System Architectures for Sensor-Based Dynamic Remaining Shelf-life Prediction

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ABSTRACT

Different storage and handling conditions in cold supply chains often cause variations in the remaining shelf life of perishable foods. In particular, the actual shelf life may differ from the expiration date printed on the primary package. Based on temperature sensors placed on or close to the food products, a remaining shelf-life prediction (RSLP) service can be developed, which estimates the remaining shelf life of individual products, in real-time. This type of service may lead to decreased food waste and is used for discovering supply chain inefficiencies and ensuring food quality. Depending on the system architecture, different service qualities can be obtained in terms of usability, accuracy, security, etc. This article presents a novel approach for how to identify and select the most suitable system architectures for RSLP services. The approach is illustrated by ranking different architectures for a RSLP service directed towards the supply chain managers. As a proof of concept, some of the most highly ranked architectures have been implemented and tested in food cold supply chains.

KEYWORDS


INTRODUCTION

Studies show that temperature in food supply chains (FSCs) often differ from the ones recommended by the producer (Hafliðason et al., 2012; Likar and Jevšnik, 2006). This might lead to shorter shelf life for perishables, such as dairy products, fresh meat and fish, and that the expiry dates printed on the primary packages no longer represent good estimates of the actual shelf life. On the other hand, food that has been well treated can often be safely consumed after the printed expiry date has passed. It has been estimated that one third of all food produced globally for human consumption is lost or wasted and that more than 40% of this food loss occur at retail and consumer levels, in industrialized countries (Gustavsson et al., 2011). With information about the actual shelf life of the products, this food waste can be reduced. One way to get an estimate closer to the actual shelf life than the printed expiry date is to use product condition monitoring. That is, to continuously measure relevant conditions of the products, such as temperature, and use these measurements to estimate the product shelf life.

Among environmental parameters in FSCs, temperature has the most significant influence on the quality of perishable food products (Jedermann et al., 2009). As a consequence, temperature abuse and fluctuations are the main reasons for product returns, food waste and financial losses (Raab et al., 2008). Scheer (2006) reports that mismanaged temperature during perishable FSC distribution can cause up to 35% in product loss. Moreover, Göransson et al. (2018a) have found significant differences in estimated product shelf life when comparing different FSCs for the same product types

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and temperature requirements, in field tests. This means that the corresponding differences between actual shelf life and the shelf life printed on the packages, also varied. By using local sensors to measure the temperature in FSCs, the actual quality of the food products can be estimated. These sensors must be present throughout the transport chain, and the closer to the products they are placed, the more accurate estimations can be made. Based on the estimated quality, the remaining shelf life can be dynamically updated in real time, enabling product owners, actors within supply chain management and final consumers, to make more informed decisions about how to handle the food and when to discard it. Furthermore, a service providing a remaining shelf-life prediction (RSLP) based on temperature sensors might be colligated with other services such as tracking and tracing, product information (for instance origin and handling instructions), carbon dioxide labeling, and dynamic pricing (Bartels et al., 2010).

An RSLP service can be implemented in many different ways, using different system architectures. For instance, the remaining shelf life can be calculated on the product or by remote servers (in the cloud), and the temperature can be measured by a sensor attached to the product or by fixed close-by device. These different options need to be evaluated before an informed decision about the system architecture can be taken. To the best of our knowledge, there are no previous studies on how this can be done in a systematic manner for this type of service. In his paper, we present and apply a novel approach to identify and evaluate the most suitable system architecture for an RSLP service for perishable food. We illustrate the approach by ranking all architectures satisfying the requirements of two particular user groups: the supply chain managers and product owners. As a proof of concept, we have also implemented and tested some of the most highly ranked architectures in a cold FSC. In summary, the aims of this paper is to:

- Present and apply a novel approach to identify and evaluate the most suitable system architecture for an RSLP service,
- Present experiences gained from implementing and testing some of the most suitable RSLP architectures in a cold FSC,
- Prove that this type of service can be implemented using the technology available today.

The remainder of this paper is structured as follows. The next two sections describe previous studies related to product condition monitoring, and the methodology applied in this paper. Thereafter, we present the results in terms of a new model for representing the system architectures, a filtering process leading to a set of architectures subject for evaluation, the final ranking of these architectures, and the experiences gained from FSC implementation and tests (as proof of concept). The paper ends with a short discussion and summary of conclusions.

**PRODUCT CONDITION MONITORING: STATE-OF-THE-ART**

Products accompanied by a higher level of intelligence than only possessing an associated ID (e.g. the simplest form of RFID), are often referred to as “smart” or “intelligent” (Meyer et al., 2009). For instance, these products may be capable of communicating with their environments, storing data, processing data, and even making autonomous decisions. Depending on the level of intelligence, such products may be capable of monitoring the local conditions during transportation (López et al., 2011), and maybe also of calculating the remaining shelf life. The intelligence related to a product may or may not be located on the product itself (Meyer et al., 2009). However, for the RSLP service, local intelligence, for instance implemented on the product, a pallet or in the vehicle, able to perform condition monitoring is required.

Within the area of communicative packaging, potential means to monitor the condition of packaged contents by enhancing the intelligence of the package itself have been investigated (Heising
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