



Development of temperature-managed traceability system for frozen and chilled food during storage and transportation

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Abstract

Temperature is one of the most important parameters of the quality control for frozen and chilled food, and then freshness is almost exclusively a function of time and temperature. As the temperature management is a very important function for fresh foods, it is desirable that the quality conditions during storage and transport are clearly understood and traceable. This paper describes the development of a temperature-managed traceability system based on RFID tag, GPS, mobile communication based on TTT theory. The system has been tested with the Haikou-Beijing transport scenario for chilled tilapia. The results show that the system is helpful in quality control, traceability and efficiency of frozen and chilled food during storage and transportation chain. In addition, the system also has significant impact on stakeholders across the supply chain via improved quality and reduced cost.

Key words: Traceability system, RFID, TTT (temperature-time tolerance) theory, food safety.

Introduction

Freshness is one of the most important aspects of fresh, specially frozen and chilled food, because consumers have a strong tendency to select very fresh and safe food. So the most important issue in fresh food trade (The term "food trade" indicates all the postproduction procedures: storage, transport, distribution and retail of final products, their export and import¹) is the assurance of freshness and the extension of shelf life to allow transport of products to distant markets.

Deterioration of frozen and chilled food products depends on extrinsic and intrinsic factors. The most important extrinsic factors are temperature fluctuation, oxygen penetration, and the mode of thawing. Intrinsic factors are defined by the biochemical properties of the fish or shellfish. Shelf life of frozen and chilled food is usually limited by microbial activities that are influenced most importantly by storage temperature².

Then temperature is one of the most important parameters of quality control, freshness is almost exclusively a function of time and temperature. As the consequence, the temperature management is becoming a very important function for frozen and chilled food and visibility & traceability is especially important in cold chains and other chains of perishable goods where the control of changing the temperature in transportation or even in production cells or control by adding the preservatives is needed to keep the quality and quantity of product at the end of the supply chain on the required level³.

In the case of frozen and chilled food that require temperature management, the major challenge is to identify the changes of

temperature during storage and transport, to determine if there has been a problem in the temperature management, even when an abnormality occurs within the product lot⁴, ensure a continuous 'cold chain' from producers to consumers so that consumers receive perishable goods in prime condition and on time⁵.

Traditionally temperature management system is using thermometers or compact temperature loggers installed in trucks and warehouses. For example, TTIs (temperature time integrators) are used for evaluating for various perishable foods including chilled fish and cold fish^{6,7}, dairy products⁸, meat and poultry^{9,10} and frozen fruit and vegetables^{11,12}. However, implementation of traditional temperature management system is of high management costs and unease of introduction and data collection. For example, when thermometers installed in warehouses and trucks are used for the management, periodical temperature checks are required. In the case of management systems that also use temperature loggers, each logger should be connected physically to a PC and the data collection becomes a manual operation^{4,5}. Consequently the system construction costs and the high labor costs of the operations have been obstacles to the introduction and deployment of traditional temperature management systems.

A RFID (Radio Frequency Identification) with temperature indicators tag is a microchip combined with an antenna in a compact package; the packaging is structured to allow the RFID tag to be attached to an object to be tracked. It also incorporates memory, a battery and a clock to record sensor data in memory at constant intervals. The characteristic has lent itself measure and record

time-temperature information and perform temperature management across multiple businesses by starting/stopping the measurement and collecting the data independently, without requiring other businesses to perform the work required for the temperature management. From the viewpoint of price, too, the cost of using RFID sensor tags is lower than for the temperature loggers, so the system can be constructed at a relatively low price^{4,5,13}.

So the properties of RFID sensor tags are suitable for meeting the requirements of the temperature-managed traceability system. This paper introduces a solution and experiment to the above problem via developing the traceability system integrated with RFID technology, GPRS, wireless networks and Internet. It contributes to effective risk management by easily enabling consistent temperature management throughout storage and transportation processes.

Methodology

System development methods: The spiral waterfall model was adopted as the development methodology, which is the traditional and popular version of the systems development life cycle model for software engineering through the phases of conception, analysis, design (validation), construction, testing and maintenance. The advantage of waterfall development is that it allows for departmentalization and managerial control.

Key decision model and data analysis method: The key decision problem during the storage and transportation is to evaluating the quality risk and shelf life of the frozen and chill food and early-warning the potential risk event. TTT (temperature, time, tolerance) theory refers to the relationship between storage temperature and storage life. It is also able to predict the effects of changing or fluctuating temperatures on quality shelf life.

Based on TTT theory, Arrhenius model has adopted to evaluate shelf life of frozen and chilled fish quality. The Arrhenius equation gives the following and describes the dependence of the rate constant k of chemical reactions on the temperature T (in Kelvin) and activation energy.

$$k = A \exp\left(-\frac{E_a}{RT}\right) \quad (1)$$

$$f_r = 1 - \sum \left(\frac{\theta_i}{\theta_s \tau_i}\right) \quad (2)$$

$$A = A_0 \exp\left[-\sum k_i \theta_i\right] \quad (3)$$

where K is equilibrium constant, R is the gas constant 1.986, and H is the heat of reaction. E is activation energy as representing the energy difference between the reactants and an activated species.

In addition, the Q_{10} factor also is adopted as the indicator to evaluate the quality change during storage and transportation, which is a measure of the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10°C, to describe the relationship between temperature and reaction rate. Q_{10} is an unitless quantity, as it is the factor by which a rate changes, and is a useful way to express the temperature dependence of a process. The Q_{10} is calculated as:

$$Q_{10} = \frac{\text{Rate at temperature } (T+10)^\circ\text{C}}{\text{Rate at temperature } T^\circ\text{C}} \quad (4)$$

$$Q_{10} = \frac{\text{Shelf life at } T^\circ\text{C}}{\text{Shelf life at } (T+10)^\circ\text{C}} = \frac{\theta_{sT}}{\theta_{sT+10}} \quad (5)$$

where R is the rate and T is the temperature in Celsius degrees or Kelvins.

System test and evaluation methods: In order to simulate the results of the application of the developed traceability system and quantitatively prove its effectiveness, the system evaluation team consisted of three academic experts, one extension agent and six stakeholders, including drivers, managers and consumers.

The evaluation was performed in two different environments: (i) static test in academic environment via code judgment and previous case and ii) dynamic test in an actual environment. The data was collected based on the experiment design with support of Beijing Fishery Company. The experiment scenario was selected as chilled tilapia fillet storage and transportation chain from Haikou to Beijing according the project requirement and taking into account the temperature fluctuations are possible relatively huge and have more impact on the quality of frozen and chilled fish. Fig. 1 illustrates the six-point data collection by RFID.

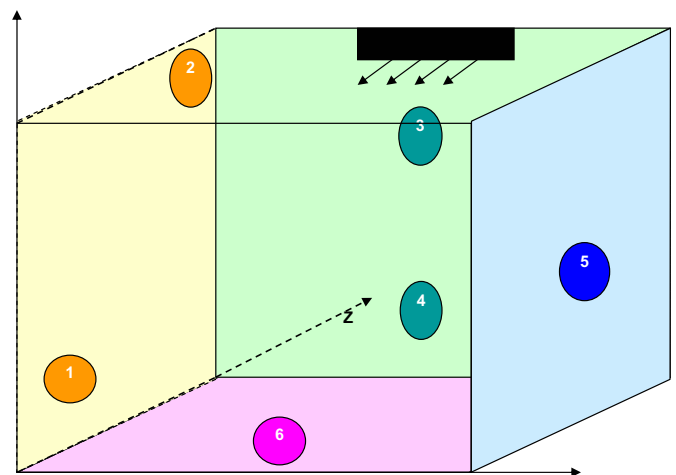


Figure 1. Temperature monitoring in the container.

Results

System function requirement: In ordering to improve rates of meeting customer needs and reducing costs of maintenance, some interviews were executed. Based on the interviews, the functionalities of a temperature-managed traceability were identified:

- *Quality evaluation & temperature control.* The system needs to collect and process information from a set of sensors distributed throughout the vehicle and real-time monitoring of temperature and mobile positioning to evaluate the quality safety risk at strategic control points of the chill chain.

- *Wireless transformation.* The system needs to transform data via radio frequency wireless communication, GPRS, database and multimedia techniques and the supply of remote guidance and location-based data retrieval by using GPS technology.

- *Work order management.* The system needs to provide the real-time interaction between truck drivers and managers in headquarters, then it makes a reality and the cold chain monitoring and management is guaranteed.

- *Information tracking.* The system needs to provide the entire chain time-temperature information for the end consumer and track abnormal event.

System structure and development: The system combines C/S and B/S network structure. B/S model is responsible to record the data into the database, retrieve, calculate and represent the data for the end user. C/S model is responsible to connect the hardware and software and read the data from hardware and communicate them to the server, and print the traceable label attached the external package. The system consists of four key components (see Fig. 2):

- *Identification.* The RFID to collect the temperature data for identification the quality information of the chilled foods.

- *Transportation.* GPS, wireless networks and transportation standards to location-based data retrieval and provide data communication.

- *Administration.* Temperature managements, quality evaluations and quality assurance system are combined to establish the temperature traceability system for the frozen and chilled food quality control.

- *Communication.* E-mail, EDI-software and XML technologies are used to provide important information with managers, drivers and customers in real time during the storage and transport.

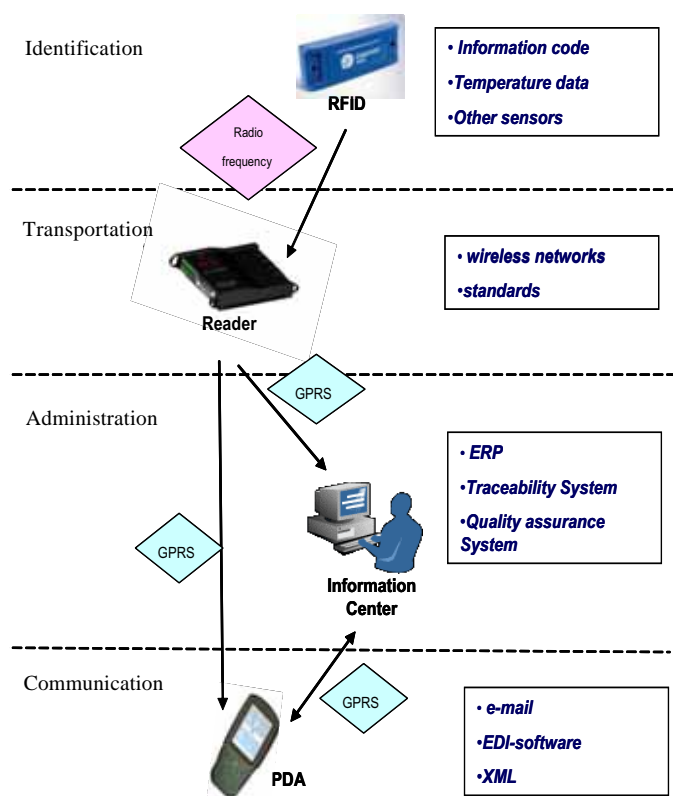


Figure 2. The structure of the traceability system.

System running and evaluations: When the system is running, it keeps recording the temperature every 10 minutes, transforming the data on time to remote server. The remote server processes this data sent to the manager and/or the driver as decision-making

aid. Then the driver may receive a pick-up order from the remote server and verify the trailer compartment's pre-cooling temperature. At the end the customer may get additional "peace of mind" by confirming online that his merchandise is in a good condition via retrieving the temperature information. Fig. 3 shows the temperature of six RFIDs embedded into the trucks.

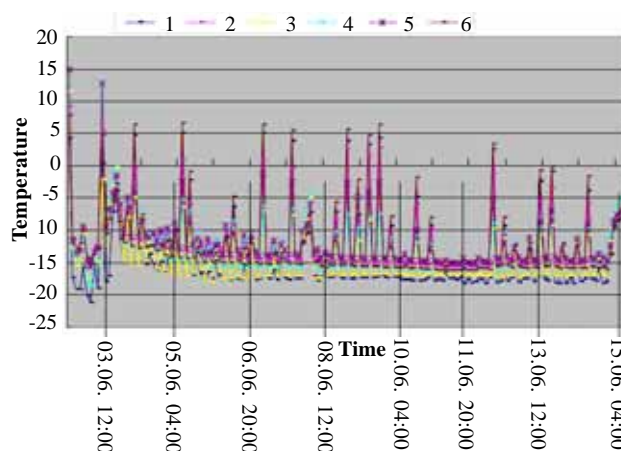


Figure 3. Temperature changes during an actual delivery of frozen tilapia fillet.

According to the above analysis methods, quality is expressed as remaining shelf-life, the time for the product to reach a spoilage level of 107 cfu/g at 0.8°C (Fig.4). Negative values indicate products that have exceeded the limit of acceptability before reaching the consumer's table. It can also be concluded that one of the major environmental factors that results in increased loss of quality for frozen and chilled foods is exposure to sharply increased temperature, especially when the door of reefer container or chilled truck open. Therefore, decrease of the door-open time is another way to keep the quality of the frozen or chilled foods.

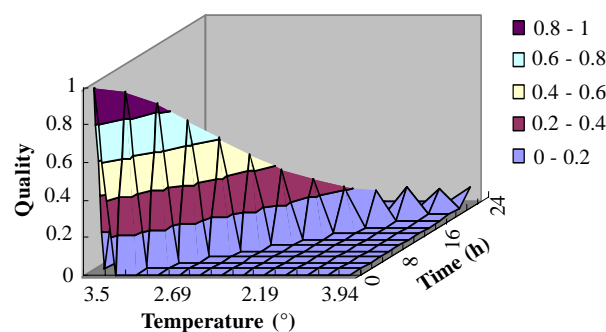


Figure 4. Distribution of quality.

Discussion and Conclusions

Compared with the traditional system, the temperature-managed traceability system integrated RFID with GPS, mobile communication with TTT theory can automate the tasks, like daily work routines, and cross-communicate information flow between the manager, the driver, the stakeholders and insecurities about arrival time.

By the system test and experiment evaluation, it has proved

itself an effective chill chain management tool that leads to minimized distribution of risks and an optimized distribution of quality, effectively reducing the percentage of high risk or spoiled products at consumption time via enabling a constant monitoring and control temperature, document any disruption in the cold chain together with the temperatures reached and the time length of the abnormal conditions.

Consequently a transparent process in storage and transport logistics of frozen and chilled food does not only increase economic benefits for the primary user (the transport and logistics company) but reassures users and the public on healthy transport conditions.

Generally speaking, the proposal system is not only collect the temperature data of the cold chain in the processing and transport stage objective and scientifically, but it provides theoretical support for establishing data integration network and general framework solution of data collection for frozen and chilled food quality evaluation in a real time.

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