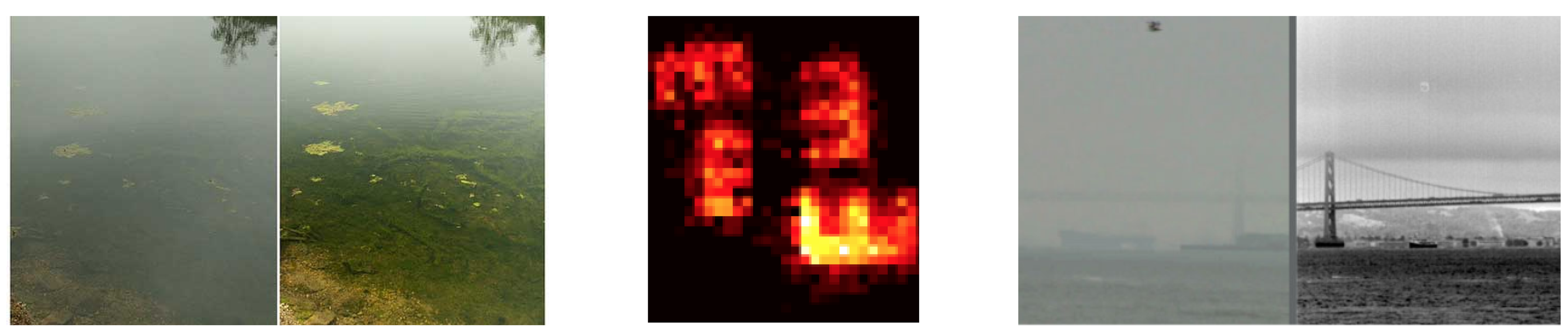
ClearCam: Enabling

Introduction

- Autonomous vehicles require digital cameres for object detection, decision making, and recognizing traffic signs & signals.
- **Unsolved Problem:** As dust, water, and particulates scatter incoming light, the observed scene radiance from the camera decreases.
- Polarizing filter partially removes scattered light.
- MIT Researchers reconstructed object silhouettes by measuring photon reflection times using a laser and single photon avalanche diode (SPAD). SPAD has extremely low spatial resolution (32x32 pixels) and no color.
- The industry standard is to use infrared cameras, which cost up to $10,000, are limited in spatial resolution, and display no color.

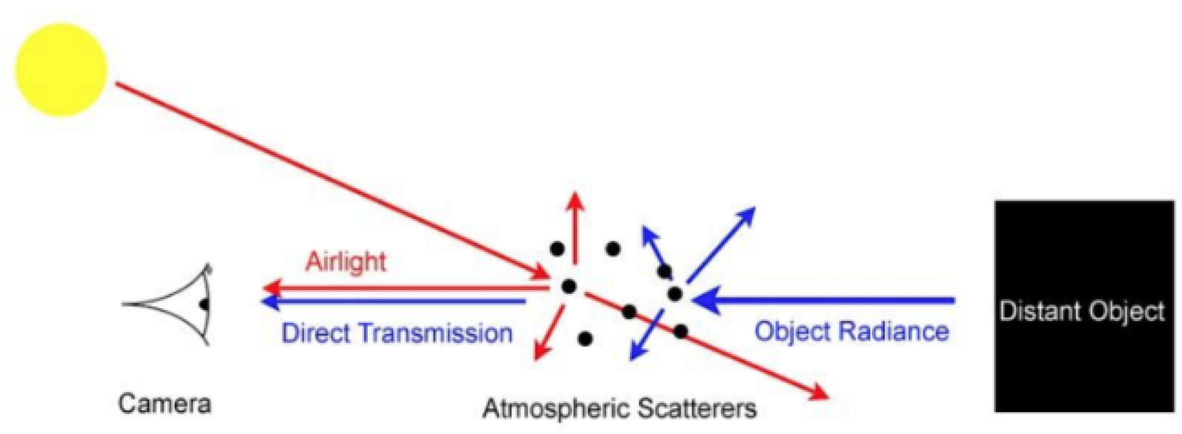


(a) Polarizing Filter (b) SPAD (magnified) (c) Infrared Cameras

- **Proposal**: Realtime dehazing software that directly remove haze from image/video input

Atomspheric Scattering

- Scattering depends on the weather conditions. Rayleigh's Law: $\beta = \dfrac{k}{\lambda^{\gamma}}$ where β is the scattering coefficent, λ light wavelength, k constant
- γ ≈ 0 for large particles (fog), γ ≈ 4 for air, in between for haze



- Incoming light is composed of attenutaed light (irradiance) from the object (signal) and airlight (noise)
- Intuitively, **irradiance** (E) decreases as the distance from the object (d), increases. Bouguer (1729) first proposed

$$dE = -\beta E dx \quad \longrightarrow \quad E = E_0 e^{-\beta d}$$

where E_0 is irradiance at d = 0. However, Bouguer assumed transmitted light can only take the shape of a column. Allard (1876) remedied this by incorporating the inverse square law for diverging beams.

$$E = \frac{\Phi_0 e^{-\beta d}}{4\pi d^2} = \frac{I_0 e^{-\beta d}}{d^2}$$

where Φ_0 is the radiant flux emitted by the object and I_0 radiant intensity.

- **Airlight**, (E') due to the scattering of environmental illumination by the atmosphere, increases the brightness of the image as d increases.
- Koschmieder (1924) proposed the change in radiant intensity of atmospheric scattering is proportional the change in view volume

$$dI = dV K \beta \qquad dV = d\omega x^2 dx$$

where the constant K accounts for the nature of illumination, $d\omega$ the solid angle of the view.

- Each dV is a source with intensity dI and produces an irradiance.

$$dE' = \frac{dI e^{-\beta x}}{x^2} \quad \longrightarrow \quad E' = \alpha(1 - e^{-\beta d}) \qquad \alpha = d\omega K$$

- Putting everything together, we have the Atmospheric Scattering Model

$$E_{total} = E + E'$$

$$E_{total} = Jt + \alpha(1 - t)) \qquad t = e^{-\beta d}, J = \frac{I_0}{d^2}$$

- E_{total} is the observed hazy image. Notice E_{total} = J when β = 0 (no scattering), so J is the clear image.

a) Bouguer's Law Formulation b) Koschmieder's Law Formulation