Results of the project
Intelligent Container

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Project focus

One third of world-wide food production does not arrive at the consumer in an acceptable state. A major portion of these losses is due to variation in environmental conditions during the cold chain. A continuous temperature monitoring from farm to fork is only partially implemented. Telematics units only provide temperature measurements from the cooling unit, but not product temperature. Barcode and RFID scanners can only trace delivery routes, not product quality.

Due to various reasons, deviations in the quality of food products cannot be avoided; for example, different harvest conditions, harvest-to-cooling time and deviating transport temperatures. Augmenting standard tracking and tracing systems with additional quality monitoring enables new strategies for transport and warehouse management.

These deviations in product quality can be compensated for by intelligent stock rotation under the condition that the remaining shelf life is known for each item. The First Expired First Out (dynamic FEFO) strategy is based on the following principle: Items with low remaining shelf life should be delivered as fast as possible to retailers in close vicinity, whereas items with high remaining shelf life should be held back for later deliveries, or deliveries to remote customers.

Implementation

A prompt reaction to deviations in product quality is only feasible if the required information is provided in real-time. Measurements of supply and return air temperature, as provided by standard telematics units are insufficient for predicting product temperatures and resulting quality deviations. The 'intelligent container' can capture spatial temperature deviations via use of a network of 10 to 20 wireless sensor nodes. The nodes measure product temperature directly inside the packaging, and biological models calculate the effect of various deviations in environmental parameters on the product quality. Gas sensors are able to monitor additional factors influencing quality. Ethylene gas in particular is related to the ripening process of several fruits.

The results from the project were verified using case studies with bananas and different meat products. The case studies included temperature mapping for truck and container transport, development and parameterisation of shelf life models, and test transport with our prototype of the 'intelligent container'. Possible decision points for implementing the FEFO principle were defined after a detailed analysis of the supply chain of three project partners.

General publications

1. Lang, W.; Jedermann, R.; Mrugala, D.; Jabbari, A.; Krieg-Brückner, B.; Schill, K.: The Intelligent Container - A cognitive sensor network for transport management. In: IEEE Sensors Journal Special Issue on Cognitive Sensor Networks, 2011, Vol. 11(3), pp. 688-698. DOI: 10.1109/JSEN.2010.2060480
2. Jedermann, R.; Nicometo, M.; Uysal, I.; Lang, W.: Reducing food losses by intelligent food logistics In: Philosophical Transactions of the Royal Society A, May/June 2014, Vol. 372(2017), 20130302. DOI: 10.1098/rsta.2013.0302

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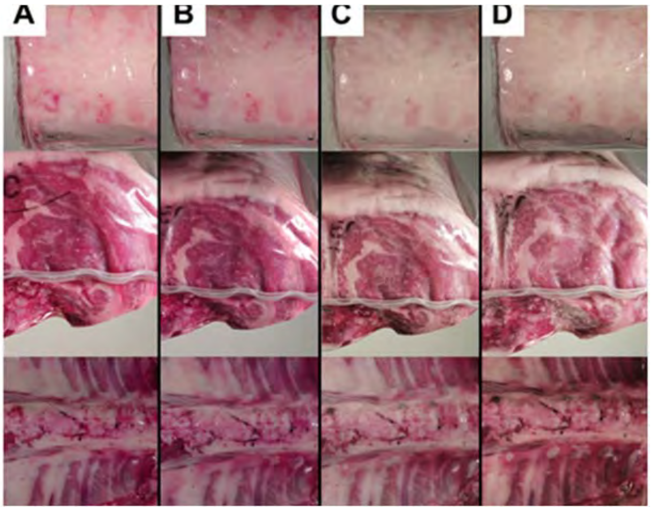
Shelf life models

Models to predict shelf life in relation to temperature and other parameters have to be adapted to the specific spoilage characteristics of each individual product. In this project, we have selected one fruit (bananas) and two meat products (vacuum-packed Irish lamb saddles, pork minute steak in modified atmosphere packaging) for detailed modelling analysis, in relation to our field tests.

Meat products

Changes in sensory attributes in relation to storage temperatures were evaluated by trained food tasters. The following parameters were evaluated for both of the selected meat products: meat colour, meat juice colour and volume, gas formation, texture and overall appearance. The results from the sensory evaluation were summarized in a model for each product [1].

The model enables us to predict the effect of temperature deviations. For example, an increase in the average transport temperature from 2°C to 4°C reduced the shelf life by a value between 21% and 30%.

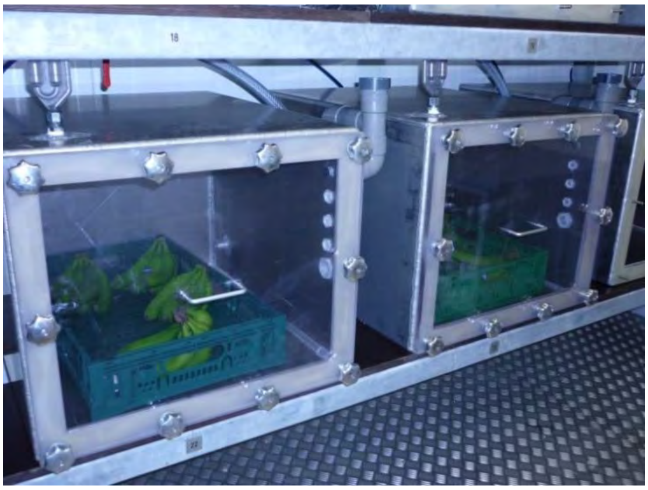


Cut surface and layer of fat of a lamb saddle A: after 0 h, B: after 144 h, C: after 240 h, D: after 348 h

Bananas

The time span until the onset of a colour change of bananas from green to yellow is named “green life”. The green life was measured by a spectral analyser in laboratory tests for different storage conditions with regard to temperature, air humidity and atmosphere composition [2].

With the measured temperature curve as an input, the model can predict their resulting effect on the green life. The green life loss per time unit is calculated after each measurement interval and subtracted from the initial value. Thereby it is possible to calculate the effects of a slowed cooling process, which can be caused by blocking of the airflow due to inadequate stowage of the pallets inside the container.



Laboratory test of green life in controlled atmosphere

Green life of bananas in relation to storage conditions after harvest

Condition	Duration of green life
13°C, normal atmosphere	31.9 ± 5 days
18°C	15.5 ± 4 days
18°C, CO_2 increased to 5%	plus 11 days, compared to CO_2 <2%
18°C, humidity reduced to 55%	minus 7 days, compared to 98%
10°C	chilling injuries after 8 hours

(Green life measured after 14 days of sea transportation at 14°C)

Relevant publications

1. Jedermann, R.; Mack, M.; Kreyenschmidt, J.: Intelligent containers for the entire supply chain - Monitoring the product quality and temperature of meat products along the supply chain. In: Fleischwirtschaft International, 2014, Vol. 28 (2), pp. 24-28.
2. Praeger, U.; Linke, M.; Jedermann, R.; Moehrke, A.; Geyer, M.: Effect of storage climate on green-life duration of bananas. In: 5th International Workshop Cold Chain Management, Bonn, Germany, University Bonn, 2013.
3. Mack, M.; Dittmer, P.; Veigt, M.; Kus, M.; Nehmiz, U.; Kreyenschmidt, J.: Quality tracing in meat supply chains. In: Philosophical Transactions of the Royal Society A, May/June 2014, Vol. 372(2017), 20130308. DOI: 10.1098/rsta.2013.0308

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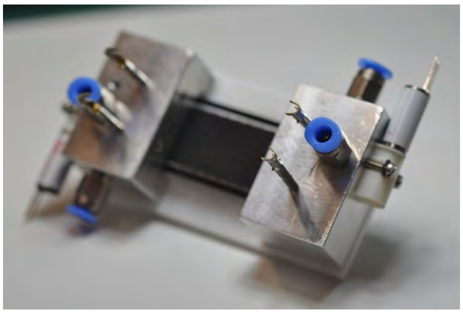
Ethylene measurement

Ethylene is a gaseous ripening hormone for fruits and plants. When they ripen, they emit ethylene and when they are exposed to ethylene, they start to ripen. The amount of ethylene that is emitted depends on the state of ripening. Thus, the concentration of ethylene gas in a container corresponds directly to the state of ripening and is therefore fundamental for monitoring the quality of climacteric fruits.

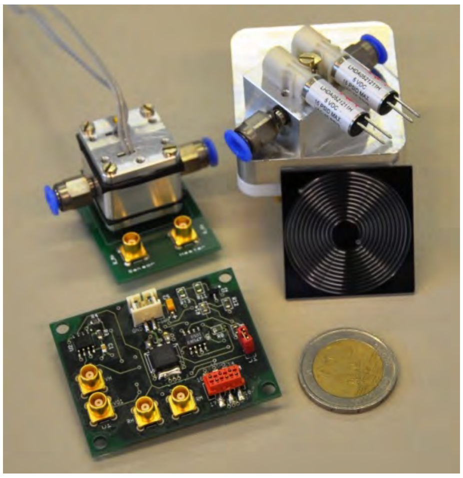


Preconcentrator

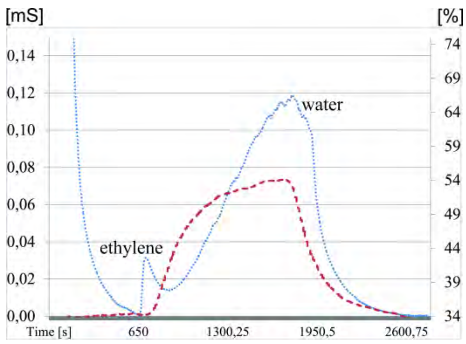
In situ measurements directly in fruit containers during transportation have been hampered by the lack of portable units that sustain the rough conditions in a container and that detect ethylene in the ppb (parts per billion) range.

During the project, a miniaturised gas chromatograph was developed, which was able to detect ethylene at very low concentrations, below 50 ppb. A commercial gas sensor was used together with two newly developed components:

- The resolution was improved by a preconcentrator device. During the adsorption phase, ethylene is accumulated in eight channels, each filled with Carbosieve SII® as a stationary phase. The silicon walls between the channels were used as a heater for the desorption process to release the ethylene. Thus, the sensitivity of the system was indirectly increased. Without the preconcentrator, the detection limit of the gas sensor was 100 ppm and with the preconcentrator this limit of detection was increased by a factor of 2000. As further advantage, the preconcentrator automates the sampling process.
- The applied gas detector is sensitive to multiple gases. Particularly, the high humidity in containers (approx. 98%) has an impact on the gas sensor that leads to variable output signals. To eliminate cross-selectivities to other gases, a miniaturised gas chromatography column was developed.



Gas chromatography column and other system components



Separation of peaks for ethylene and water/humidity

- In tests under laboratory conditions, Carbosieve SII® was found to be the best suited stationary phase for the column. Components of the gas sample are separated from each other in the column and thus they arrive at the gas sensor at different times. With the knowledge of the retention time, every peak in the output signal can be assigned to a specific gas component.

The complete gas chromatograph system is much smaller than standard laboratory devices. It consists of the miniaturised preconcentrator, the miniaturised gas chromatography column and a sensor element. The functionality of the system has been proven under laboratory conditions. Field-tests are at the planning stage.

Relevant publications

1. Janssen, S.; Tessmann, T.; Lang, W.: High sensitive and selective ethylene measurement by using a large-capacitiy-on-chip preconcentrator device. In: Sensors and Actuators B: Chemical, 2014, Vol. 197, pp. 405–413.
DOI: 10.1016/j.snb.2014.02.001
2. Janssen, S.; Schmitt, K.; Blanke, M.; Bauersfeld, M.L.; Wöllenstein, J.; Lang, W.: Ethylene detection in fruit supply chains. In: Philosophical Transactions of the Royal Society A, May/June 2014, Vol. 372(2017), 20130311. DOI: 10.1098/rsta.2013.0311

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Wireless sensor networks for remote monitoring of food transport

In order to provide an accurate prediction of shelf life, it is necessary to measure temperature inside food pallets or transport boxes. In total, 10 to 20 sensors were required to capture local temperature deviations inside a truck or container.

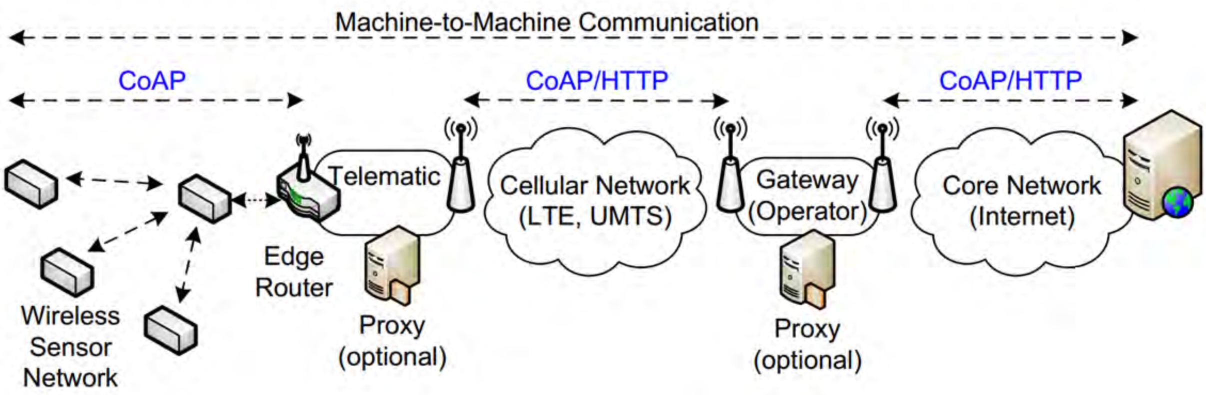
The implementation of wireless sensor networks is hindered by the high signal attenuation of food products due to their high water content. This is especially the case for frequencies above 1 GHz, as measurements and models for signal propagation have shown [3]. A reliable communication can only be provided if messages are forwarded over multiple hops between the sensors. In a world-wide scenario, sensors of different manufacturers and transport operators have to be linked together. Therefore, it is inevitable to identify and further develop adequate standardised communication protocols.

Java enabled Preon32 sensor node and Preon Cube with CO_2 Sensor

6LoWPAN and CoAP

Common Internet protocols such as HTTP have achieved a high level of standardisation. During the project we were able to show that it is feasible to obtain a high degree of compatibility between these protocols. In order to deal with the constrained nature of sensor nodes, there are mainly two protocols used:

- The *IPv6 over Low power Wireless Personal Area Networks* (6LoWPAN) protocol enables wireless sensor nodes to be addressed as any other internet device.
- The *Constrained Application Protocol* (CoAP) is specially adapted to the requirements of *Machine-to-Machine* (M2M) communication. CoAP is designed for easy interfacing with HTTP, but provides a reduced message length.

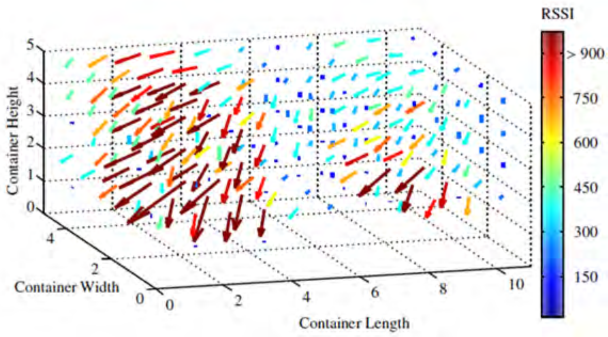


A CoAP implementation for the TinyOS operating system was developed for the intelligent container project and thus provided a CoAP platform for wireless sensor nodes. In further work, it was also made possible to exchange messages with sensor nodes, which were running the alternate Contiki operating system.

Hardware platform

During our field tests we applied the standard TelosB node as well as two alternate hardware platforms for wireless sensor nodes, which were developed by our project partners:

- The Preon32 sensor node from Virtenio is based on an energy efficient ARM processor. Its high CPU power enables the programming of algorithms for complex shelf life models, directly on the sensor. Programming is simplified by the Preon32's capability to directly execute Java code.
- A tremendous portion of the node's battery capacity was required to power up the radio periodically in order to listen for requests from other sensors. The second new hardware approach implements a wake-up circuit by use of semi-passive RFID technology, thereby removing the need for such idle-listening. As long as no wake-up signal is received, the node requires almost no energy.



Signal strength vector (RSSI)

Additionally, the sensor node measured the strength of the wake-up signal along the three spatial axes. This information is planned to be used for estimating the node's position inside the container.

Relevant publications

1. Pötsch, T.; Kuladinithi, K.; Becker, M.; Trenkamp, P.; Görg, C.: Performance evaluation of CoAP using RPL and LPL in TinyOS. In: Proceedings of Fifth IFIP International Conference on New Technologies, Mobility and Security (NTMS 2012). Istanbul, Turkey. 7.-10.5.2012. DOI: 10.1109/NTMS.2012.6208761
2. Heidmann, N.; Hellwege, N.; Peters-Drolshagen, D.; Paul, S.; Dannies, A.; Lang, W.: A low-power wireless UHF/LF sensor network with web-based remote supervision - Implementation in the intelligent container. In: Sensors, 2013 IEEE, pp. 1-4. DOI: 10.1109/ICSENS.2013.6688422
3. Jedermann R, Pötsch T, Lloyd C.: Communication techniques and challenges for wireless food quality monitoring. Philosophical Transactions of the Royal Society A, May/June 2014, Vol. 372(2017), 20130304. DOI: 10.1098/rsta.2013.0304

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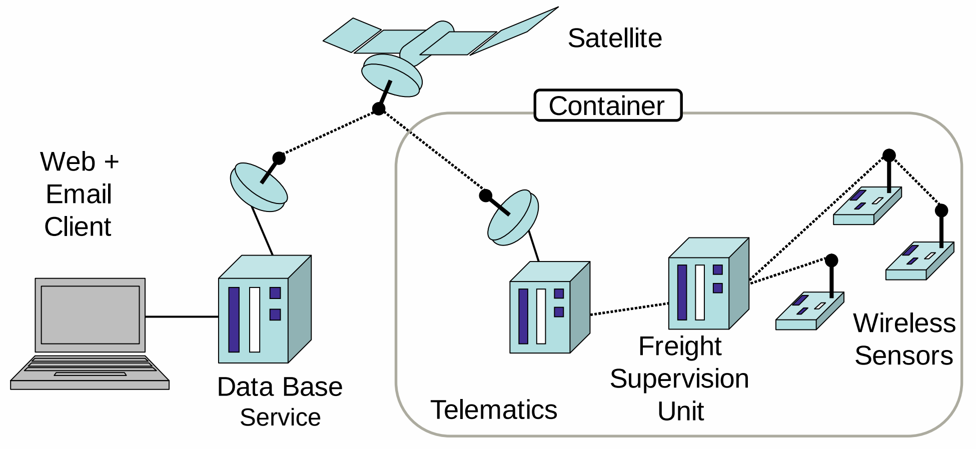
The container as a communication and decision support tool

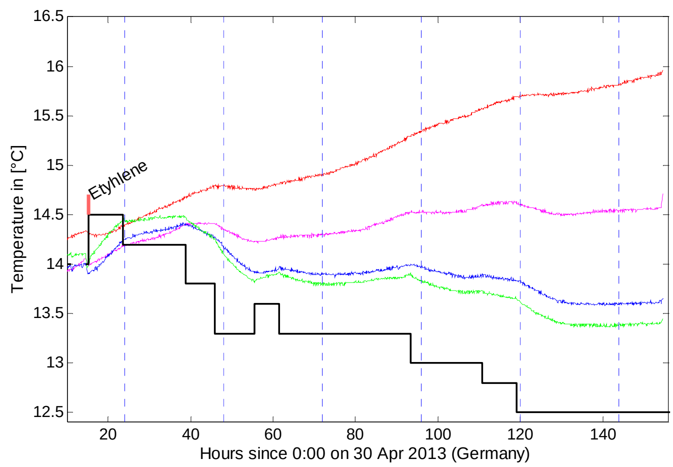
A so-called 'Freight Supervision Unit' (FSU) operates as the interface between the internal sensor network and external communication. Global communication is provided by a telematics unit. The container can be equipped with different units, either for the Iridium satellite network (OHB, Germany) or the GSM network (Cargobull Telematics, Germany).

The project title, 'intelligent container', indicates that the FSU is more than just a communication gateway. The basic function of the FSU is the provision of a software platform for a decision support tool (DST). Different freight-specific software bundles can be uploaded remotely, containing a shelf life model for the selected food product. The DST is able to detect 'dangers' for the specific products, and to trigger warning messages automatically. The software platform consists of the Jamaica Virtual Machine from AICAS, the OSGi framework from Prosyst, basic software bundles to control the container temperature set point, the sensor network and the communication system. The software packages from our partners were adapted to the target platform and extended to support the CAN bus for sensor interfaces.



We verified by measurements of required CPU time that even complex algorithms can be executed on the FSU and it is also possible to run shelf life models on sensor nodes and to install them remotely over a wireless network [1,2].

The feasibility of remote access during trans-ocean and road transport was verified during several field tests. The data from the wireless sensor nodes were transferred once per day per satellite during a test transportation journey using bananas. The first estimation of remaining green life, cooling efficiency and respiration heat was calculated after 3 days. The estimation was continuously updated, and if a correction was necessary, the new values were sent over the satellite network, especially if a hazard for freight quality was detected.



Changes of temperature and of the set point during ripening

A few hours before arrival at the harbour, access to the full recorded data was available, when the container was able to link to the GSM network. Temperature curves were displayed in a web browser. Remote monitoring continued during the subsequent ripening process. The temperature set point was adjusted several times to compensate for the higher respiration heat during ripening.

Relevant publications

1. Dannies, A., Palafox-Albarrán, J., Lang, W., Jedermann, R.: Smart dynamic software components enabling decision support in Machine-to-machine networks, International Journal of Computer Science Issues, January 2013, Vol. 10(1), pp. 540-550, ISSN (Print): 1694-0784 | ISSN (Online): 1694-0814
2. Palafox-Albarran, J.; Dannies, A.; Sanjeeva, B. K.; Lang, W.; Jedermann, R.: Combining Machine-to-Machine communications with intelligent objects in logistics. In: Proc. of ImViReLL'12 - the Impact of Virtual, Remote and Real Logistics Labs. Springer 2012, pp. 102-112. DOI: 10.1007/978-3-642-28816-6_11

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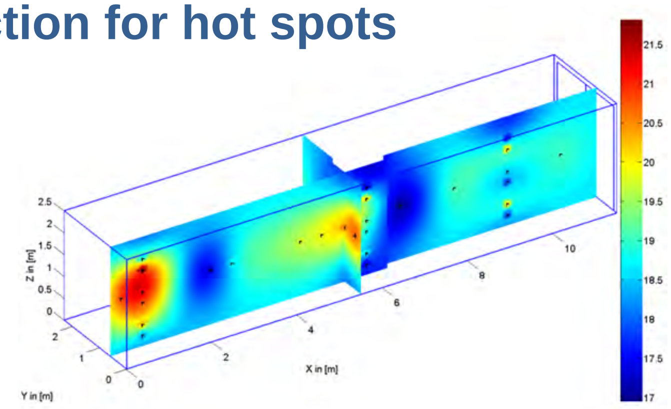
Prediction and risk reduction for hot spots

Climacteric fruits, such as bananas, can create tremendous amounts of heat by respiration. If the generated heat per box or pallet exceeds the amount of heat that can be removed by cooling, this creates hot spots, where the temperature increases beyond control. In turn, the increased temperature accelerates the biological processes.



Spatial temperature distribution and zones with deficient cooling

Thermal model

In order to analyse and quantify the conditions that lead to a hot spot, it is necessary to extract the effects of biological heat generation and cooling from the measured temperature curves. A thermal model was developed during our project, which enables the estimation of heat generation and removal as separate parameters [1]. The data in the table on the right were calculated from the temperatures recorded from our field tests. Bananas produce approximately 50 Watts per tonne thermal energy under a normal atmosphere. This value decreases under a controlled atmosphere, but increases with advanced ages of fruits.

Condition	Generated heat
Controlled atmosphere (4.5% CO_2 / 3% O_2)	16.1 W/t
Film packing/Banavac (4% CO_2 / 17% O_2)	24.0 W/t
Normal atmosphere	50.3 W/t
Ripening at 15°C	70 ... 115 W/t
Ripening at 17°C	185 ... 210 W/t

Improved packing and stowage

The airflow from the cooling unit can remove 60 Watts per tonne for standard packing conditions, or 1 kW for the full container load, which is less than 10% of the nominal cooling capacity of the refrigeration unit. This poor relationship indicates that the airflow conditions inside a container are far from being optimal. During the project we showed that the heat removal from the banana boxes can be increased by up to 50%, by a combination of a new box design, the use of spacers to create gaps between pallets and a modified layout to stow the pallets inside the container [1].

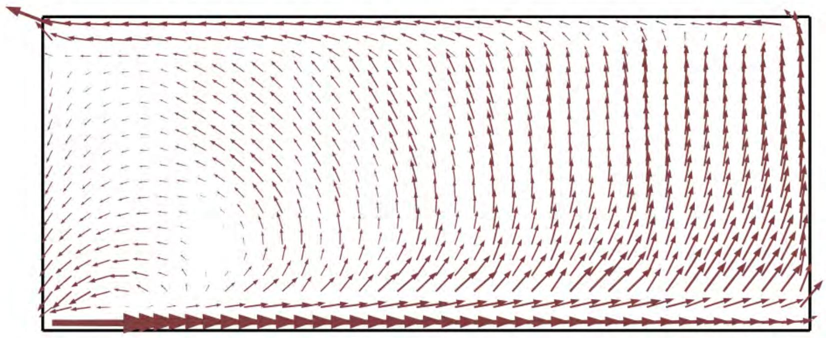
Packing / Stowage	Removed heat
Standard packing	58.7 W/t
Blocked gaps	41.6 W/t
Gap of 3 cm	68.0 W/t
Improved boxes, gaps and chimney layout	92.1 W/t

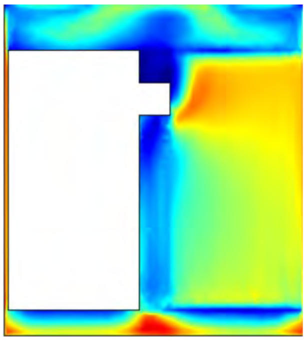
Container ripening

The feasibility of carrying out the ripening process directly inside the container was demonstrated during the project with three practical tests. During the last 2 days of ripening, when the heat generation is the highest, the temperature set point can be reduced by 0.5°C. With the improved packing and stowage, it is then possible to fully compensate for the heat production during ripening at 15°C.

Air flow simulation

A computational fluid dynamics simulation in COMSOL provided additional proof for the advantage of the modified stowage layout [2]. The simulation showed that the airflow speed is increased in the upper layers of the pallets, where the highest temperatures are usually observed. Furthermore, the simulation provided an explanation for the deficient cooling of the two pallets stowed directly at the back end of the container. An eddy in this section largely reduces the air exchange.

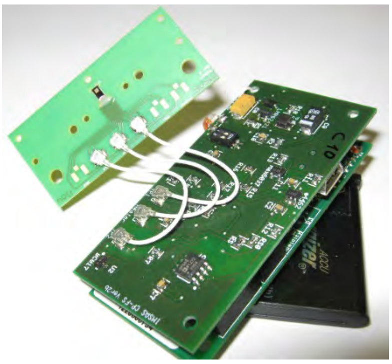




Eddy on the side of the cooling unit and increased airflow in the upper layers of a pallet (orange/red = high air speed)

Wireless airflow sensors

The necessary parameters for the airflow simulation were adjusted according to the measurements obtained from a set of wireless airflow sensors. The devices were based on a sensor element that was developed at IMSAS. The sensors were integrated into the wireless network for temperature monitoring [3].



Airflow sensor, housing and electronics

Relevant publications

1. Jedermann, R., Geyer, M., Praeger, U., Lang, W.: Sea transport of bananas in containers – Parameter identification for a temperature model, Journal of Food Engineering, April 2013, Vol. 115(3) , pp. 330–338, DOI: 10.1016/j.jfoodeng.2012.10.039.
2. Issa, S.; Lang, W.: Airflow Simulation inside Reefer Containers. Presented at: 4th International Conference on Dynamics in Logistics (LDIC 2014), Bremen, Germany, Proceedings to appear in Springer, Lecture Notes in Logistics, 2014.
3. Lloyd, C.; Jedermann, R.; Lang, W.: Airflow Behavior under Different Loading Schemes and its Correspondence to Temperature in Perishables Transported in Refrigerated Containers. Presented at: 4th International Conference on Dynamics in Logistics (LDIC 2014), Bremen, Germany, Proceedings to appear in Springer, Lecture Notes in Logistics, 2014.

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Data processing for transport monitoring and supply chain control

The data, generated during the field tests, was collected on a server by the project partner SEEBURGER. Two different telematics units from OHB Teledata and Schmitz Cargobull Telematics were used to transfer temperature, position and food quality data to the server. An email notification was sent to the transport operator, when a parameter deviated from the allowed range. Alternatively, authorized cold chain partners were able to log in to a web-interface to directly query product status and sensor data.

A tablet PC App, developed by OTARIS enabled access to sensor data directly from a loading ramp during cold chain processing. The actual quality status of the product was displayed by a traffic light indicator.

In our current field tests, the system for remote quality monitoring was only used to inform the operator. But in the future, the data will also be used for the automated control of cold chain processes. The concept of dynamic FEFO was converted by BIBA to a new control method. The method for ‘quality based distribution logistics’ used the data provided by the intelligent container to calculate a forecast of product quality. The quality forecast will be matched with transport times and customer expectations. Distribution is organised in a way that products are not only at the right place at the right time, but also in the right quality. The concept was verified in simulation studies [1,2].

Relevant publications

1. Lütjen, M.; Dittmer, P.; Veigt, M.: Towards quality driven distribution of intelligent containers in cold chain logistics networks. In: Denkena, B.; Gausemeier, J.; Scholz-Reiter, B. (eds.): Proceedings of 1st Joint Symposium on System-Integrated Intelligence (SYSINT 2012). New Challenges for Product and Production Engineering, PZH Verlag, Garbsen, 2012, pp. 171-174
2. Lütjen, M.; Dittmer, P.; Veigt, M.: Quality driven distribution of intelligent containers in cold chain logistics networks. In: Production Engineering Research and Development, April 2013, Vol. 7(2-3), pp. 291–297. DOI: 10.1007/s11740-012-0433-3

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Field tests

The project was implemented to establish a close link between scientific research and practical cold chain applications. Several field tests were carried out to demonstrate and verify how the developed models, sensors and communications systems operate under the real-world conditions of cold chain logistics. The tests included truck as well as trans-ocean container transport.

Banana cold chain

The remote monitoring of the banana cold chain was tested three times in cooperation with Dole Fresh Fruits. Bananas were packed in boxes in Costa Rica [1,2]. Some of the boxes were equipped with wireless sensors. Remote monitoring started after palletisation and stowing into the container.

The container was trucked to the harbour (4 hours), shipped to Antwerp (2 weeks) and transported by truck to Hamburg (1 day). The set points for temperature and air exchange rate were adjusted during the sea transportation by remote access.

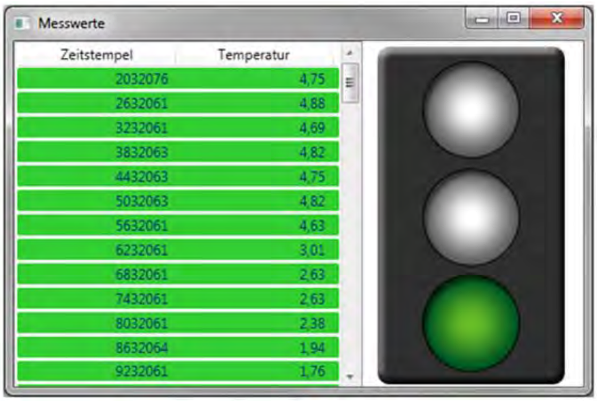
Ripening was started after arrival in Hamburg by a technical ethylene treatment. During the next 5 days, the respiration activity increased by a factor of 5 to 10. The progress of the ripening process was monitored by analyses of the temperature curves instead of the usual manual or visual inspections. The set point was remotely reduced step-by-step to compensate for the increased heat production. After 5 days, the bananas were sold to a wholesale trader.

The meat chain

Two field tests were carried out to demonstrate the concept of the intelligent container in the supply chain of meat. For the first test, a truck of the partner company KÜHN-Transporte was equipped with the necessary technical components (Freight Supervision Unit/FSU and Telematics). The transport condition of minced meat was monitored within Germany (Münster to Stelle).

The second tests covered the transport of vacuum-packed lamb saddles from Ireland, via France, to Germany [3]. Two pallets were equipped with sensors directly after production.

The sensors were started in the offline-mode; temperature data were only logged to the memory. The pallets were transported by truck to a depot in Paris, and from there, transported to the main premises of RUNGIS express in Meckenheim, Germany. At stock receipt in Meckenheim, the sensor data were retrieved and evaluated by a tablet PC to replace manual quality control procedures.



The sensors remained attached to the packed meat during the de-palletisation and consolidation processes. For the subsequent transport, the sensors were switched to online-mode. A truck, equipped with FSU and telematics, was used for the final transport to a retail market in Bremen, via a depot in Landbergen.

The data recorded in the offline-mode showed that all logistical processes in this particular chain, including transhipments and depot handling, complied with the recommended cold chain conditions. Whenever means of transport are equipped with telematics and interfaces to connect to the wireless sensors, the online-mode can be used. Information about any problems during transportation is available in real-time in the online-mode and thus enables for prompt actions to be undertaken to avoid food losses.

Relevant publications

1. Jedermann, R.; Dannies, A.; Moehrke, A.; Praeger, U.; Geyer, M.; Lang, W.: Supervision of transport and ripening of bananas by the Intelligent Container. In: 5th International Workshop Cold Chain Management, Bonn, Germany, University Bonn, 2013.
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3. Mack, M.; Dittmer, P.; Veigt, M.; Kus, M.; Nehmiz, U.; Kreyenschmidt, J.: Quality tracing in meat supply chains. In: Philosophical Transactions of the Royal Society A, May/June 2014, Vol. 372(2017), 20130308. DOI: 10.1098/rsta.2013.0308

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New challenges

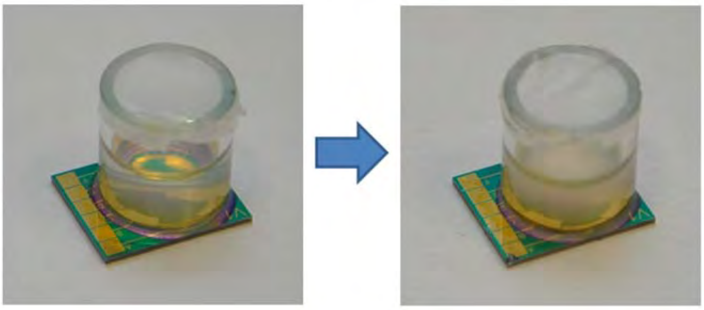
The prototype tests and scientific studies with the intelligent container demonstrated the feasibility of remote monitoring of food quality. Several improvements of the cold chain and logistic processes were identified during the project. Nevertheless, not all important issues concerning cold chain logistics could be covered by the project.

Mobile measurement of mould contamination

Detection of mould contamination in fresh foods during transportation is of great interest. Without careful cleaning, a container can be polluted by mould spores, or food products that already contain mould spores can be stowed in the container. In both cases, the initial concentration of spores might be below the detection threshold, but increase dramatically during transport. In order to develop a new mobile measurement device for the detection of mould infections during transport, the MaUS (micro reactor system for the autonomous measurement of mould contaminations) project was started in October 2013 by IMSAS.

The measurement principle is based on the well-known method of growing a probe on a culture medium. A set of miniaturised probe chambers, containing a culture medium in combination with an automated sample unit and sensors can be used for the estimation of fungal growth.

If the main fungi for the specific food product are known, an adequate set of culture mediums can be selected. By comparing optical and chemical changes of the culture media with the fingerprint of the relevant fungi, it is possible to quantify the degree of contamination as well as to classify different species.



Change of transparency and impedance.
Figure by P. Vinayaka

Relevant publications

1. Janssen, S.; Pankoke, I.; Klus, K.; Schmitt, K.; Stephan, U.; Wöllenstein, J.: Two underestimated threats in food transportation — Mold and acceleration. In: Philosophical Transactions of the Royal Society A, May/June 2014, Vol. 372(2017), 20130312. DOI: 10.1098/rsta.2013.0312

Contact

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Project partners and sponsorship

The research project 'Intelligent Container – linked intelligent objects in logistics' was supported from July 2010 until June 2013 by the Federal Ministry of Education and Research, Germany, under reference no. 01IA10001. Six research and 15 industrial partners participated in the project with total funding of 9 million Euros. A follow-up project concerning the detection of mould infections was started in October 2013. Two further project applications are currently under evaluation.

Research partners

Partner	Tasks
Institute for Microsensors-, actuators and -systems, University of Bremen	• Project management • Micro technology for new sensor principles • Spatial analyses of temperature profiles with wireless sensor nodes
Communication Networks Working Group (ComNets), University of Bremen	• Communication protocols for telematics units and wireless sensor networks
Institute of Electrodynamics and Microelectronics (ITEM.me), Bremen	• Combination of passive and active communication technologies for wireless sensor nodes
Bremer Institut für Produktion und Logistik GmbH (BIBA)	• Methods for efficient control of cold chain logistics • Studies on economic feasibility
Leibniz Institute for Agricultural Engineering Potsdam-Bornim	• Shelf life model for bananas
University of Bonn, Institute of Animal Science (ITW)	• Shelf life models for meat products

Industrial partners

Partner	Task
aicas GmbH	Java real-time environment for embedded systems
Cargobull Telematics GmbH	Telematics for trucks and semi-trailers
CHS Spezialcontainer - Shelter and Engineering GmbH	Retrofitting of container prototype
Dole Fresh Fruit Europe OHG	Field tests/applications in logistics and ripening of bananas
Elbau Elektronische Bauelemente GmbH	Sensors for airflow and spectral colour
European Microsoft Innovation Center (EMIC)	Software virtualization
ISIS IC GmbH	Special housing and contactless charging of sensor nodes
Kühn Transport und Lagerungsgesellschaft mbH	Application and field tests in meat logistics
OHB Teledata Business Unit	Satellite communication for containers
OTARIS Interactive Services	Tablet PC software for electronic bill of loading and retrieval of sensor data Evaluation of security aspects
ProSyst Software	OSGi framework for telematics units with software installation on-demand
RUNGIS express AG	Field tests/applications in the cold chain for meat products
SEEBURGER Business Integration	Interfaces for integration of food-specific information into company databases
Texas Instruments	Development of special RFID-sensor nodes and antennas
VIRTENIO GmbH	Wireless sensor nodes for logistics applications

For further information and complete publication list, see

www.intelligentcontainer.com