DASH7 UAG Research Symposium

University of Bremen, Germany
18th and 19th of October 2012

Dr.-Ing. Reiner Jedermann

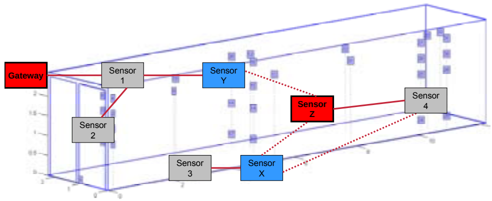
Changes of Dash7 in Logistics

Outline

- Show at our example who sensor networks can be applied in food logistics
- No general solution, just to motivate you to create own applications
- Discuss from our experience what advantages can be (hopefully) expected from dash7

Sensor Networks vs. single point measurements

- Measure the spatial distribution of a physical property
  - Local deviations
  - Find the Hot-Spot
- Either direct communication with base station /gateway **or** forwarding inside the network
- Just to measure in one point you don't need to develop a new communication standard



The intelligent container project

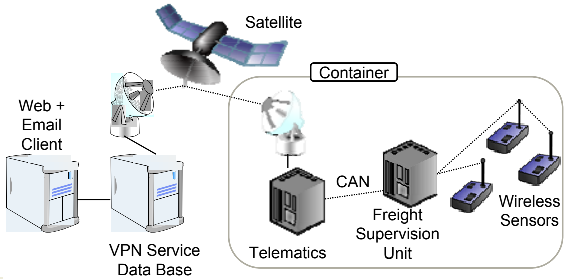
- Supervision of fresh foods
  - Chilled Transport of **bananas** from Central America to Europe
  - Transport of meat within Europe
  - Initial transfer project 2008 and 2009
  - Industrial cooperation project since 2010, ending mid of 2013

Supported by THERMO KING
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

The intelligent container project

- Sensor network **inside** the container
- Satellite Link / GSM network **outside** the container

- Sensors in different pallets / positions inside pallets
- 20 pallets with 1 ton of bananas in 48 boxes each, Total 1000 boxes



What to measure

What	Why / why not	
Temperature	Cheap and accurate sensors, most influence to quality of fresh foods	√
Humidity	Low sensor accuracy, chaotic measurements e.g. humidity close to saturation, changing temperatures	✗
Acceleration / shock	Some industrial interest (large paper rolls, beverages) but no project	✗

- Using a sensor network means TEMPERATURE

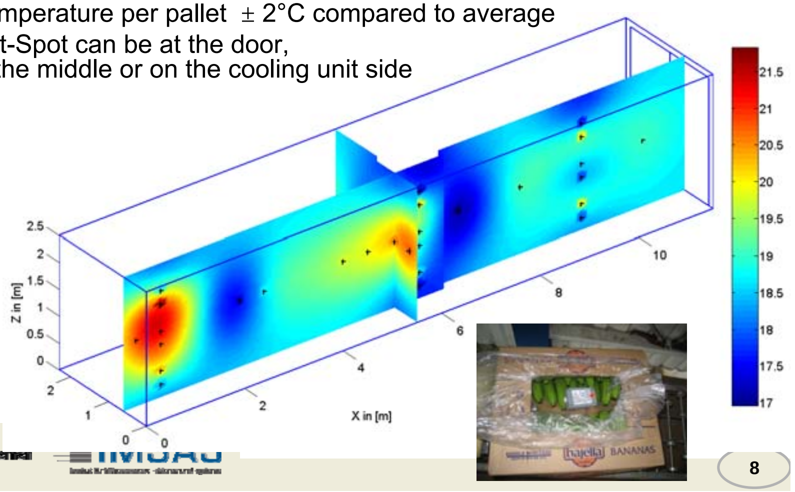
The problem

- Bananas should arrive in green 'unripe' state
  - Ripening by gas treatment in Europe

- From time to time a container arrives in poor quality state
  - Some / all bananas already started ripening
  - Only know it, if you open the container (Without remote sensor supervision)

The good news

- Whenever you measure temperature, you find local deviations
  - Temperature per pallet ± 2°C compared to average
  - Hot-Spot can be at the door, in the middle or on the cooling unit side



The bad news

- We don't know where the Hot-Spot is
  - Temperature profile mainly influenced by gaps between pallets
  - Distribution of gaps unpredictable
  - Hot-Spot can be anywhere
  - Measure in every box

Why to measure temperature?

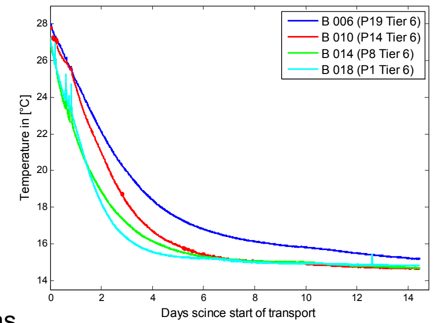
- It's fun to play around with sensor nodes! √
- You get some research money! √
- Is there anyone outside who wants to have hundreds of temperature curves on his desk every day? ✕
  - A logistic company handling 1000 containers per day cannot waste to much time on a single temperature curve
  - What is the benefit of detailed spatial temperature supervision?

Processing of sensor data

- In order to sell sensor nodes, you have to find a way for automated data processing
  - Embedded processing saves communication costs
  - Which information does the user really wants to know?
- If you a just doing threshold warnings, you loose 90% of the information
- Translate temperature curve into useful information

Case study bananas

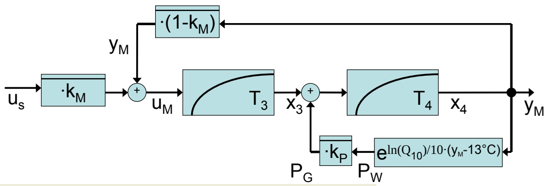
- Bananas are loaded 'warm' at 25°C
  - Cooled down to 14°C during transport
- Bananas produce heat by respiration
  - Conversion of starch to sugar
  - Increasing with the age of bananas

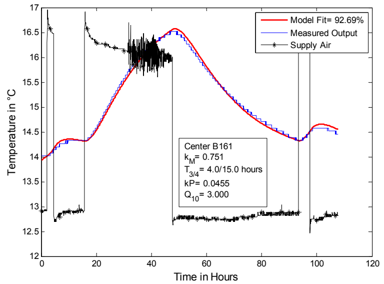


- Translate temperature curve into useful information
  - Does cooling operate properly?
  - Is the biological activity of the bananas increasing?

Extracting parameters from temperature curves

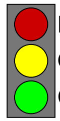
- Example for bananas
  - Hand-made model, only valid for certain type of packing
  - State space model + parameter identification
- Find a useful model structure with meaningful parameters
  - k_M = Coupling to air flow
    = cooling performance inside one box
  - k_P = Respiration heat of bananas





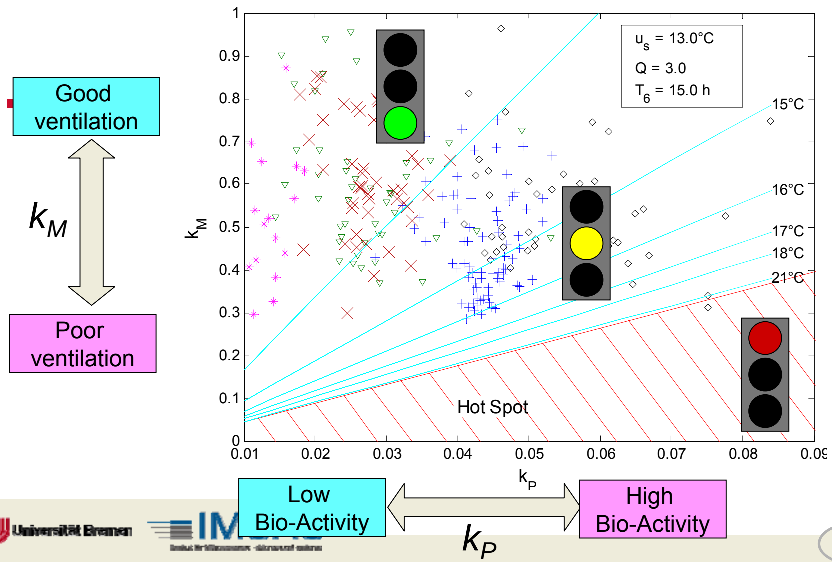
The model in real-time

- Not fully implemented yet, only wireless temperature measurement
- But model identification can be implemented on modern sensor nodes (Java / ARM 72 MHz) or processing unit inside container
- Instead of full temperature data, the sensor transmits only updates, if model parameters have changed
- Logistic operator gets directly the information he wants to have
- Traffic light

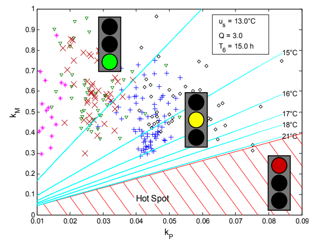


Refuse delivery
Quality inspection required, sort out some pallets
Container OK

Example of parameter pairs in our field tests

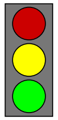


Application of banana model



- Good curve fitting
  - Different temperature curves can be explained by changing only two parameters
- Logistic application
  - Warning on poor ventilation
  - Warning on early ripening (high respiration)
  - Warning if low relation between cooling performance and respiration heat
    → Heat cannot be channelled away
    → Creation of a Hot-Spot

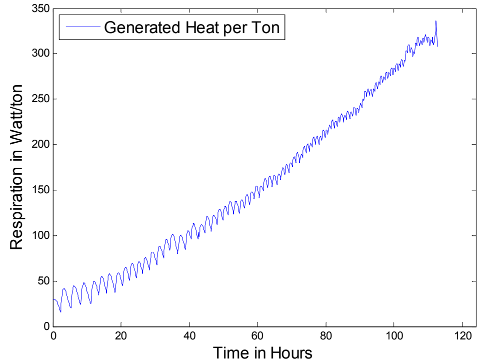
Application of quality information



- If you know in advance, which container arrives in poor quality state
  - Priority handling in harbour
  - Inform the farm (new forklift driver not instructed?)
  - Compensate by warehouse management / planning of ripening
  - Container with boxes branded for a special customer
    → real problem, more time to handle it
  - Adjusting cooling unit
  - Refuse delivery (save of import taxes)

Application to ripening

- Respiration heat almost constant during transport
- Increases after special gas treatment for ripening
- Calculate ripening heat from temperature curve
  - BAD (noisy) approach: subtract effect of cooling from temperature curve
  - ACCURATE approach: Kalman filter
  - General approach to filter noisy signals



Application to ripening

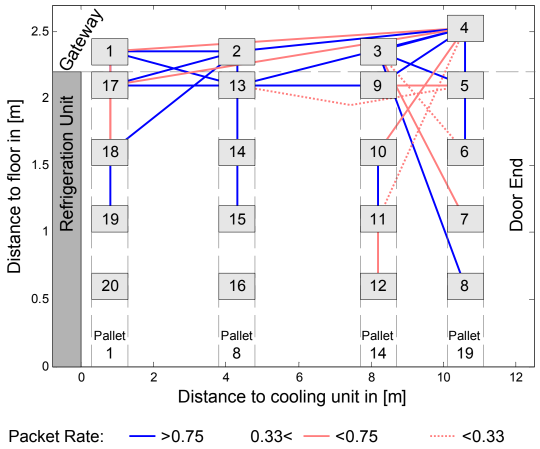
- The Kalman filter
  - Estimate internal states of model by measurement of one/multiple outputs
  - Recursive implementation
  - Matrix multiplications + one division / matrix inversion (if more than one output)
    → embedded application
  - Estimate respiration heat as additional state variable of the model
  - Difficulty: Find noise amplitude/model for each model state

Why is dash7 better?

- So far tests with 2.4 GHz (802.15.4 / TelosB)
  - Problems with signal attenuation by “wet” food products
  - Multi-Hop message forwarding is a waste of energy
- Expectations on dash7
  - Longer communication range, less sensitive towards water containing products
  - Direct communication with base station / gateway
  - Not tested yet

Signal attenuation at 2.4 GHz

- After 0.5 meters:
  - 1/3 OK
  - 1/3 some black-outs
  - 1/3 no communication

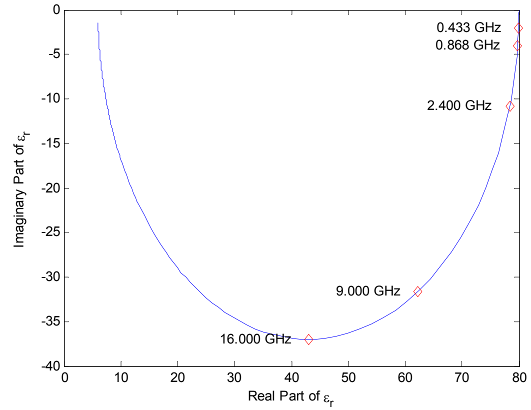


Signal attenuation at 2.4 GHz

- Cole Cole diagram
  - Capacity of water as function of frequency
  - Imaginary part means losses
  - Attenuation almost linear to frequency in considered range

$$\varepsilon_R(f) = \varepsilon_\infty + \frac{\varepsilon_0 - \varepsilon_\infty}{1 + j\dfrac{f}{f_{\text{Reso}}}}$$

$\varepsilon_\infty = 6$, $\varepsilon_0 = 80$,
fReso = 16 GHz



Energy consumption of multi hop protocols

- Sending a message with some bytes of sensor data takes 15 ms radio up time (TelosB, 2.4 GHz), raw data < 1 ms
- In order to forward the messages of 30 sensors over maximum 6 hops, each sensor has to be powered for ~5 seconds per frame
- Most time spend for idle listening
- Even worse if sensors not synchronized / time frames for communication have not been negotiated yet
  - Only this last problem can be solved by low-power-listening
- Direct communication
  - Sensor sends it's data every 15 minutes
  - Keeps the radio shortly on after sending to see if new command from base station

How to start a project

- Start tests with data loggers
  - As much as you can get (>100)
  - Cheaper, don't worry if you loose some of them
  - Be ready for surprises
- Get some ideas of the temperature problems
  - Show the customer what you can see from the data
  - Be careful, most (temperature) problems can be solved by common sense, without installing hardware.
  - Find the right places to install reduced number of expensive sensors

How many sensors

- Dreaming of hundreds
- Even 30 sensors can by nasty
  - Assembling water protected housing, changing batteries, install software, repair broken contacts
- Customer don't want to pay for even 20 sensors per container
- Not only hardware costs, also sensor installation
  - Send 100 sensors + installation instructions to Central America and wonder what happens

Summary and Conclusions

- In real world applications, most sensor networks do only temperature measurements
- Providing automated data processing is crucial to 'sell' sensor networks
  - System identification and Kalman Filter introduced as example
- Dash7 will provide remote supervision at less energy/battery costs

Thanks for your attention

www.intelligentcontainer.com

Dr. Ing. Reiner Jedermann
University Bremen, FB1
Institute for Microsensors, -actors and –systems (IMSAS)
Otto-Hahn-Allee, NW1
D-28359 Bremen, GERMANY
Phone +49 421 218 62603, Fax +49 421 218 98 62603
Email rjedermann@imsas.uni-bremen.de