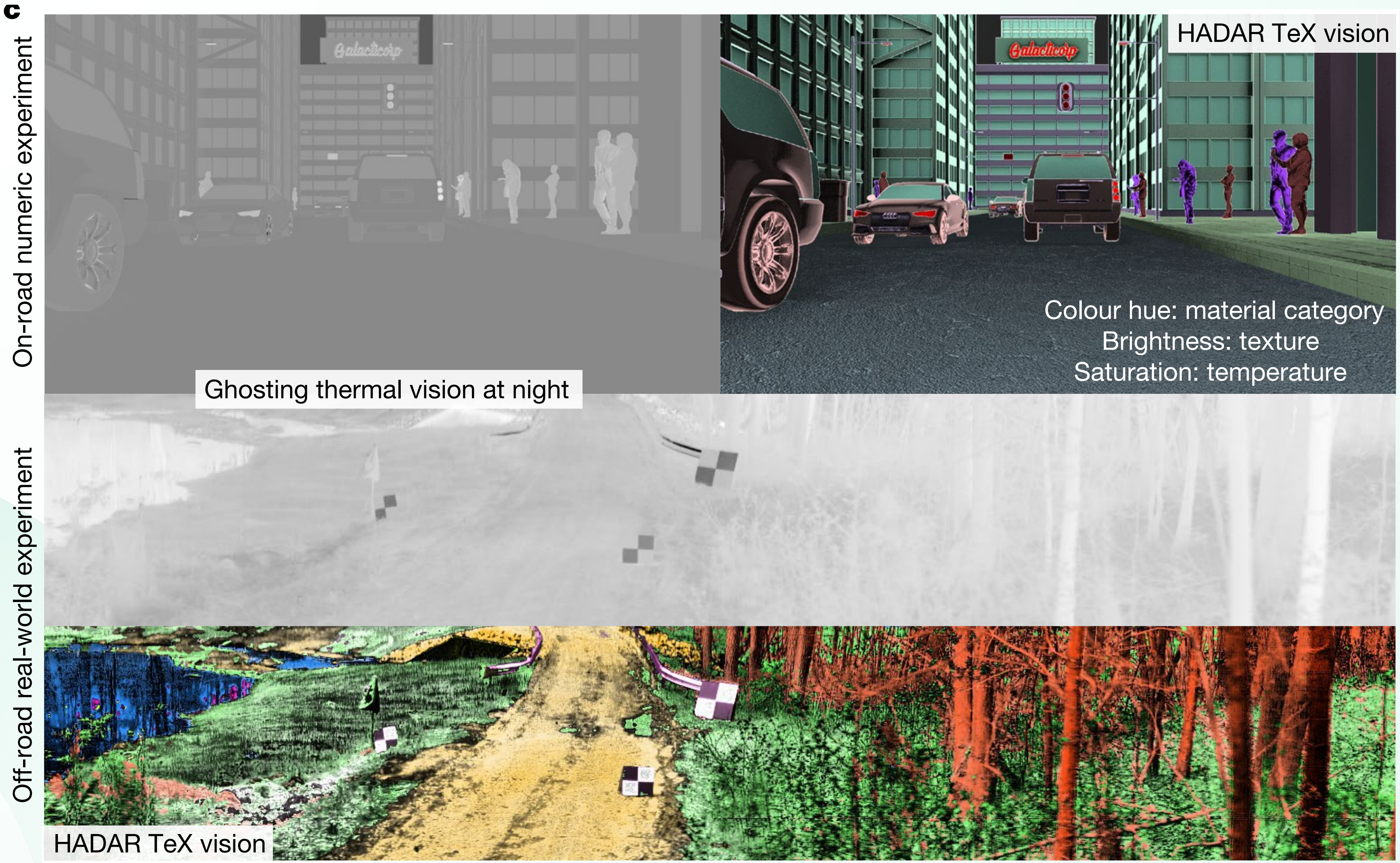
TeX Decomposition

H = e
S = T
V = X

3 Research Goals



3 Research Goals



3 Challenges

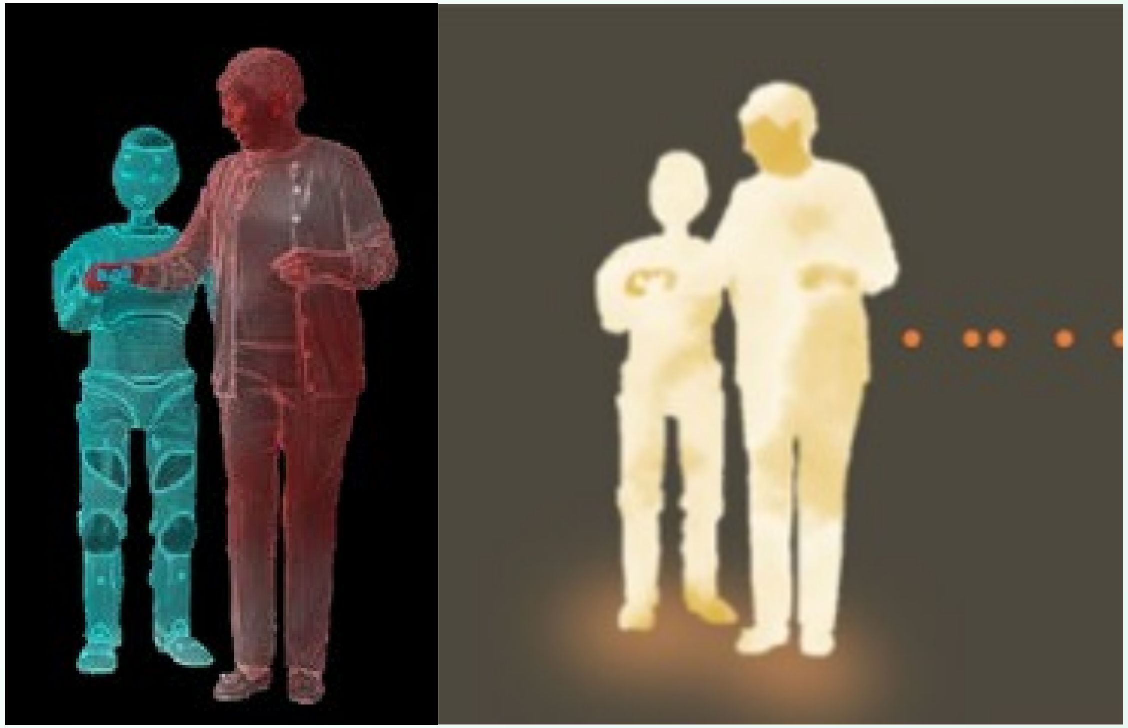
$$S_{\alpha\nu} = e_{\alpha\nu} B_\nu(T_\alpha) + [1 - e_{\alpha\nu}] X_{\alpha\nu}$$

TeX Degeneracy:

$\{T_\alpha, e_{\alpha\nu}, X_{\alpha\nu}\} \neq \{T'_\alpha, e'_{\alpha\nu}, X'_{\alpha\nu}\}$ while $S_{\alpha\nu} = S'_{\alpha\nu}$

as long as

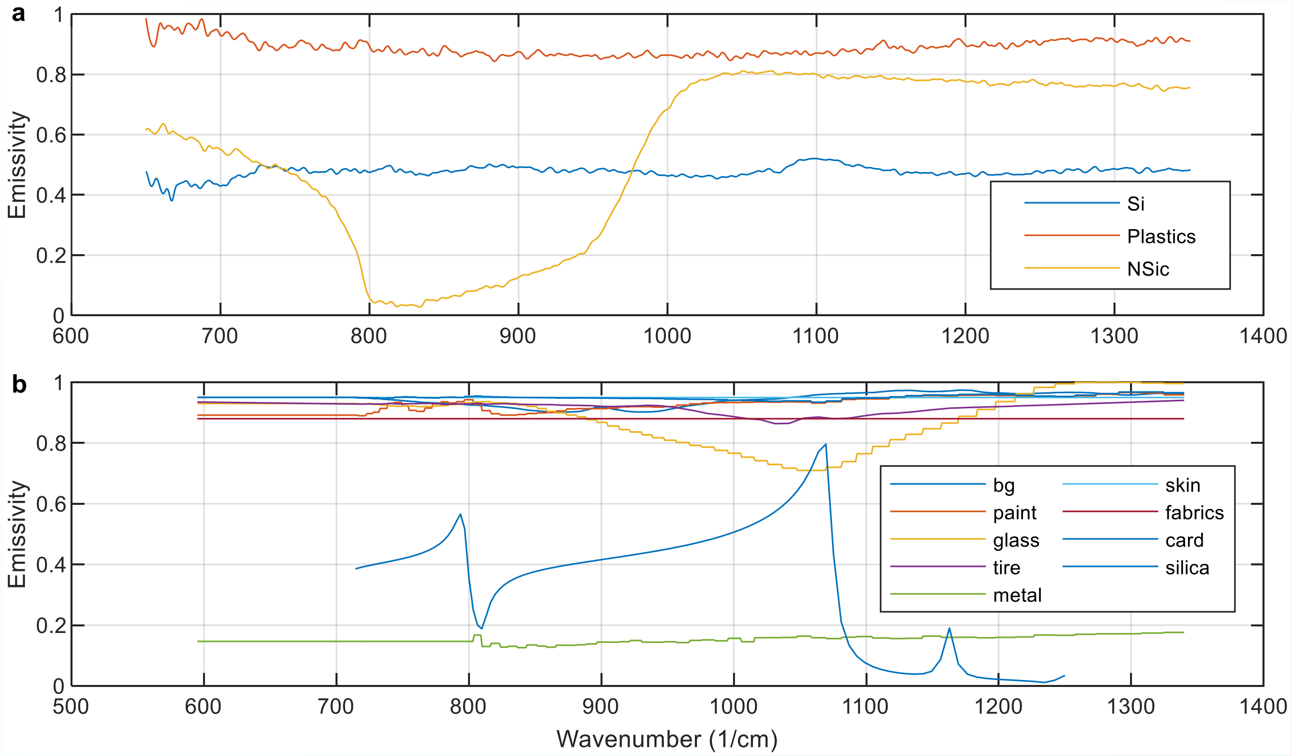
$$e'_{\alpha\nu} = \frac{e_{\alpha\nu}[B_\nu(T_\alpha) - X_{\alpha\nu}] + [X_{\alpha\nu} - X'_{\alpha\nu}]}{B_\nu(T'_\alpha) - X'_{\alpha\nu}}$$



Despite different emissivities, the human body (37°C, red) and the robot (aluminum, 72.5°C, blue) have nearly **identical incident spectra**.

4 Methods

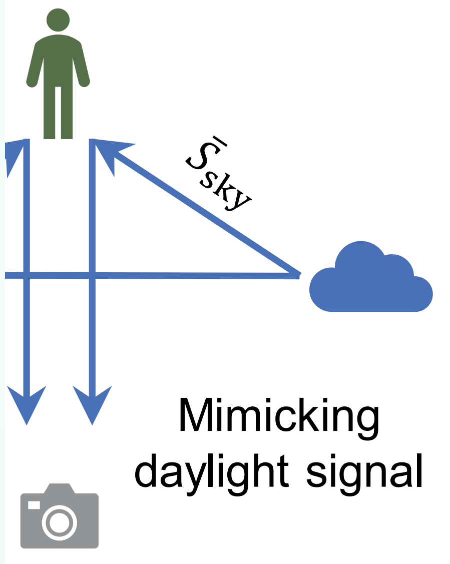
4 Blessing of Industrial Standards



Library of materials, which usually have **industrial standards**

Blessing of Industrial Standards => Dimensional Deduction $\mathcal{M} = \{ e_\nu(m) \mid m = 1,2,\cdots,M \}$

4 TeX-SGD



TeX-SGD (Semi-Global Decomposition)

Simplified Thermal Infrared Signal Model:

$$S_\nu = e_\nu(m)B_\nu(T) + [1 - e_\nu]V_0 B_\nu(T_0) \quad (3)$$

- T_0 : a specific ambient temperature, e.g., the radiation **solely** derived from sky

$$e_\nu \to 1,\ S_{\alpha\nu} = e_{\alpha\nu}B_\nu(T_\alpha) + [1 - e_{\alpha\nu}]X_{\alpha\nu} \approx B_\nu(T_\alpha) \quad (4)$$

- Solving e

via the material classifier

- semantic distance:

$$d_0(m, m_\alpha) = 1/2\sigma_0(m, m_\alpha)$$

- statistical distance

$$d(m, m_\alpha) = \sqrt{N/(1+\gamma)}d_0(m, m_\alpha)$$

- Solving T

via the derivative of Eq. (3) w.r.t. ν

$$[S/(1-e)]' = [e/(1-e)]' B_\nu(T)$$

- Solving V_0 and X

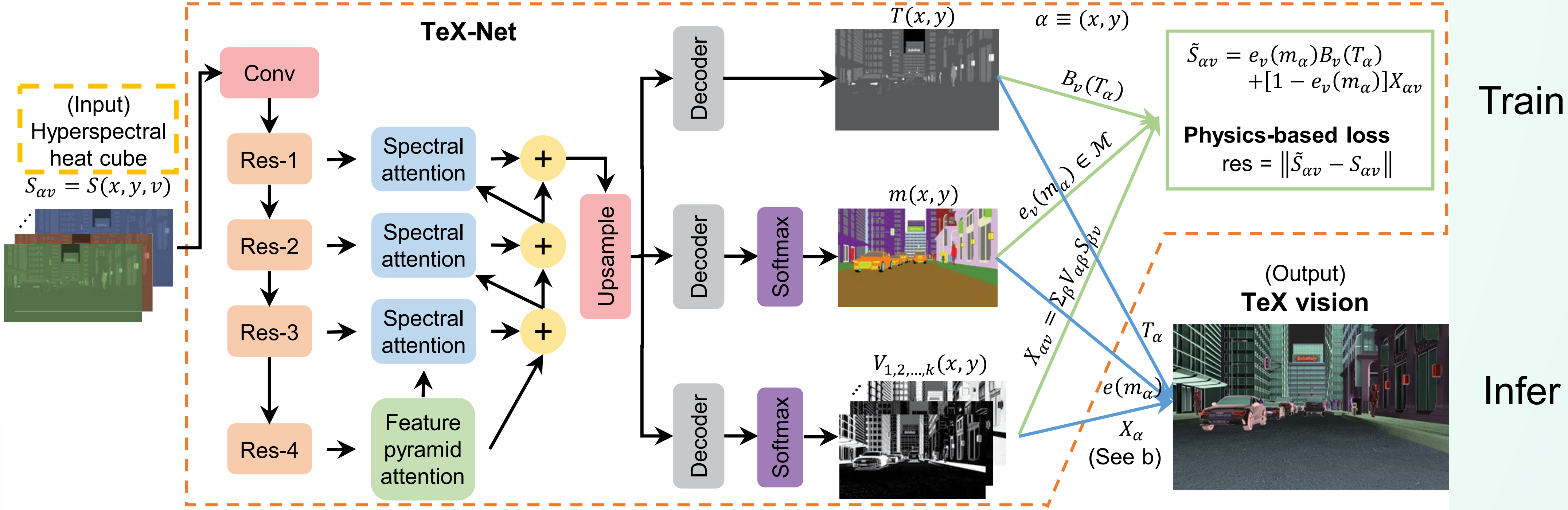
via Eq. (3)

$$V_0 = \frac{S_\nu - e_\nu B_\nu(T)}{(1 - e_\nu)B_\nu(T_0)}$$

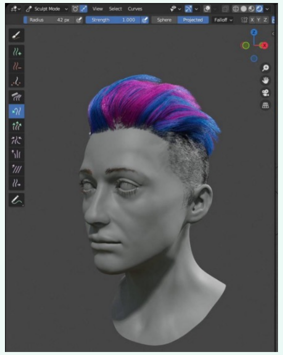
$$X = \int V_0 B_\nu(T_0)$$

Iterative Solving T, e, V

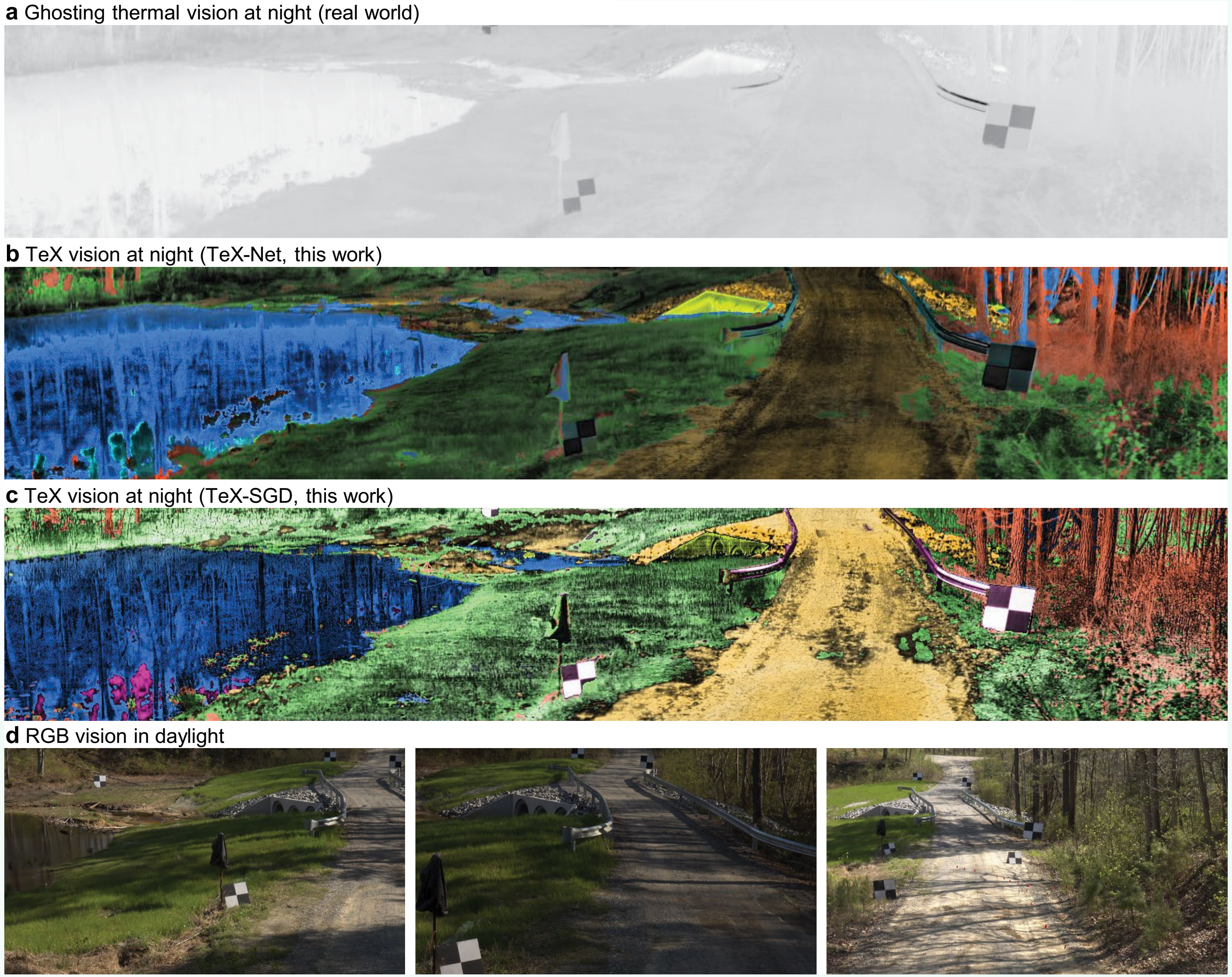
4 TeX-Net



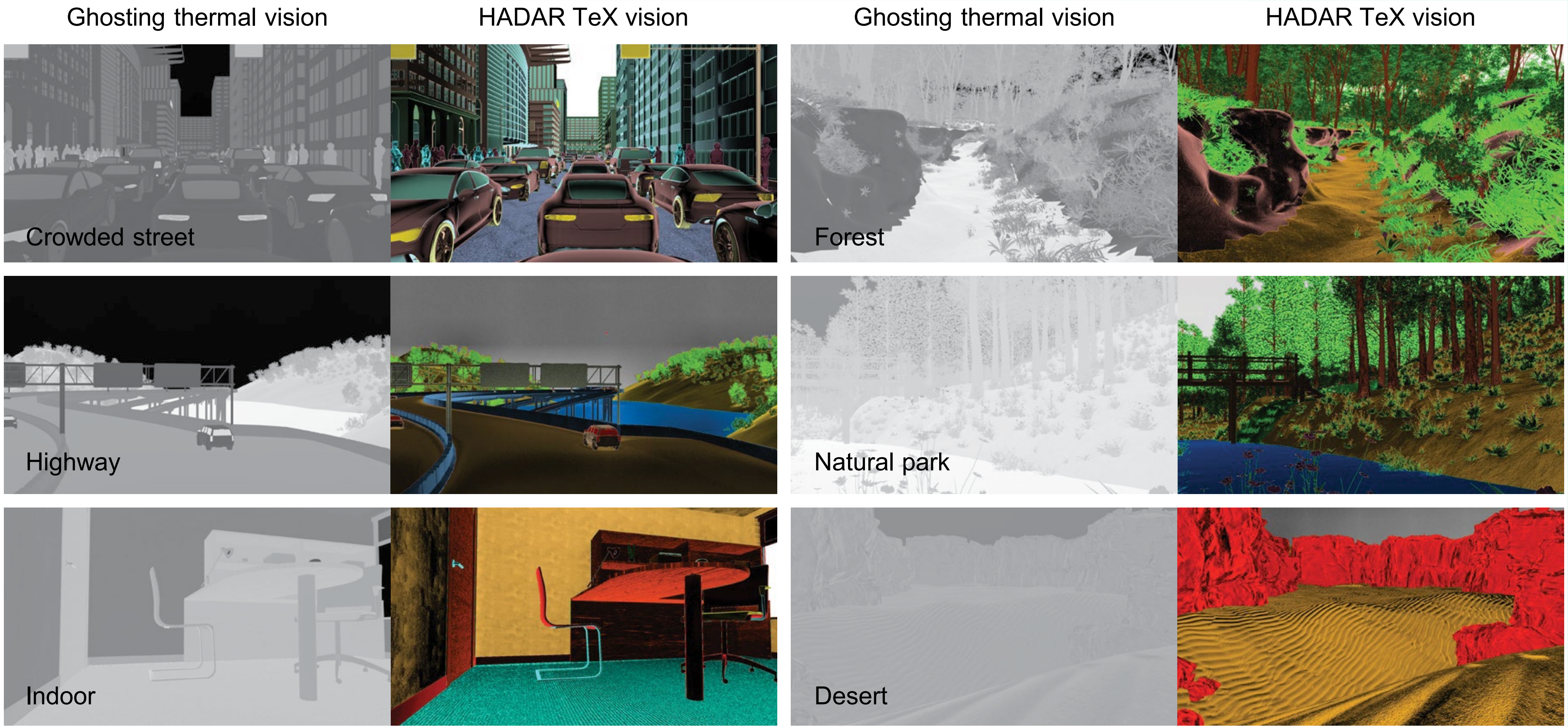
- To ensure the uniqueness of the inverse mapping, regress V rather than X, due to TeX degeneracy $X_{\alpha v} = \sum_{\beta \neq \alpha} V_{\alpha\beta} S_{\beta v}$
- Data and GT:
  - Synthetic data by Blender
  - TeX-SGD results



4 Result

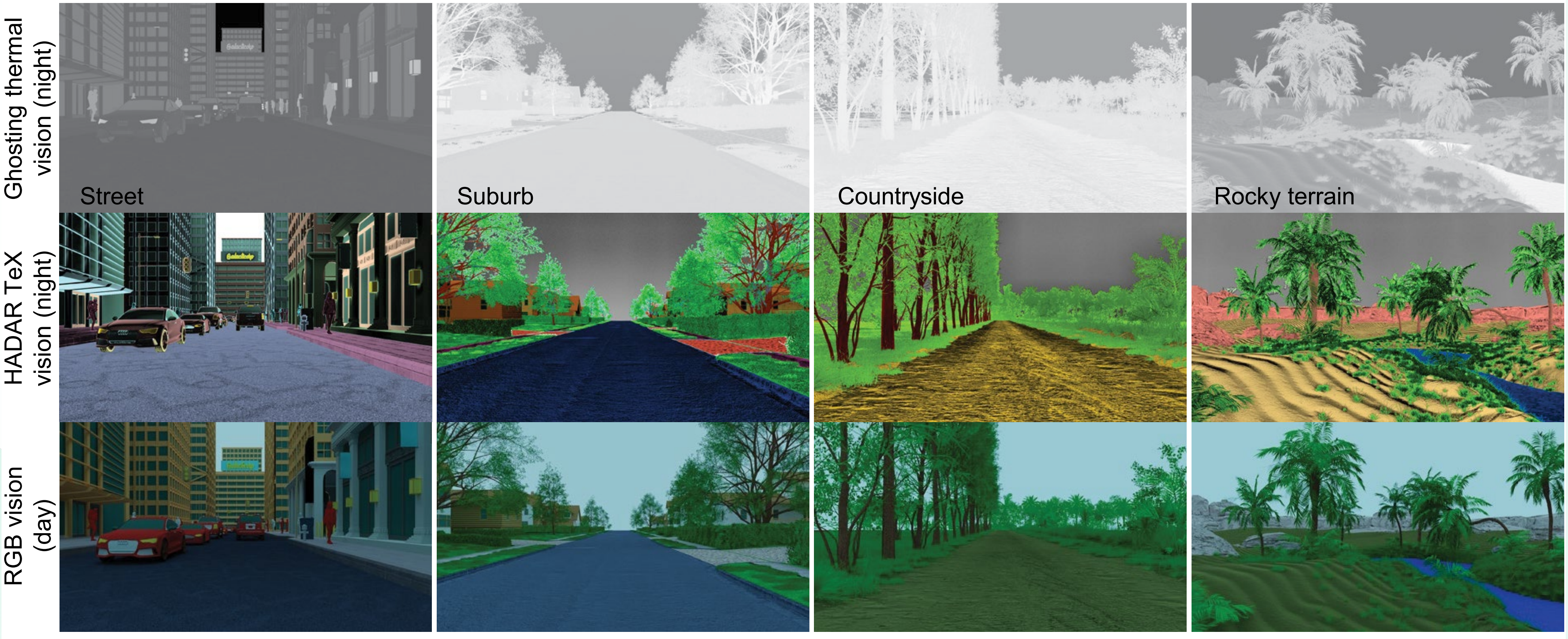

a Ghosting thermal vision at night (real world)
b TeX vision at night (TeX-Net, this work)
c TeX vision at night (TeX-SGD, this work)
d RGB vision in daylight

4 Result



Ghosting thermal vision
HADAR TeX vision
Ghosting thermal vision
HADAR TeX vision
Crowded street
Forest
Highway
Natural park
Indoor
Desert

4 Result


Ghosting thermal vision (night)
HADAR TeX vision (night)
RGB vision (day)
Street
Suburb
Countryside
Rocky terrain

THANKS