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Linking keeping quality models and sensor systems to an autonomous transport supervision system

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Introduction

- Tracing & Tracking systems onboard trucks increasingly popular (50% of Dutch transport companies have them and 75% of the rest want them)
  - Efficiency and logistic control
  - Extra customer service

- About 35% of all trucks transports in Europe carry perishables (vegetables/fruits)
Introduction

- Telemetric monitoring of product behaviour can help
  - limit product losses (by changing storage conditions during transport)
  - limit replacements costs when the products is unacceptable
  - enhance product quality in the chain (warehouse planning)
Keeping quality

- product behaviour
- intrinsic properties
- product quality

- consumer attitude
- economical + psychological circumstances
- acceptance limit

“Quality”

Keeping quality: the time the product quality remains acceptable
Keeping quality for one quality attribute

- For a single quality attribute product behavior can be described by:

\[ f(Q) = \frac{Q_0 - Q_l}{k} \]

- Keeping quality = \( \frac{f(Q)}{k} \)

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>( f(Q) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>linear</td>
<td>( Q_0 - Q_l )</td>
</tr>
<tr>
<td>exponential</td>
<td>( \log_e \left( \frac{Q_0}{Q_l} \right) )</td>
</tr>
<tr>
<td>logistic</td>
<td>( \log_e \left( \frac{Q_{inf} - Q_l}{Q_l \cdot C_{ba}} \right) )</td>
</tr>
</tbody>
</table>
Temperature dependence of the KQ

- **Arrhenius Law':**
  
  \[ k = k_{\text{ref}} \cdot e^{ \frac{E_a}{R} \cdot \left( \frac{1}{T_{\text{ref}}} - \frac{1}{T} \right) } \]

- Keeping quality can then be expressed in KQ_{\text{ref}}

\[ KQ = \frac{KQ_{\text{ref}}}{k_{\text{ref}} \cdot e^{ \frac{E_a}{R} \cdot \left( \frac{1}{T_{\text{ref}}} - \frac{1}{T} \right) }} \]

\[ k_{\text{ref}} = 1 \text{ at } T = T_{\text{ref}} \]
Keeping quality for multiple quality attributes

- Many horticultural crops have different quality limits at different temperatures:
  - Which quality attribute is limiting at each temperature? Each attribute has its own $k$
- For tomatoes:

![Graph showing the keeping quality of pink, red, and green tomatoes at different temperatures.]

- $\text{KQ}_{\text{ref}} = 6.389$ days
- $T_{\text{ref}} = 10 \, ^\circ\text{C}$
- $k_1 = 0.24$
- $E_1 = 77190$
- $k_2 = 0.76$
- $E_2 = -421380$

- Chilling injury
- Firmness loss
Example: temperature-time scenarios for tomatoes

- Extension to a dynamic KQ model needs to integrate over time, but needs only one fast numerical integration.
How to assess the maturity / KQ estimation

- Climacteric products produce ethylene (plant ripening hormone) depending on their maturity
- Tomatoes:
  - **maturity**
    - green tomatoes: increasing ethylene concentration over time
    - pink tomatoes: constant ethylene concentration over time
    - Red tomatoes: decreasing ethylene concentration over time

- Continuous ethylene measurement can give an indication of the maturity
- Combination of time + temperature + ethylene sensors + KQ model can provide an KQ estimation
Autonomous transport supervision

- Research Centre “Autonomous cooperating processes in Logistics” (University of Bremen)
- Autonomous transport supervision system
- Extend T&T: “We not only want to know the current location, but also in which state it is”
- Online-Calculation of KQ-models
- Transport operator should worry about quality not about temperature values
Central or local processing?

Sensor Raw Data

Quality Modelling
Transport Operator

Standard T&T

Quality Information

Transport Operator

Quality Modelling
Standard T&T + Processor
Local quality estimation

- Local calculation of dynamic quality models
  - Reduces communication volume and costs
  - Robust against communication failures
  - Advanced sensor supervision
- Technical implementation
  - Demonstrator
  - Extra hardware costs for processor ~ 100 €
Software Agents

- Mobile quality models
  - Electronic consignment note contains quality model
  - Accompanies freight item along the supply chain
  - Contains handling and supervision instructions

Software agents
- AI-Approach
- Informs the owner at emerging risks
- JAVA: dynamic and platform independent language
Linking RFIDs and Quality Models

**Intelligent Agent**
- Software representation of the physical object
- Transport- and handling-instruction

**Logistical object**
- Passive RFID-Label

**Dynamic link**

**RFID-Tag is read at transshipment**

**Container requests agent at loading**

**Warehouse or Means of Transport**
- CPU platform
- Sensors
- RFID-Reader

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IMSAS
The intelligent container

- RFID Reader
- Local Pre-Processing
- Freight Object (RFID)
- Sensor Nodes
- External Communication
Wireless Sensors

- Ultra low power design for extended service intervals
- Autonomous configuration

Sensor Node
ITEM, University of Bremen
Create Agent for new Freight item

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UID</td>
<td>e00401000749c536</td>
</tr>
<tr>
<td>Modell Order</td>
<td>2</td>
</tr>
<tr>
<td>Kind of good</td>
<td>Tomatoes,pink</td>
</tr>
<tr>
<td>Reference Temp</td>
<td>10.0</td>
</tr>
<tr>
<td>Recommended Temp</td>
<td>14.0</td>
</tr>
<tr>
<td>KQ-Ref</td>
<td>6.389</td>
</tr>
<tr>
<td>Expected lifetime</td>
<td>14.366</td>
</tr>
<tr>
<td>k-Ref1</td>
<td>0.2409</td>
</tr>
<tr>
<td>Warning level</td>
<td>10.0</td>
</tr>
<tr>
<td>k-Ref2</td>
<td>0.7591</td>
</tr>
<tr>
<td>Activation Energie 1</td>
<td>77910.0</td>
</tr>
<tr>
<td>Host platform</td>
<td>hades</td>
</tr>
<tr>
<td>Activation Energie 2</td>
<td>-421380.0</td>
</tr>
<tr>
<td>Origin</td>
<td>Bremerhaven</td>
</tr>
<tr>
<td>Destination</td>
<td>Frankfurt</td>
</tr>
<tr>
<td>TimeUnit</td>
<td>Minutes</td>
</tr>
</tbody>
</table>

Required Sensors:
- [x] Temperature
- [x] Humidity
- [ ] Illumination
- [ ] Gas
- [ ] Acceleration

Write data on tag and start agent
<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
<th>Message</th>
<th>UID</th>
<th>Product</th>
<th>Priority</th>
<th>KQ/Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>17:04:38</td>
<td>...</td>
<td>Low shelf life, contact transport manager!</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>red</td>
<td>0.96</td>
</tr>
<tr>
<td>17:03:13</td>
<td>...</td>
<td>Unexpected change in shelf life!</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>yellow</td>
<td>7.95</td>
</tr>
<tr>
<td>17:02:53</td>
<td>...</td>
<td>10 days shelf life left</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>normal</td>
<td>9.88</td>
</tr>
<tr>
<td>17:02:17</td>
<td>...</td>
<td>Recommended Temperature overstepped</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>yellow</td>
<td>12.95</td>
</tr>
<tr>
<td>17:01:44</td>
<td>Vehicle IP-57</td>
<td>OK - All Sensor available</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>normal</td>
<td>...</td>
</tr>
<tr>
<td>17:01:20</td>
<td>Vehicle IP-57</td>
<td>Moved to new vehicle</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>normal</td>
<td>13.98</td>
</tr>
<tr>
<td>17:01:16</td>
<td>Vehicle IP-57</td>
<td>Sensor missing: Humidity</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>red</td>
<td>...</td>
</tr>
<tr>
<td>17:01:04</td>
<td>Warehouse-51</td>
<td>Freight item waiting for transport</td>
<td>e00401000749eeb9</td>
<td>Tomatoes,pink</td>
<td>normal</td>
<td>full</td>
</tr>
</tbody>
</table>

Time: 17:03:13

Message: Unexpected change in shelf life!

UID: e00401000749eeb9

Product: Tomatoes,pink

Priority: yellow

KQ/Days: 7.95
The Ethylene Scale

Exhalation of Pineapples
Exhalation of Lettuce
Climacteric Rise of Bananas
Exhalation of Pears
Exhalation of Apples

Ripening induced to Kiwis

Shortened Preclimacteric (Bananas)

Exhalation of Tomatoes

0.1 ppb  1 ppb  10 ppb  100 ppb  1 ppm  10 ppm  100 ppm  1000 ppm

\[
\frac{1 \, \mu l}{kg \cdot h} \sim 1 \ldots 2 \, ppm
\]

1 ton of fruits in 0.5 ... 1 m³ free air volume after one hour
Ethylene sensors

- Requirements for improved ethylene measurement
  - Detection of pre-climacteric states
  - Detection of small changes over time
  - Selective
  - Mobile
  - Maintenance free
  - Cost effective
The Ethylene Scale

- Exhalation of Pineapples
- Exhalation of Lettuce
- Climacteric Rise of Bananas
- Exhalation of Pears
- Exhalation of Apples

- Exhalation of Tomatoes

Exhalation Levels:
- 0.1 ppb
- 1 ppb
- 10 ppb
- 100 ppb
- 1 ppm
- 10 ppm
- 100 ppm
- 1000 ppm

Measurement Devices:
- (Large) Portable Measurement Devices
- Laboratory Instruments

Required Range
Concept for sensitive and selective sensor

- **Increased resolution by pre-concentrator**

- **Increased selectivity by gas chromatography**
Summary

- Current state
  - KQ-Model for tomatoes / different maturity states
  - Prototype for an autonomous quality supervision system (intelligent container)

- Further research
  - High sensitive mobile ethylene sensor
  - Extend KQ-Library for influence factors like humidity, ethylene and maturity
  - Integration into commercial T&T systems
Thank you for your attention

For further information please contact:

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