Sensitivity of different methods for simultaneous evaluation of emissivity and temperature through multispectral infrared thermography simulation

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Introduction and nomenclature

This study focuses on the simultaneous evaluation of temperature and emissivity with multispectral infrared thermography (IRT). It leans on the study and development of an IRT simulator able to address 3D scene in static or dynamic configuration. The sensitivity of 4 different temperature and emissivity joint estimation methods are then evaluated.

IRT Simulator through the radiosity method

View factor

Geometrical coefficient for radiative exchange between two diffuse elements

\[ F_{k \rightarrow j} = \int_{A_k} \frac{\cos(\theta) \cdot \cos(\theta_j)}{\pi r^2} dA_k dA_j \]

Radiosity equation

\[ B_{k, \Delta \lambda} = M L_{k, \Delta \lambda} + \left( 1 - \epsilon_{k, \Delta \lambda} \right) \sum_{j = 1}^{J \cdot \text{sources}} \sum_{k = 1}^{J \cdot \text{sources}} V_{k,j} F_{k \rightarrow j, \Delta \lambda} \]

Temperature and emissivity retrieval

With Bouguer’s law and for infinitesimal surfaces:

\[ E_{\text{Sensor}, \Delta \lambda} = \int \frac{L_{\text{Sensor}, \Delta \lambda} \cos(\theta_{\text{Sensor}})}{\pi} d\Theta \]

\[ E_{\text{Object}, \Delta \lambda} = g \left( \epsilon_{\text{Object}, \Delta \lambda} \right) e \lambda_i L(\Delta \lambda, T) \]

Compared methods

Non linear optimization

\[ \arg\min_{\Delta \lambda_i} \sum_{j = 0}^{N} \left( Y_{\Delta \lambda_i} - \epsilon_{\Delta \lambda_i} \right)^2 \]

\[ \epsilon_{\Delta \lambda_i} = \sum_{j = 0}^{N} \phi_j \theta_{\Delta \lambda_i} \Delta \lambda_i; \quad 0 \leq \epsilon_{\Delta \lambda_i} \leq 1; \quad (\phi_j)_{j=1,2} \text{orthonormal basis (Chebychev-1)} \]

\[ 200K \leq T \leq 400K \]

\[ \Delta \lambda_i \text{ Wavelength interval of } i^{th} \text{ band} \]

\[ \epsilon_{\Delta \lambda_i} \text{ Emissivity of patch } k \text{ in } \Delta \lambda_i \]

\[ M_{\epsilon, \Delta \lambda_i} \text{ Emissivity of patch } k \text{ in } \Delta \lambda_i \]

\[ V_{ij} \epsilon_{\Delta \lambda_i} \text{ Visibility between patches } i \text{ and } j \]

3D Model

A target with 4 different materials properties

Fig. 2: (a) Spectral emissivity distribution of 4 artificial materials for the target in the 7.5um – 13um bandwidth

(b) Simulation results for \( T = 313.15K \)

(c) Camera, target and environment in the visible (d) Temperature ranges

Multi-temperature

\[ \arg\min_{\Delta \lambda_i} \sum_{j = 0}^{N} \left( Y_{\Delta \lambda_i} - \epsilon_{\Delta \lambda_i} \right)^2 \]

\[ \epsilon_{\Delta \lambda_i} = \sum_{j = 0}^{N} \phi_j \theta_{\Delta \lambda_i} \Delta \lambda_i; \quad 0 \leq \epsilon_{\Delta \lambda_i} \leq 1; \quad 200K \leq T_1 \leq 400K; \quad 200K \leq T_2 \leq 400K \]

Bayesian (Monte-Carlo Markov Chain (MCMC))

A priori known laws:

\[ T = \left( T_{\min}, T_{\max} \right) \]

\[ \epsilon = \left( 0.6, 0.6 \right) \]

\[ \text{With } \mu_{\text{estimation}} = \left( 0.6, 0.6 \right) \text{ and } \sigma_{\text{estimation}} = \left( 0.8, 0.8 \right) \text{ Gibbs sampler.} \]

Conclusion and perspectives

Conclusion:

• Comparison of 4 methods to estimate simultaneously emissivity and temperature

• Study and development of a 3D scene IRT simulator

Perspectives:

• Add measurement noises in the simulation process to observe their effect

• Combine temporal and spatial information in Bayesian methods for further improvements of joint estimation

Bibliography


