Plausibility of road weather data: Methods for offline and online detection of erroneous measurements
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Preconditions for the Traffic safety and traffic flow

Critical Road Weather / surface condition

Detection by stationary sensors

Well chosen thresholds

precise real time detection

Control algorithms

Variable Message Signs: Warnings, Speed limits

Acceptance by road user!

Traffic safety and traffic flow
Authorities operating traffic management systems often have trouble with malfunctioning road weather sensors and adjustment of sensor systems, because ...

- Atmospheric conditions are because of their inhomogeneous and unsteady characteristics hardly to check in their exact value
- External disturbances (Spiders / bats, contamination)
- Inhomogeneity of meteorological situations (local detection vs. areal occurrence)
- Subjectivity of occurrence
- In day-to-day operations errors in environmental data acquisition were detected not at all or late respectively by random

▶ a special test site was established
Test site “Eching Ost” for road weather and road condition monitoring

- Evaluate the plausibility of different sensors
- Find out the sensors limitations
- Compare established and new technologies
- Give Feedback to the manufacturers
- Develop methods for automatic plausibility checking
- Evaluation and classification of sensors as
  - “applicable”
  - “appropriate with restrictions”
  - “not appropriate”

- Enhance road weather and road surface condition detection
Organization of the Test Site

Federal Ministry
   Finances
Federal H R Institute (BAST)
   Support

State Authorities
   Field reports

Munich University
   of Technology
   Monitoring & Evaluation

Quarterly Workshops
Continuing Sensor Improvements

Bavarian State Authority
   Test Site Operation

Sensor Manufacturers
   Sensor Development & Implementations

Monthly Reports

Dinkel / Leonhardt / Piszczek

CHAIR OF TRAFFIC ENGINEERING AND CONTROL
Univ.-Prof. Dr.-Ing. Fritz Busch
Test Site Project – Workflow

Reference measurements

Sensor measurements

If necessary:
Adaption of Hard- & Software

Database

Statistical evaluation

Plausibility Checks

Processing and visualizing the results

Evaluating the sensors

Feedback to the manufacturers

Reference measurements

Sensor measurements

If necessary:
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Evaluating the sensors

Feedback to the manufacturers
### Road Weather Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (intensity / type)</td>
<td>Direct input data for environmental control</td>
</tr>
<tr>
<td>Water film thickness</td>
<td>Direct input data for environmental control</td>
</tr>
<tr>
<td>Visibility</td>
<td>Direct input data for environmental control</td>
</tr>
<tr>
<td>Windspeed / direction</td>
<td>plausibility purposes</td>
</tr>
<tr>
<td>Temperature (air, road surface, freezing, melting point, ground)</td>
<td>plausibility purposes</td>
</tr>
<tr>
<td>Road surface condition</td>
<td>plausibility purposes</td>
</tr>
<tr>
<td>Relative air humidity</td>
<td>plausibility purposes</td>
</tr>
</tbody>
</table>
Offline evaluation

Precipitation Intensity

Daily precipitation sums of the sensors were compared to the daily precipitation sums of a reference system “Pluviometer”. The measurements of the Pluviometer were corrected with respect to precipitation type and wind speed.

Water film Thickness

The sensors’ measurements are compared to a known water film thickness that is brought on the sensor by the use of a “spraying box“ - a computer controlled Airbrush spray gun that gives specified amounts of water on the sensor.
Offline evaluation  Visibility

- Visibility Estimation based on WebCam Images
- Plausibility checks for Sensors
- 1 Image per Minute
- Per Day ~ 720 „usable Minutes“ (luminance) (x 365 Day / Year …)

since 2004, a lot of work…

Whish for Partial Automation of the evaluation
Offline evaluation  Visibility

Visibility estimation with automatic image processing:

*For each Image*

1. calculation of grey values (Matrix of grey values)
2. Luminance estimation (image usable: yes / no)
   
   IF Image IS usable:
   
3. Convolution with edge detector (Edge-Matrix)
4. Visibility Estimation (Edge Intensity (Sum, Median, Maximum))
   
   Visibility in „Pixel-Rows“
   
   Visibility in Meters

   END

Next Image

Graphical output image and calculated visibility:
Online evaluation

**Time Series based (one parameter)**

Does the actual measurement fall in a plausible range?

\[ \text{value}_{\text{min}} \leq \text{measurement}(t) \leq \text{value}_{\text{max}} \]

<table>
<thead>
<tr>
<th>Proposed basic provision (extract)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation Intensity</td>
<td>[0, 20] mm/min</td>
</tr>
<tr>
<td>Road Surface Condition</td>
<td>(adapted) WMO Code List</td>
</tr>
<tr>
<td>Water film Thickness</td>
<td>[0, 3] mm</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>[-30, 60] °C</td>
</tr>
<tr>
<td>Humidity</td>
<td>[10, 100] %</td>
</tr>
<tr>
<td>Visibility</td>
<td>[10, 2000] m</td>
</tr>
<tr>
<td>Road Surface Temperature</td>
<td>[-30, 80] °C</td>
</tr>
<tr>
<td>Dew Point Temperature</td>
<td>[-30, 30] °C</td>
</tr>
<tr>
<td>Windspeed</td>
<td>[0, 60] m/s</td>
</tr>
<tr>
<td>Winddirection</td>
<td>[0, 359] °</td>
</tr>
</tbody>
</table>
Online evaluation

**Time Series based (one parameter)**

Does the time series show the expected *dynamics*?

\[ \text{measurement}(t) = \text{measurement}(t-1) = \ldots = \text{measurement}(t-n) \]

E.g. proposed basic provision for visibility:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Maximal duration with no change in time series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility</td>
<td>&lt; 500 Meter</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>

![Graph showing accumulation of identical consecutive values](image-url)

Period August 2006 – August 2007

Accumulation of identical consecutive values
Online evaluation

Time Series based (one parameter)

Is the rate of change not too big?

\[ |\text{measurement}(t) - \text{measurement}(t - 1)| \leq \Delta r_{\text{max}} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximal rate of change (per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water film Thickness</td>
<td>+/- 2 mm</td>
</tr>
<tr>
<td>Air Temperature</td>
<td>+/- 2 °C</td>
</tr>
<tr>
<td>Humidity</td>
<td>+/- 10 %</td>
</tr>
<tr>
<td>Road Surface Temperature</td>
<td>+/- 7 °C</td>
</tr>
<tr>
<td>Temperature in Depth 1</td>
<td>+/- 0.5 °C</td>
</tr>
<tr>
<td>Dew Point Temperature</td>
<td>+/- 1 °C</td>
</tr>
<tr>
<td>Windspeed</td>
<td>+/- 15 m/s</td>
</tr>
</tbody>
</table>
# Online evaluation

## Cross Correlations (extract)

<table>
<thead>
<tr>
<th>First Check</th>
<th>Second Check</th>
<th>Plausible value</th>
<th>Implausible Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility ≤ Visibility$_{\text{max}}$ (500 Meters)</td>
<td>Precipitation Type = “None” AND Humidity &lt; Humidity$_{\text{dry, max}}$ (60%)</td>
<td>Visibility</td>
<td>Visibility</td>
</tr>
</tbody>
</table>

**Graph**

- **Data Points:**
  - Plausible Values
  - Implausible Values

**Axes:**
- **Y-axis:** Relative Air Humidity [%]
- **X-axis:** Visibility [m]
Online evaluation

Cross Correlations: Example Visibility
Online evaluation

Cross Correlations (extract)

<table>
<thead>
<tr>
<th>First Check</th>
<th>Second Check</th>
<th>Plausible value</th>
<th>Implausible value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation Intensity &gt; 0,5 AND Water film Thickness = 0</td>
<td>ΔTDry &gt; 3 Minutes AND Humidity &lt; Humidity dry max (60%)</td>
<td>Water film Thickness</td>
<td>Precipitation Intensity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Precipitation intensity</th>
<th>Precipitation Class</th>
<th>Relative humidity</th>
<th>Waterfilm thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.09.2006 18:30</td>
<td>0</td>
<td>0</td>
<td>51.8</td>
<td>0</td>
</tr>
<tr>
<td>11.09.2006 18:31</td>
<td>0</td>
<td>0</td>
<td>51.9</td>
<td>0</td>
</tr>
<tr>
<td>11.09.2006 18:32</td>
<td>1.077</td>
<td>Rain</td>
<td>51.8</td>
<td>0</td>
</tr>
<tr>
<td>11.09.2006 18:33</td>
<td>0.604</td>
<td>Rain</td>
<td>51.9</td>
<td>0</td>
</tr>
<tr>
<td>11.09.2006 18:34</td>
<td>0.715</td>
<td>Rain</td>
<td>52.3</td>
<td>0</td>
</tr>
<tr>
<td>11.09.2006 18:35</td>
<td><strong>0.527</strong></td>
<td>Rain</td>
<td><strong>52.2</strong></td>
<td>0</td>
</tr>
<tr>
<td>11.09.2006 18:36</td>
<td><strong>0.924</strong></td>
<td>Rain</td>
<td><strong>52.6</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

Result:
- Water film thickness plausible
- Precipitation implausible
Online evaluation

Long Term Cross Site based Plausibility Checks

Observations and comparisons between several sites can reveal systematic errors. The results have to be evaluated carefully and with respect to local meteorological and topological characteristics. The following parameter can be evaluated in this manner:

- Precipitation Sum
- Average Air Temperature
- Visibility
- Precipitation Type
Online/offline evaluation

Cross Site based Plausibility Checks – Visualization Example

Smooth gradients indicate plausible measurements

Method could be extended to other parameters
Publications

- Huge database with matching observations
  - Used for development and
  - Application
    of plausibility checks
Plausibility checks will be published:

- Evaluation and classification of sensors is published:
Questions, Comments …?

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