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Demo Abstract: Wireless quality monitoring in the food chain

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Abstract—**The pre-processing of measurement data inside a wireless sensor node reduces the volume of communication. A model that predicts the effects of temperature deviations on the quality of fresh food products was developed for two different sensor platforms. Optimized integer arithmetic allows the model to be calculated using the resources of the existing hardware.**

Index Terms—**Food logistics, shelf life modeling, wireless sensor networks.**

I. INTRODUCTION

Monitoring cool chain transports is an important application for wireless sensor networks. Food products are very sensitive to temperature mismanagement. According to the U.S. Food and Drug Association (FDA), 20% of all perishable food is wasted during transport [1].

Spatial temperature deviations between 1 °C and 5 °C, which can be found in almost any transport, can reduce the remaining product lifetime by several days. Commercial solutions for wireless monitoring of single packages became available in 2008. But so far, these tools have not yet been able to evaluate the effects of temperature deviations on product quality. Because of high costs, neither the manual processing of one temperature chart per pallet nor the transmission of the complete sensor data over cellular networks are possible.

A. Definition of shelf life

The concept of shelf life has become a useful concept to describe the current state of the quality of a product. The shelf life of a product batch gives the number of remaining days until its quality falls below an acceptable limit and the consumer would reject purchasing the product. In other words, it states how many days the product can be kept in the shop 'on the shelf'. The shelf life depends on the product's temperature history, but must also be scaled to the temperature of the shelf or the final storage condition T_S.

B. Modeling shelf life

There are several approaches to calculate shelf life by using a mathematical model:

a) A model can directly describe the chemical processes which contribute to color changes and other decay processes [2].
b) Another approach measures reference curves for a quality attribute at certain constant temperatures. The prediction for changeable temperatures uses an interpolation between the reference curves [3].
c) For implementation on low-power micro controllers, we used a simplified model that calculates the loss of shelf life per day L as a function of the temperature T. The remaining shelf life $Q(t)$ at time t is calculated by the initial quality Q_R minus the integral over the loss per day [4], [5].

The temperature dependency of the decay process is assumed to follow Arrhenius' law for reaction kinetics [6], which calculates the reaction rate k by equation (1) with T_R as reference temperature, k_R as reaction rate at T_R, E_A as activation Energy and R_{Gas} as gas constant = 8.314 $J \cdot mol^{-1} \cdot K^{-1}$:

$$k = k_R \cdot e^{\frac{E_A}{R_{Gas}} \cdot \left(\frac{1}{T_R} - \frac{1}{T}\right)} \qquad (1)$$

Two Arrhenius functions can be combined to achieve a better fit of the physical properties of the product. The loss per day is calculated according to equation (2):

$$L(T) = \frac{k_1(T) + k_2(T)}{k_1(T_S) + k_2(T_S)} \qquad (2)$$

Fig. 1 shows the typical loss per day functions for fruits and vegetables, scaled to a standard temperature T_S of 15 °C. These products are affected not only by accelerated decay at high temperatures, but also by chilling injuries at low temperatures.

II. IMPLEMENTATION OF A SHELF LIFE MODEL ON SENSOR HARDWARE

In the first step, the model was implemented on the well-known TelosB / TmoteSky platform [7] with a MSP430 16-bit processor and a Chipcon CC2430 radio chip. The restricted resources of this microcontroller proved to be a challenge to the project. First, the model was required to fit into the limited program and user memory of the microcontroller. Second, the energy usage of the CPU to

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calculate the model should not significantly shorten the sensor life time. In order to adhere to these restrictions, we avoided using floating point operations in the model implementation. All mathematical operations were scaled to 16-bit integer arithmetic, except for a few critical variables that were handled as 32-bit values. The exponential function was replaced by an interpolation of value tables.

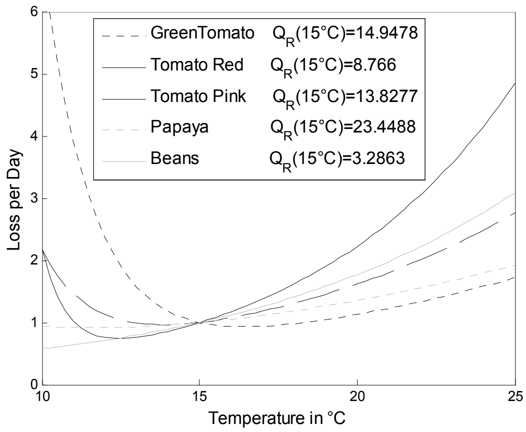

Fig.1. Loss of shelf life as function of temperature (Final storage temperature T_S = 15 °C)

A. *Measurement of calculation time and memory requirements*

The performance of the model implementation was tested on the TmoteSky platform. The source code was compiled by the IAR "C" Compiler. The code requires 1216 bytes of program memory. The calculation of one model step required 1999 instruction cycles. At a clock speed of 8 MHz, this is equivalent to 0.24 ms or an energy consumption of 5.8 µJ for a 3 volt supply. Compared to other operations of a sensor note this value might possibly be neglected. For example, sending the message over the radio takes 15 ms and consumes 780 µJ of energy.

B. *Implementation on an 8-bit controller*

Unfortunately, the TmoteSky sensors can only be used for prototype tests using real-world transport conditions. The absence of water-protected housing and its high price prevent a commercial use of the system. In cooperation with a manufacturer of sensor systems, a second microcontroller implementation was developed. The Ambient 3000 SmartPoint contains a Chipcon CC2430 radio chip with a built-in 8-bit 8051 processor.

C. *Accuracy of integer arithmetic*

The shelf life prediction by the sensor was compared to a floating point model that was simulated in Matlab. The error for the loss per day calculated by integer arithmetic was between 0.68 % and 1.37 % for the different products in Fig. 1.

III. THE SENSOR NETWORK

Ambient's networks consist of three elements: A GateWay, each network contains a single GateWay, which provides the interface between corporate IT systems and the Ambient network. It is mains powered and provides a serial interface (RS-232) for communication with an external device. Each network contains up to 255 MicroRouters, which provide the backbone of the wireless infrastructure. The MicroRouters wirelessly communicate with the GateWay, with each other and with the SmartPoints. SmartPoints are battery-powered devices that have a similar role as traditional active RFID tags, but with significantly enhanced capabilities. SmartPoints monitor their environment using a default temperature sensor. SmartPoints can be extended with additional sensors (I2C, 1-Wire, SPI, ADC, and GPIO). SmartPoints are self-locating. Based on the wireless communication with Ambient's infrastructure, a SmartPoint is able to calculate its own location in the network.

IV. DEMONSTRATOR SETTING

Each type of fruit has an individual set of parameters for use with the Arrhenius model and a different reaction to temperature deviation. A demonstration of the enhanced wireless sensors compares the shelf lives for different food products that are exposed to the same temperature conditions during a mixed transport (Fig 2). One sensor is programmed with the parameters for 'Strawberries' and another one for 'Lettuce'. The sensors are placed inside a box with the corresponding product. The differences in the speed of quality decay are displayed by the graphical interface of the control software. A second demonstration setting shows the difference in shelf life for two batches of one product that are stored with different temperature conditions.

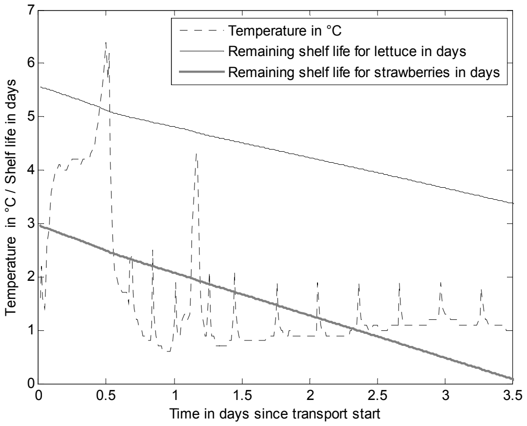

Fig. 2. The quality curves for two different food products stored at the same temperature in a chilled transport (T_S = 5 °C).

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