Winter risk estimations through infrared cameras and principal component analysis

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1- Objectives

Context:
- Instrument on a vehicle to establish road susceptibility to ice
- Measurements on one lane at a time ⇒ tests too long
- Measurements on a small spot (*radiometer FOV 20°*)
- No appreciation of road radiative environment
- No dynamic appreciation with season of ice occurrence susceptibility

Objectives:
- Improve the winter risk determination of road network with an infrared camera
  (*several lanes, environment contribution evaluation, ...*),
- Extend measurements season (*spring and fall*)
- Build itinéraire thermal fingerprints forecasts (*Principal Component Analysis*).
2- Winter risk index and thermography

Thermal images sequence of the Itinerary
Radiometric corrections
- low distance and clear atmosphere: $\tau_{\text{atmosphere}} \approx 1$
- no specularity: Stefan law $L = \sigma T^4$
- emissivity correction over the pavement ROIs
  $\Rightarrow$ emissivity distribution over pavement ROI

$$T_{\text{measured}}^4 = \varepsilon_{\text{pavement}} T_{\text{pavement}}^4 + \left(1 - \varepsilon_{\text{pavement}}\right) T_{\text{environment}}^4$$

Observation angle:
- $\alpha_{\text{average}} \approx 7^\circ$
- $\alpha_{\text{min}} \approx 4^\circ$
- $\alpha_{\text{max}} \approx 11^\circ$
Consistency with seasons and infrastructure

Approach based on a moving average

\[ WR = 2 \cdot WR(T_s) + WR(T_d), \]

with \( WR(T_s) = 0 \) if \( 0°C \leq T_s, \text{moving average} < 0.5°C \); \( 1 \) if \( 0.5°C \leq T_s, \text{moving average} < 1°C \); ... and \( WR(T_d) = 0 \) if \( 0°C \leq T_d, \text{moving average} < 0.5°C \); \( 1 \) if \( 0.5°C \leq T - T_d, \text{moving average} < 1°C \); ...

why a high risk here ???

greater consistency with the infrastructure ...

... and with seasons

2009-01-31
former conventional WR as a function of distance (in m)

2009-01-31
moving average WR as a function of distance (in m)

2009-08-19
moving average WR as a function of distance (in m)
3- Winter risk index and PCA

Principal Component Analysis (PCA) = statistical sensitivity analysis method to deal with a large set of data.

Among a set of descriptive techniques (mainly mathematical matrix algebra) without guessing any probabilistic model.
Statistical tool = correlations matrix, or the variance-covariance matrix

Research of the correlations within the dataset.

Related variables considered as a single entity, to produce an overall result taking the relationship among the variable into account.
Linear transformations of a group of correlated variables obtained in such a way that certain optimal conditions are reached.

Most important conditions: transformed variables are uncorrelated.

Existence of a generic profile to be adapted
- with seasons,
- with weather conditions
Excellent match between field measurements and thermal fingerprints re-calculated with PCA data (mean matrix + (scores matrix)x(loading matrix))

calculations on the whole itinerary section

+ interpolations between PCA results

Excellent match with field measurements
Possibility to generate winter risk index based on measurements/forecast of atmospheric parameters
Thanks for your attention

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