RFID JOURNAL

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RFID Temperature Sensors Improve Food Quality

Background

- Microsystems Center Bremen
  - Microsensor and –system applications
- LogDynamicsLab
  - RFID test facilities
- Global RF Lab Alliance
  - Project study with University Florida

MCB

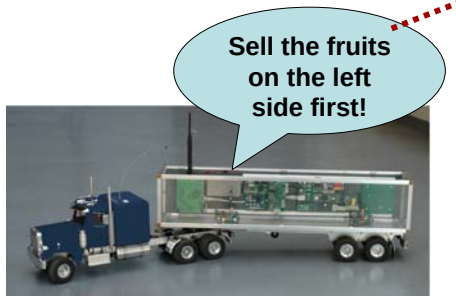
LogDynamics

Global RF Lab Alliance

University of Bremen

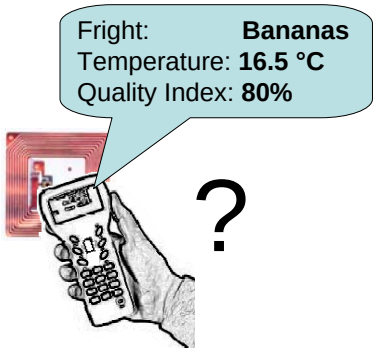
Autonomous logistics

- Automated freight supervision and transport coordination



SFB 637

RFID for the cool chain



- Beyond tracing and tracing
  - Combination with sensors for temperature and quality monitoring
  - Write back to tag
  - Pro-active self-supervising goods

Outline

- Existing RFID sensor hardware
  - Sensor application (passive HF)
  - Temperature profiles of cool chain transports
- Food chain demands on UHF-RFID
- New approaches for cool chain supervision
  - Intelligent RFID
  - Combination with active sensor systems

Current RFID sensor applications

Passive Tags
- HF + UHF
- EPC Gen2
- No sensors

Semi-Passive
- HF-Data loggers
- Battery for sensors

Active Tags
- Wireless Sensor networks / Class 4
- To expensive for item level

Miniaturized data loggers

- 2 HF-RFID loggers
- 1 with electrical interface
- Required Accuracy:
  - << 0.5 °C
- Tests in climatic chamber
  - Standard deviation: 2/3 of all values are inside $\pm\delta$

Comparison of different logger types

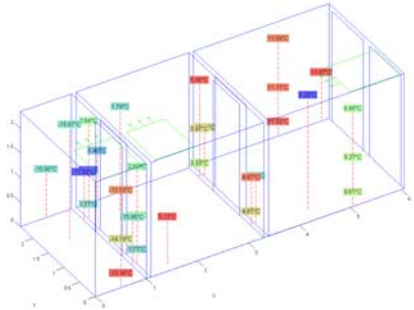
Type	KSW	TurboTag	iButton
Data points	700	700	4000
Battery	±	+	++
Resolution	~ 0.3 °C	~ 0.2 °C	0.0625 °C
Tested Accuracy	± 0.4 °C	± 0.18 °C	< ± 0.1 °C
Interface	RFID	RFID	One-Wire
Price	5-10$	5-10$	> 30 $
Handling	+	++	-
Software	±	++	±

Temperature deviations in typical transports

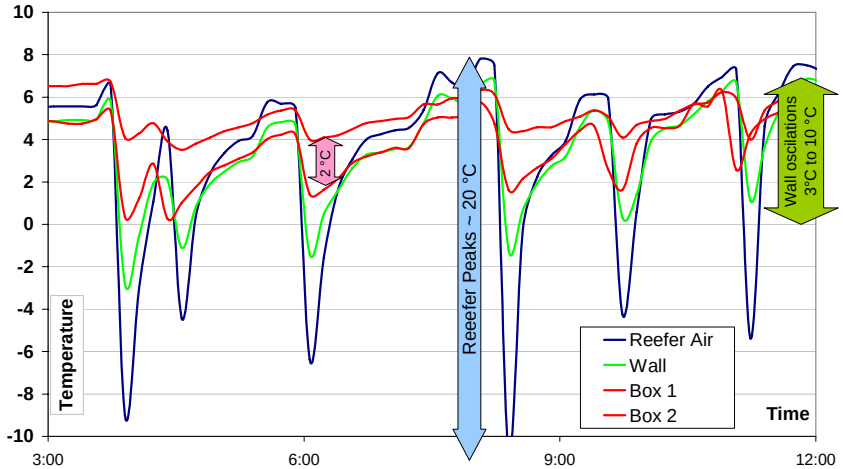
- Rungis Express
- CCG Holding AG and CCG FRA
- Sealed Air Corporation
- Gildemeister
- Carl Schröter (Insurance company)

Test at trucks for express delivery

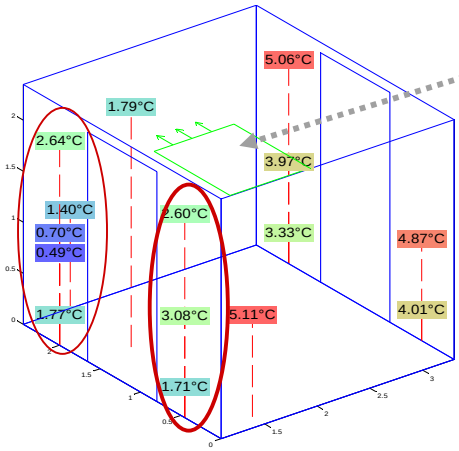
- Rungis Express
- Trucks with 3 temperature zones



Temperature oscillations in delivery truck

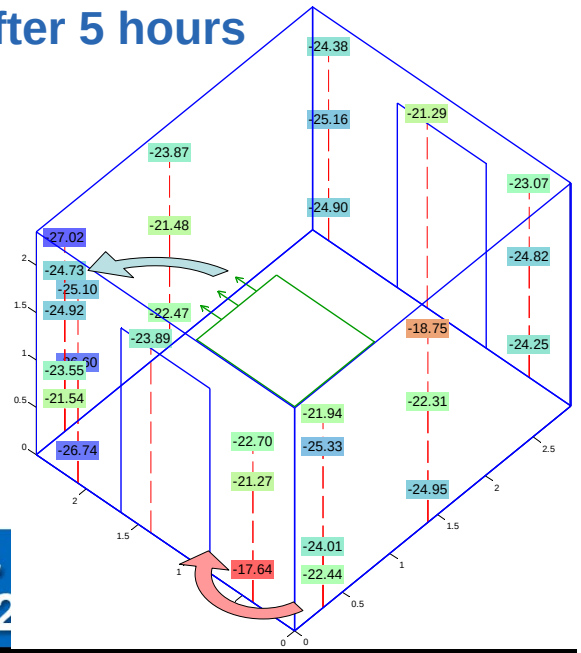


Meet compartment

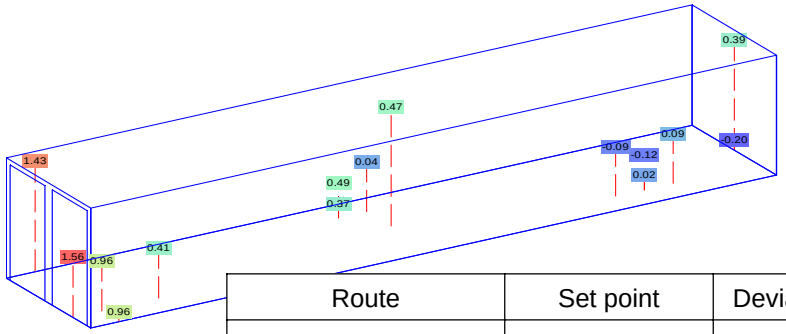


- Average of reefer side ~2 °C colder than other side
- Single loggers behave 'chaotic'
- No simple averaging

Deep freezer after 5 hours



Measurement in sea containers



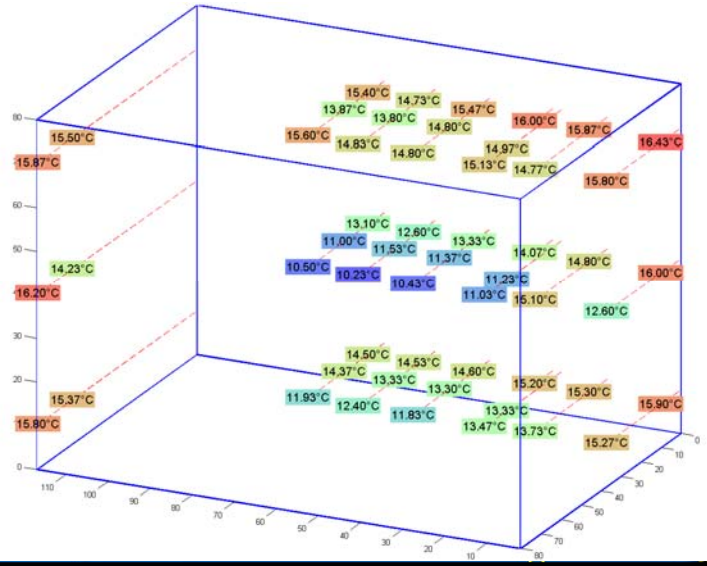
Route	Set point	Deviation
Bremen – Nigeria	-18 °C	5 °C
Chile – England	0 °C	1.8 °C
Hong Kong – Bremen	Non chilled	2.6 °C

Temperature inside palette

After 60 hours in warm ambient

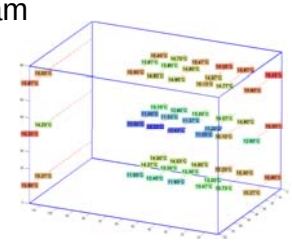
7°C
→20 °C

Time constant 0.3 ... 3 days



How and where to measure

- Wall, packing and core temperature
  - Quality depends on core temperature
  - Wall temperature = Surface of palette + Isolation losses + Air stream



Time constant
0.3 … 3 days

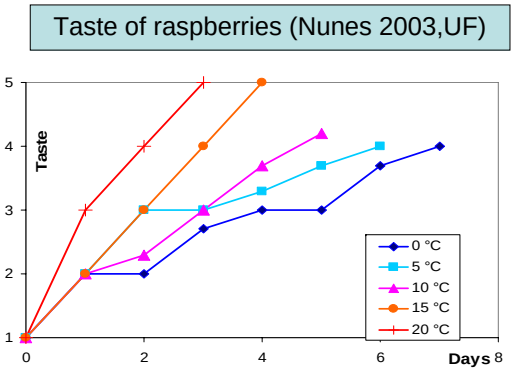
Time constant
3 … 5 hours

How to define and measure quality?

- Legal requirements: only temperature thresholds
- Multiple factors:
  - Colour, firmness, taste, vitamin C content ….
- Generalized Scale: Keeping quality / Shelf life
  - Number of remaining days until a defined threshold will be passed (colour loss, bacteria limit, consumer acceptance …)

Mathematical modeling approaches

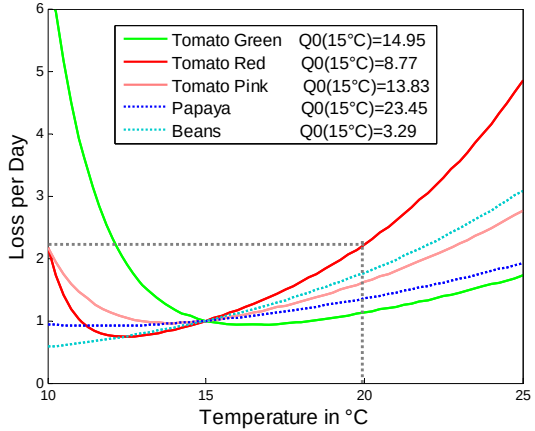
- Reference curves
  - Recorded for constant temperatures
  - Interpolation for dynamic temperatures



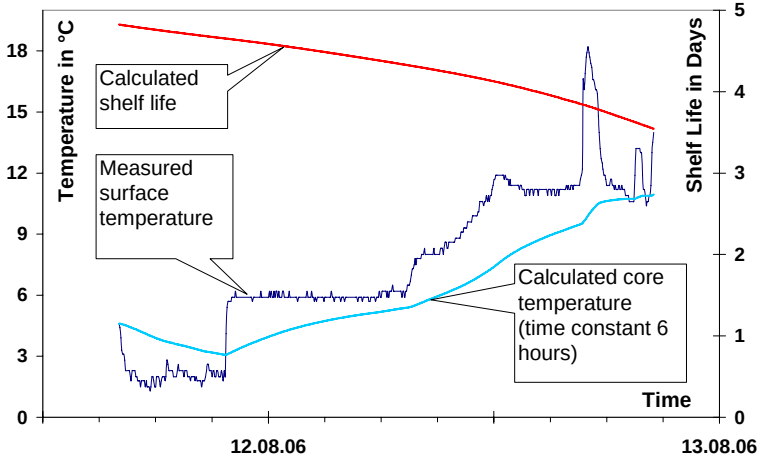
Shelf life modelling

- Calculation of loss per day as function of temperature
  - Arrhenius equation for reaction kinetics
  - Look up table

WAGENINGEN UNIVERSITY
PLANT SCIENCES
Horticultural Production Chains (HPC)

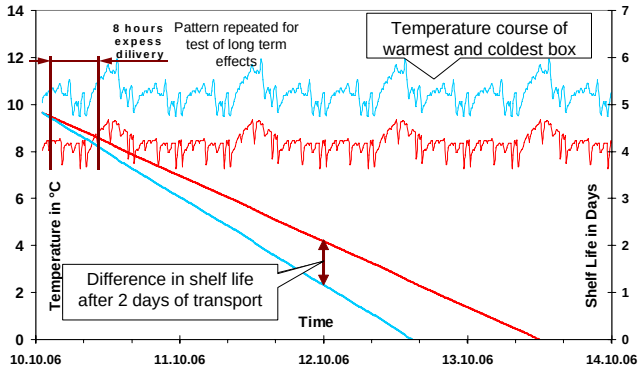


Effect of small temperature peaks



Application to recorded data

Box	Average	Zero Shelf life
Coldest	8.21 °C	3.5 days
Warmest	10.31 °C	2.5 days



Strawberries – Case Study

UF UNIVERSITY of FLORIDA IFAS

- Study by the University of Florida
  - Temperature sensors inside and at surface of 24 palettes
  - Manual quality assessment
  - Comparison with shelf life prediction
- First expires first out (FEFO)
  - Split truck load by low / high shelf life palettes for delivery to nearby / distant stores

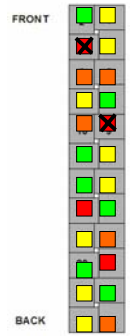
Strawberries – Case Study

UF UNIVERSITY of FLORIDA IFAS

- Temperature tracing and shelf life prediction would give the following recommendation:

= 3 full days
= 2 full days
= 1 full day
= 0 day

2 pallets → reject immediately
2 pallets → rejected at arrival
5 pallets → sent immediately for stores
8 pallets → sent to nearby stores
7 pallets →no special instructions (remote stores)



Center for Food Distribution and Retailing (J.P. Emond)

Strawberries – Case Study

UF UNIVERSITY of FLORIDA IFAS

Waste at the store level (22 pallets sent)

Days left	Number of pallets	Waste random retail	Waste (RFID + Model)	(Recommendation)
0	2	91.7%	(rejected)	(don't transport)
1	5	53 %	(25%)	(sell immediately)
2	8	36.7%	(13.3%)	(nearby stores)
3	7	10%	(10%)	(remote stores)

Revenue and profit

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	Actual	RFID + Model
REVENUE	$47,573	$58,556
COST	$49,876	$45,480
PROFIT	($2,303)	$13,076

Steps towards UHF

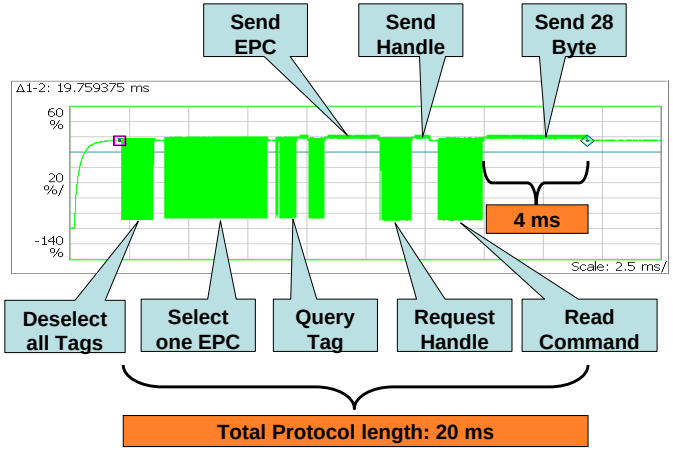
- EPC Standard
  - Better pulk reading and higher data rate
  - Range ~ 3m
  - Gen-2 with password protection
  - Currently up to 28 bytes user memory (NXP-Tags)
- 3 Warnings: UHF needs careful planning, but still is the best solutions

#1: Be aware of the speed of forklifts

- Reading speed is critical
  - Large tag-populations
  - High (temperature) data amount
- What is the effective Gen-2 data rate?
  - European UHF Bandwidth 2 MHz ⇔ 20 MHz USA
  - Maximum of 640 kBit / sec hardly reached

Analysis of Gen-2 protocol

- Reading 28 Bytes user memory



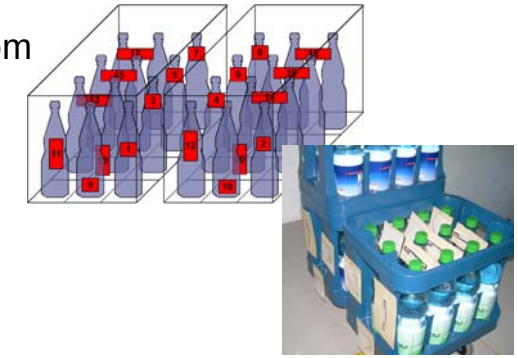
The communication bottleneck

Data rate	Pessimistic	Medium
Interrogator -> Tag	40 kBaud	80 kBaud
Tag -> Interrogator	64 kBaud	160 kBaud
4 Tags Inventory + 700 Temperature data each	1388 ms	688 ms

- Even with Gen-2 Protocols it is hardly possible to transfer full temperature history of multiple items

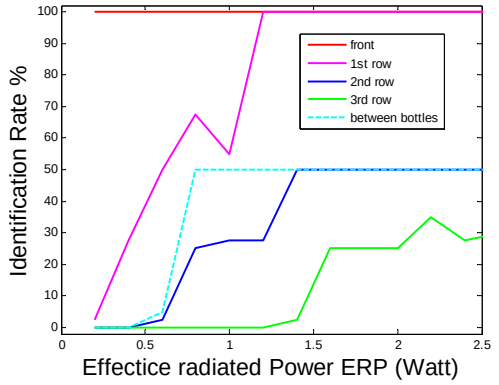
#2: The influence of water

- Best of 3 reads from different positions
- Distance 50 cm
- Reader: Feig Obid ISC-LRU 2000
- Tags: NXP / TagNology



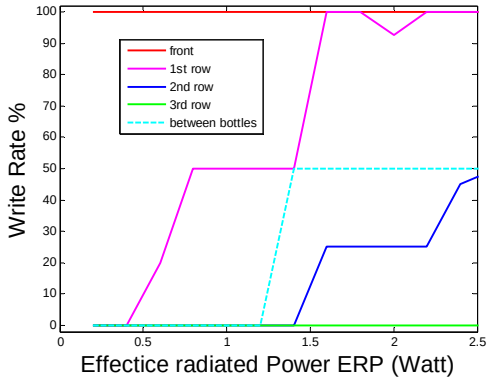
Identification rate

- Strict recommendation: Tags only at surface
- Inside → very limited penetration
- Distance surface to water bottles 2.5 cm
- HF: less sensitive, but also less range

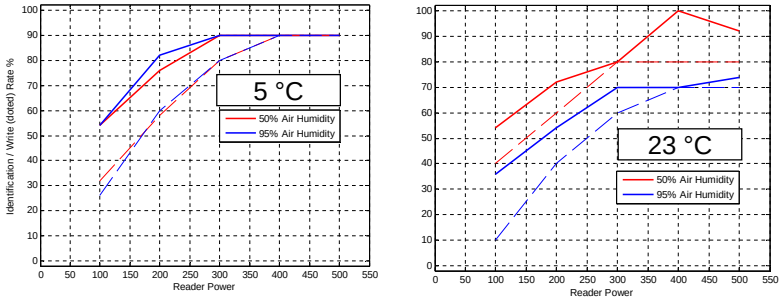


Writing to the tag

- Write back
  - Maximum transport temperature
  - Calculated quality index
- Surface
  - No problems
- 1st row
  - 30% more power but rate < 100%



#3: The influence of air humidity



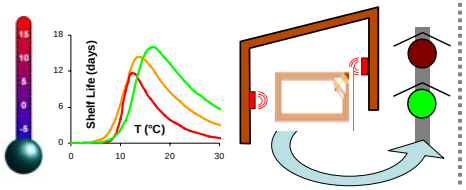
- Low max. absolute humidity at low temperatures
  - 6.5 g/m³ (5°C) ⇔ 19.5 g/m³ (23°C)
- Minor influence chain applications < 15°C

Solutions for the communication bottleneck

On-Chip processing of sensor data by Intelligent RFID / sensor label

Shelf life model to assess effects of temperature

Only state flag transmitted at read out



Split between identification and measurement task

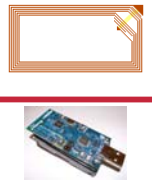
Standard identification tag at item level + Active sensor nodes for permanent access

Chain supervision by intelligent RFID

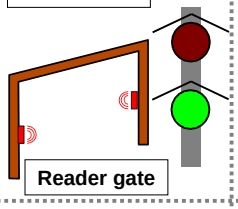
Step 1: Configuration

Manufacturer

Step 2: Transport



Step 3: Arrival



Reader gate

Step 4: Post control

Handheld Reader

Measures/stores temperature

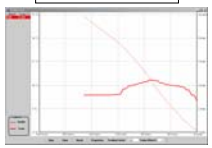
Calculates shelf life

Low quality flag

List

- **Remaining shelf life per item**

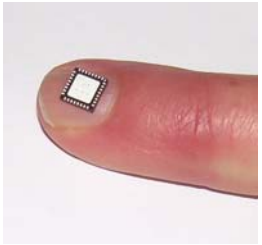
Full protocol



Required hardware resources

- Is it feasible to squeeze a shelf life model into a micro-chip?

Type of Resource	Calculation of Arrhenius equations
Processing time	1.02 ms
Program memory	868 bytes
RAM memory	58 bytes
Energy	6 µJoule



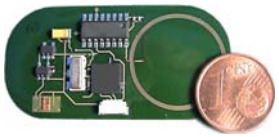
Available energy

- Very small additional recourses compared to circuit of data logger
- Shelf life model can run by paper thin batteries

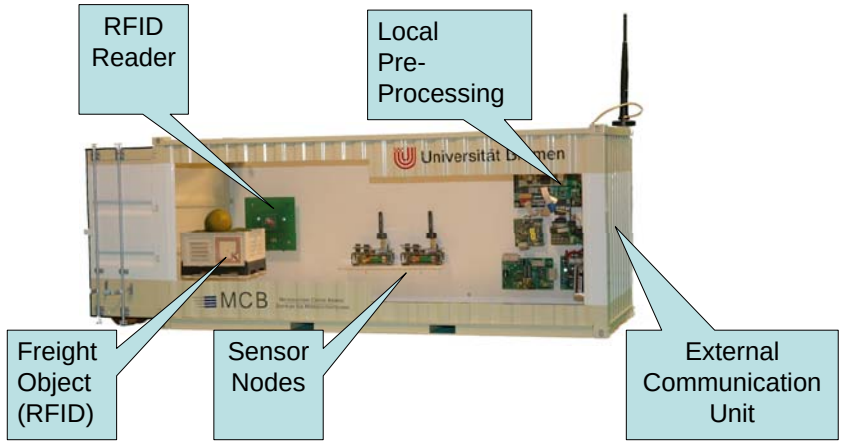
Power consumption per month	
Update every 15 minutes	0.020 J / month
Stand by current of MSP430 (1µA at 2.2V)	5.7 J / month
Turbo Tag (Zink oxide battery	80 J

Hardware platforms

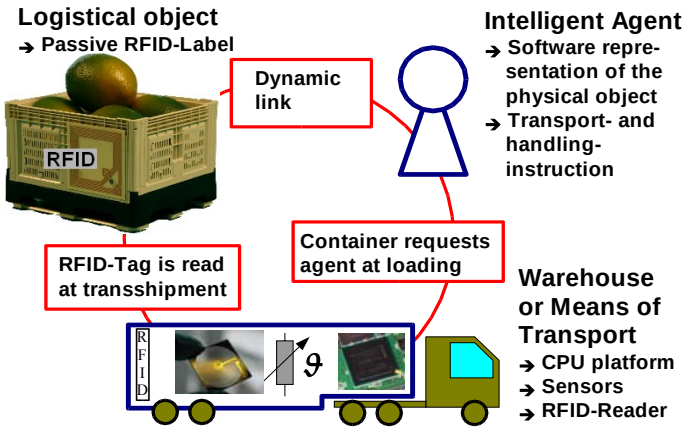
- Wireless sensor nodes
  - Tmode Sky / Sentilla
  - Own development
- Goal:
  - Integration into passive UHF-RFID-Tag
  - Conversion of existing HF Interface



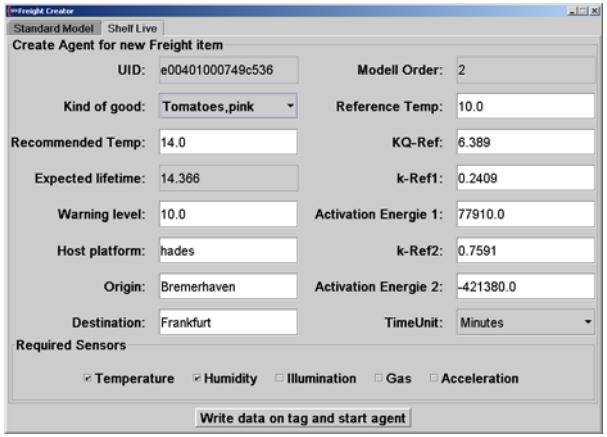
Hardware of the intelligent container



RFID and information flow

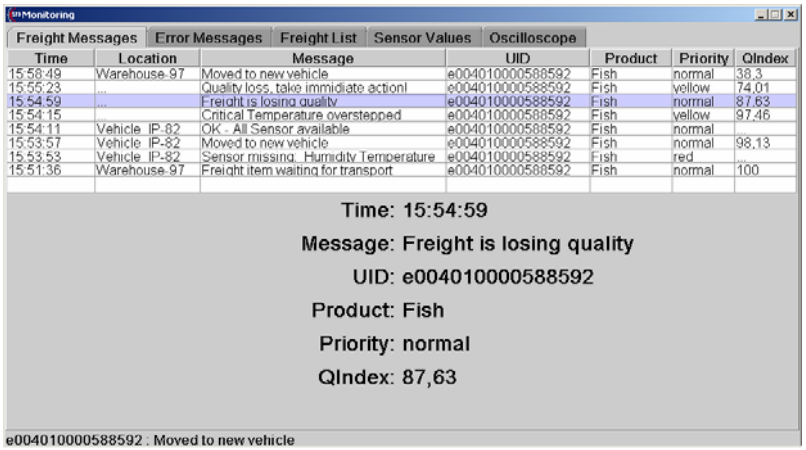


Creation of transport order



Oscilloscope view

Message screen



Sensor tracing technologies

Technology	*Online accessibility*	*Local processing*	*Granu-larity*	*Current state*
Telemetric systems	✓	-	-	Available
RFID data loggers	-	-	✓	Short range available
Wireless sensors	✓	-	✓	Prototypes, pilot studies
Intelligent RFID	-	✓	✓	Concept
Intelligent Sensors	✓	✓	✓	Under development
Intelligent Container	✓	✓	✓	Demonstration system

Summary and outlook

- Case study (strawberries) showed the potential to reduce waste and increase profits
- Quality evaluation of the level of RFID tags is feasible
- Development of new UHF hardware required
- The intelligent container offers online access to temperature and quality data

For more information and publications please visit

www.intelligentcontainer.com

- **Report**: Technische Grenzen des Einsatzes von UHF Identifikationssystemen (RFID) im Lebensmittelbereich
- **Industrial Meeting**: December 6th, 2007 in Bremen

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