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

\[ F_{A \rightarrow B} = \int_{A} \int_{B} \frac{\cos(\theta_i) \cos(\theta_o)}{\pi} dA_1 dA_2 \]

Radiosity equation

\[ B_k,\Delta\lambda_i = M_{k,\Delta\lambda_i} + (1 - \epsilon_{k,\Delta\lambda_i}) \sum_{j=1}^{N_e} V_{k,j} F_{k\rightarrow j} / \Delta\lambda_i \]

\( \Delta\lambda_i \) : Wavelength interval of \( i \)th band

\( \epsilon_{k,\Delta\lambda_i} \) : Emissivity of patch \( k \) in \( \Delta\lambda_i \)

\( T \) : Object’s temperature

\( B_k,\Delta\lambda_i \) : Radiosity of patch \( k \) on \( \Delta\lambda_i \)

\( M_{k,\Delta\lambda_i} \) : Emittance of patch \( k \) on \( \Delta\lambda_i \)

\( V_{k,j} \rightarrow 0,1 \) : Visibility between patches \( k \) and \( j \)

Temperature and emissivity retrieval

With Bouguer’s law and for infinitesimal surfaces:

\[ E_{\text{sensor}}(\Delta\lambda_i) = I_o(\text{Object},\Delta\lambda_i) \cos(\theta_{\text{sensor}}) \]

\[ \frac{\cos(\theta_{\text{object}}) d\text{Object}}{\pi} \]

\( \Rightarrow \) Undetermined system with \( \epsilon_{\Delta\lambda_i} \) and \( T \) unknowns

\[ E_{\text{sensor}}(\Delta\lambda_i) = g(\theta_{\text{object}},\theta_{\text{sensor}},T) e_{\Delta\lambda_i} L(T) \]

Non linear optimization

\[ \text{argmin}_{\Delta\lambda_i} \sum_{k=1}^{N_e} \left( I_o(\text{Object},\Delta\lambda_i) \cos(\theta_{\text{sensor}}) \right)^2 \]

\[ \epsilon_{\Delta\lambda_i} = \sum_{j=1}^{N_e} \phi_j (\Delta\lambda_i) ; 0 \leq \epsilon_{\Delta\lambda_i} \leq 1 \]

\( \phi_j \) : Orthonormal basis (Tchebychev-1)

\( 200K \leq T \leq 400K \)

Comparison of 4 methods to estimate simultaneously emissivity and temperature through multispectral infrared thermography simulation

Sensitivity of different methods for simultaneous evaluation of emissivity and temperature

Study and development of a 3D scene IRT simulator

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

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

Results

Fig. 3: Temperature estimation for the 4 different methods

Fig. 4: Emissivity estimation for the 4 different methods

Stopping criteria

• Optimization algorithms => local minimum

• Metaheuristic => 10000 iterations

Observations

• Non linear methods find a local minimum without any guarantee on the physical solution

• TES relies on a correlation based on a database linked with airborne based applications

• MCMC is a metaheuristic that requires a long time and effort to be computed

Bibliography


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