

Monitoring Cold Chain Logistics by Means of RFID

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1. Introduction

Every day, millions of tons of temperature sensitive goods are produced, transported, stored or distributed worldwide. For all these products the control of temperature is essential. The term “cold chain” describes the series of interdependent equipment and processes employed to ensure the temperature preservation of perishables and other temperature-controlled products from the production to the consumption end in a safe, wholesome, and good quality state (Zhang, 2007). In other words, it is a supply chain of temperature sensitive products. So temperature-control is the key point in cold chain operation and the most important factor when prolonging the practical shelf life of produce. Thus, the major challenge is to ensure a continuous ‘cold chain’ from producer to consumer in order to guaranty prime condition of goods (Ruiz-Garcia et al., 2007). These products can be perishable items like fruit, vegetables, flowers, fish, meat and dairy products or medical products like drugs, blood, vaccines, organs, plasma and tissues. All of them can have their properties affected by temperature changes. Also some chemicals and electronic components like microchips are temperature sensitive.

1.1 Problematic

The quality of these products might can change rapidly, when inadequate temperature and relative humidity conditions during transport and storage. Temperature variations can occur in warehousing, handling and transportation. Studying and analyzing temperature gradients inside refrigeration rooms, containers and trucks is a primary concern of the industry. Any temperature disturbance can undermine the efforts of the whole chain (Meenke, 2006). In refrigerated trucks or containers, temperatures rise very quickly if a reefer unit fails. A recent study shows temperature-controlled shipment rise above the specified temperature in 30% of trips from the supplier to the distribution centre, and in 15% of trips from the distribution centre to the store. Lower-than required temperatures occur in 19% of trips from supplier to distribution centre and in 36% of trips from the distribution centre to the store (White, 2007).

Source: Sustainable Radio Frequency Identification Solutions, Book edited by: Cristina Turcu, ISBN 978-953-7619-74-9, pp. 356, February 2010, INTECH, Croatia, downloaded from SCIYO.COM

The supply chain management for temperature sensitive goods requires fast decisions; goods are forwarded within hours. Appropriate planning calls for more information than that which could be provided by standard RFID tracking and tracing. It is essential to ensure that temperatures are adequate. Reports from literature indicate gradients of 5°C or more, when deviations of only a few degrees can lead to spoiled goods and thousands of Euros in damages (Tanner & Amos, 2003; Nunes et al., 2006; Rodríguez-Bermejo et al., 2007). Loss and damage of perishable goods during storage and transportation is a substantial global issue. Inadequate temperature is second on the list of factors causing foodborne illness, surpassed only by the initial microflora present in foods (Sánchez López & Daeyoung, 2008). It is estimated that 300 million tons of produce are wasted annually through deficient refrigeration worldwide (IIR/UNEP, 2002). The Cool Chain Association (CCA) estimates that 30% of temperature-sensitive products are lost during transport (Hoffman, 2006). International refrigerated trade continues growing at 6% per annum (Coates, 2003). Quality control and monitoring of goods during the cold chain is an increasing concern for producers, suppliers, transport decision makers and consumers. Commercial systems are presently available for monitoring containers, refrigerated chambers and trucks, but they do not give complete information about the cargo, because they typically measure only a single or very limited number of points (Ruiz-Garcia et al., 2007). Also, there is an increasing demand of traceability in the cold chain, statutory requirements are growing stricter and there is increasing pressure to develop standardized traceability systems. Each event in the chain, like production of transportation, packing, distribution or processing results in a different product which can have its own information associated within the tracing system. From the raw material to the sale of goods, more and more information like temperature, humidity or tamper needs to be gathered and made available. Supplementary information may also be collected at any step, in order to provide data for analysis and optimization of production practices (Thompson et al., 2005).

Parties involved need better quality assurance methods to satisfy customer demands and to create a competitive point of difference. Successful cold chain logistics calls for automated and efficient monitoring and control of all operations. The monitoring should allow the establishment of better knowledge of the cold chain, the detection of weakness and the optimization of the whole process, all things that potentially would have a significant impact on the supply chain (Vervest et al., 2005).

The cold chain is involved in many industries as it was mentioned previously. However, existing applications on the cold chain topic are associated mainly with food and pharmaceuticals. Therefore, the scope of this chapter will focus on these products.

1.2 Perishable food products

The internal biological and chemical processes of fresh produce continue after harvesting. Produce is a living, breathing commodity, which emits heat and carbon dioxide. The risk of a failure in the cold chain could cause excessive ripening, weight loss, softening, color and texture changes, physical degradation and bruising, and attack by rot and molds. These factors affect freshness, desirability, and marketability. Strict temperature control throughout the supply chain can minimize the risk of food-borne illnesses because low temperatures drastically reduces the growth rate of most human pathogens (Ukuku & Sapers, 2007).

Depending on the temperature requirements we can identified four groups of products (Fernie & Sparks, 2004):

- Frozen is -25°C for ice cream, -18°C for other foods and food ingredients.
- Cold chill is 0°C to 1°C for fresh meat and poultry, most dairy and meat-based provisions, most vegetables and some fruit.
- Medium chill is 5°C for some pastry-based products, butters, fats and cheeses.
- Exotic chill is $10\text{-}15^{\circ}\text{C}$ for potatoes, eggs, exotic fruit and bananas.

EN 12380 (1999) legislation demands class one temperature measurement for refrigerated food transport. Measurement has to be feasible in the range between -25°C up to $+15^{\circ}\text{C}$ with an accuracy $\pm 1^{\circ}\text{C}$ and resolution $\leq 0.5^{\circ}\text{C}$ (CEN, 1999).

It is not easy to maintain appropriate conditions over the whole chain, negligence or mishandling in the logistic of perishable food products is very common, including goods poorly or excessive cooled. Roy et al. (2006) analyzed the supply of fresh tomato in Japan and quantified product losses of 5% during transportation and distribution (Roy et al., 2006). Tanner and Amos (2003a and 2003b) studied thermal variations during long distance transportation of fruits from New Zealand to Europe. The results showed that the products were out of the set-point more than 30% of the time, with a significant variability both spatially across the width of the container as well as temporally along the trip. In those experiments monitoring was achieved by means of the installation of hundreds of wired sensors in a single container, which makes this system architecture commercially unfeasible (Tanner & Amos, 2003).

Global food safety policies concerning the cold chain have been stipulated by Governmental authorities with the aim of protecting the safety and quality of food. In the European Union Manufacturers, distributors and other supply chain partners must follow the ATP (Agreement on the international carriage of perishable foodstuff and on the special equipment to be used for such carriage) (UNECE, 2003). In the United States of America the HACCP (Hazard Analysis and Critical Control Point) (HACCP, 1997), Bioterrorism Act (FDA, 2002) and COOL (Mandatory Country of Origin Labeling) (USDA, 2009).

1.3 Medicinal cold chain

As it was mentioned previously, medical products like vaccines, blood, some pharmaceuticals and others are temperature sensitive. Most of these products require temperatures in the range of $2\text{-}8^{\circ}\text{C}$. So, they need a cold chain logistic in order to prevent damage caused by heat exposure. Thus, temperature control and monitoring is one of the most critical factors in the pharmaceutical supply chain and is gaining more attention from the industry. For example, in the case of vaccines, keeping too cold can be just as harmful as keeping them too warm, since many vaccines may be damaged by freezing. For safety and quality, temperature needs to be carefully and continuously monitored and controlled in each stage of the supply chain. The effort expended in reaching children with immunizations services will be lost if vaccines are improperly handled so that they are damaged by incorrect temperature maintenance (Bishara, 2006).

The cold chain of pharmaceutical products is complex. This complexity is engendered by the globalization of pharmaceutical companies. Various packagers, primary and secondary distributors, retail pharmacies, hospitals and others may have handled the drug before getting the final consumer. In this framework counterfeit is a main problem. For example, of the top 34 drugs that are of most concern for counterfeiting according to Florida's Bureau of Statewide Pharmaceutical Services and Drug Wholesaler Advisory Council, more than 61% have strict cold-chain requirements. Cold chain drugs are most commonly counterfeited due to their higher added value (Ames, 2006; Floridashealth, 2006).

All the members of the pharmaceutical supply chain have various global regulatory requirements to meet while handling, storing, and distributing environmentally sensitive products. The World Health Organization specifies: "where special storage conditions (e.g. temperature and relative humidity) are required during transit, these should be provided, checked, monitored and recorded." And also states: "temperature mapping of vehicles (where applicable) should support uniformity of the temperature across the vehicle. Recorded temperature monitoring data should be available for review." Other regulations like the Canadian Guidelines for Temperature Control of Drug Products during Storage and Transportation remark that "temperatures should be controlled and monitored using calibrated monitoring devices and records of temperature and alarms, were applicable, should be maintained" (Health Canada, 2006). Similar statements are in the "Guidelines on Good Distribution Practice of Medicinal Products for Human Use" of European Union (European Union, 2003) or in the recommendations for "Good Storage and Shipping Practices" of the United States Pharmacopeia (USP, 2005).

2. The role of RFID in cold chain

RFID is entering in a new phase. RFID technologies are said to improve the performance of the cold chain. Recent advances offer vast opportunities for research, development and innovation in the cold chain. This is the consequence of lowering costs of ownership, engineering increasingly smaller sensing devices and the achievements in radio frequency technology and digital circuits.

RFID was originally developed for short-range product identification, typically covering the 2 mm - 2 m read range and has been successfully applied to food logistics and supply chain management processes. However, recent developments in RFID hardware outfitted with sensors extend its range of application. Adding sensors to the same tags used to track items moving through the supply chain may also alert if they are not stored at the right temperature and predict the remaining shelf life. There are active and semi-passive tags that can measure temperature (Amador et al., 2008; Jedermann et al., 2009), humidity (Chang et al., 2007; Abad et al., 2009), shock/vibration (Todd et al., 2009) or light (Cho et al., 2005; Abad et al., 2009). Moreover, the last generation of Class 4 RFID tags can be configured in a mesh network. In this type of network, the tags can communicate each other to get to a reader circumventing environmental obstacles and extend the size of the system (Sarma & Engels, 2003).

2.1 Advantages of RFID monitoring

Current temperature monitoring systems like strip chart recorders or temperature dataloggers are usually expensive and not automated, thus requiring manual inspection. RFID devices are more accurate and can be read without opening the container or package (Abad et al., 2009). Specialized RFID monitoring devices promise to revolutionize the shipping and handling of a wide range of perishable products. They can be placed in transport vehicles in order to monitor the on-the-go environment and can be the basis for distributed systems, enabling environment sensing together with data processing (Ruiz-Garcia et al., 2007); giving suppliers and distributors continuous and accurate readings throughout the chain. Precise, frequent and automated readings, interpreted by software and coordinated with existing and planned product inventories, should translate into more intelligent goods management and fewer rejected batches.

The lowering cost of RFID will provide the opportunity to track and trace not only large and expensive products, but small and cheap ones, creating a new generation of intelligence products (Meyer et al., 2009). From the raw material to the sale of goods, more and more information can be gathered and made available. Moreover, this information can be linked with a traceability system in each step of the life of the product, “*from farm to fork*”, tracking and tracing products from the field to industry in a new exhaustive way. The concept of “cold traceability” has been introduced to trace groups of temperature-sensitive products are transported in different atmosphere requirements (Ruiz-Garcia et al., 2009).

2.2 FIFO vs. FEFO

If a direct access to the means of transport is not possible, online notifications offer new opportunities to improve transport planning. If fixed delivery commitments require ordering of a replacement, the time of information is very crucial. Improved cool chain management methods such as the Quality Oriented Tracking and Tracing Systems (QTT) offer new features (Scheer, 2006). An example of this approach is the Safety Monitoring and Assurance System (SMAS) that was developed to reduce customers’ risk of consuming microbiologically contaminated meat (Koutsoumanis et al., 2005). The growth rate of pathogens was estimated based on temperature history. At a control point the package was either sent to the local or the export market. A case study of cooked ham was carried out based on previous surveys of distribution chain conditions. Following the SMAS approach, the number of products with zero shelf life could be reduced from 12 % to 4% in the export store compared to normal FIFO (First In, First Out) handling. A retailer that knew which of the cases had the shorter shelf life could put it out before the one with the longer shelf life. This is known as FEFO (First Expire, First Out) (Emond & Nicometo, 2006).

3. Applications of RFID in cold chain tracking and monitoring

Several applications for monitoring cold chain logistics by means of RFID have been reported. The majority are oriented to perishable food products. Here are the most representative to our knowledge.

The use of microbial growth models combine with information from active RFID has been faced. These models allow the prediction of microbiological safety and quality of foods, by monitoring the environment without recourse to further microbiological analysis. Thus immediate decisions on the quality and/or safety of fresh produce can be made based on the temperature profile of the supply chain. Three different cases were studied: frozen dairy product, meat carcass chilling and fermented meat processing (McMeekin et al., 2006).

An important step in cold chain management is recording the temperature throughout the supply chain. Implementation of HACCP requires measurements to ensure that the prescribed control limits are not being violated. Ogasawara and Yamasaki (2006) reported a cold chain solution that uses RFID tags with embedded temperature sensors. It also introduced a temperature-managed traceability starter kit that contributes to effective risk management by easily enabling consistent temperature management throughout transportation processes (Ogasawara & Yamasaki, 2006).

The integrity of the cold chain must be maintained from the very beginning of production or processing, through each link (loading, unloading, transport, handling, storage) to the consumer end. Gras (2006) monitored a cold chain of frozen goods using semi-passive and active RFID instrumented with temperature sensors. The experimental work covers four

steps of the cold chain: production, transportation, storage and delivery. Data was linked with computerized cold chain management system (Gras, 2006).

Environmental temperature can differ from each other depending on the location of the logger, packing material or heat dissipation of the product (Moureh et al., 2002; Raab et al., 2008). RFID tags can be also used to measure, not just the walls of the vehicle, but also inside the boxes. Amador et al. (2008) showed the use of RFID for temperature tracking in an international shipment of pineapples from a packing house, in Costa Rica, to a wholesale storage, in USA. They studied the use of RFID in temperature monitoring by comparing the performance of RFID temperature tags versus conventional temperature tracking methods, as well as RFID temperature tags with probe versus RFID temperature tags without probes and their utilization along the supply chain. The temperature mapping of a shipping trial comprising pallets of crownless pineapples instrumented using different RFID temperature dataloggers and traditional temperature dataloggers and packed in two kinds of packages (corrugated boxes and reusable plastic containers) inside a container was performed. The results showed that RFID temperature tags are analogous with regards to accuracy to the conventional methods, but have a superior performance because they allow quick instrumentation and data recovery and the possibility of accessing the sensor program and data at any point of the supply chain without line of sight (Amador et al., 2009).

The fresh fish logistic chain has been also monitored using RFID. Abad et al. (2009) validated a RFID smart tag instrumented with light, temperature and humidity sensors. The system provides real-time traceability information of the product to the different fish distribution chain links. The RFID tag was placed on a corner of the fish box to ensure a correct real-time reading of the temperature and relative humidity measurements (maximum reading distance of about 10 cm) from the outside without the need of opening the fish box (Abad et al., 2009).

The accuracy of data loggers is a critical issue in cold chain management. This accuracy becomes even more important if the objective is early detection of temperature changes and gradients. Standards for food distribution allow deviations of $\pm 0.5^\circ\text{C}$ from the set point (CEN, 1999). Jedermann et al. (2009) compared three different RFID loggers in order to find the most appropriated one for monitoring cold chain logistics. Several tests were carried out in a climatic chamber. In separate experiments with 20 to 40 samples per logger type, the temperature in the chamber was increased stepwise. The sampling rate of the loggers was set to 5 minutes. Constant temperatures of -10°C , 0°C , 15°C and 30°C were maintained over a time span of at least of 30 minutes, giving a minimum of 7 valid samples per logger and temperature step. For the test temperatures, the average and standard deviation δ (root mean square deviation) were calculated separately for the three logger types in Table 1. Part of the difference between the average temperature and the set point might have resulted from tolerances of the climatic chamber, which were specified by the manufacturer to be 0.1°C . The percentage of measurements with a difference to the average value less than the deviation $\pm\delta$ was between 66% and 73%, which was very close to the expected value for a Gaussian distribution of 2/3. The iButtons produced the best results with a deviation of $\pm 0.09^\circ\text{C}$, followed by the TurboTags with $\pm 0.19^\circ\text{C}$, and the KSW tags with $\pm 0.36^\circ\text{C}$.

Jedermann et al. (2009) also studied the temperature distribution inside a packed and sealed pallet. For evaluation of the penetration depth of temperature changes, two test pallets were equipped with 50 or 70 KSW Variosens data loggers. The tags were placed in pre-cooled boxes of dairy products. 180 boxes were loaded in 5 layers onto a pallet of 80 cm by 120 cm to a height of 95 cm. The tagged boxes were placed in the bottom, middle and top layers.

	Experiment 1: KSW (23 units)	Experiment 2: Turbo-Tag (36 units)	Experiment 3: IButton (20 units)
Temperature (°C)	Mean and Standard deviation (°C)	Mean and Standard deviation (°C)	Mean and Standard deviation (°C)
-10	-10,00±0,41	-9,81±0,25	-9,90±0,15
0	0,13±0,32	0,16±0,18	0,12±0,06
15	15,17±0,29	15,05±0,17	15,02±0,06
30	30,23 ±0,42	30,05± 0,18	29,99±0,09

Table 1. Test of different logger type in climatic chamber (Jedermann et al., 2009)

After one day at the optimal temperature of 6.5 °C the pallet was moved to a non-refrigerated storage space with a temperature of about 20 °C. Because of the lack of air ventilation, the surface of the pallet warmed up to only 16.5 °C. After 3 days the pallet was moved back to the refrigerated room. The positions and temperatures of different measurement points inside the densely packed pallet of the first setting are displayed in Figure 1. Due to the large thermal mass of the goods, the effect of changes in the ambient temperature on the temperature of the pallet core was delayed for several days. After 60 hours the change in core temperature had only reached 50% of the change in ambient temperature.

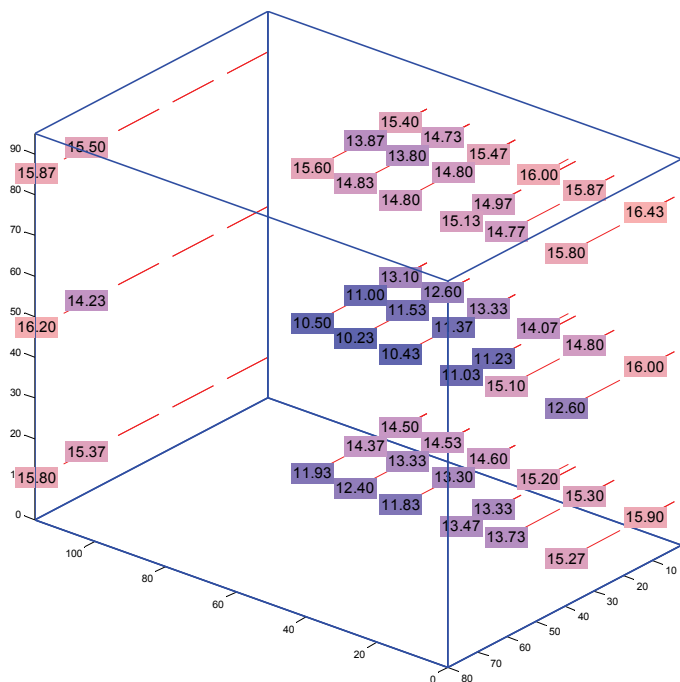


Fig. 1. Temperature rise inside a sealed palette after 60 hours without refrigeration (Jedermann et al., 2009).

Demands for mixed loads of products require different storage temperatures and the trend of refrigerated transport is to use multi-compartmental vehicles. Jedermann et al. (2009) monitored 16 multi-compartmental trucks using semi-passive RFID instrumented with temperature sensors (Turbo Tag) detecting temperature gradients. The authors concluded that semi-passive tags can be used to monitor environmental variables such as the temperature of chilled food refrigerated goods, to identify problem areas and to raise alarms. RFID loggers are good tools are cost-effective for the characterization of refrigerated transport units such as trucks or containers (Jedermann et al., 2009).

Average temperature often lies. The average information does not provide information about gradients, maximum of minimum temperatures during a shipment. Moreover, if two shipments have the same average temperature does not means that both have were of the same performance. Jedermann et al. (2009) make use of a normalized temperature difference (ΔTn_{ij}) developed by Rodriguez-Bermejo et al. (2007) , which is computed with respect to the set point and to the outside temperatures (Equation 1). This value gives a normalized measure with respect to the varying ambient conditions of the experiments in order to judge the difference between them. Values over zero indicate that the temperature inside the transport was higher than the set point, which was the case of majority of the shipments (Rodríguez-Bermejo et al., 2007).

$$\Delta Tn_{ij} = \frac{\overline{T}_{ij} - T_{si}}{\overline{T}_{at} - T_{si}} \quad (\text{with } -1 < \Delta Tn_{ij} < 1) \quad (1)$$

ΔTn_{ij} = Normalized temperature difference for experiment i and logger j

T_{ij} = Temperature for experiment i and logger j (°C)

T_{si} = Set point (°C)

T_{ai} = Ambient temperature (°C)

One statistical parameter that provided interesting information is the variance of ΔTn_{ij} , known as "Mean Normalized Variance". If this value is more than one that means temperature has fluctuated more inside the transport than outside. For the experiment of the 16 trucks all values were under 1, which indicates that the fluctuations inside were less than outside (Jedermann et al., 2009)

In the intermodal transportation, the performance of radio waves inside metal enclosed areas was studied. Furh and Lau (2005) tested a radio frequency device in a metal cargo container and demonstrated that it is possible to communicate with the outside world (Fuhr & Lau, 2005). Jedermann et al. (2006) presented a system for intelligent containers combining wireless sensor networks and RFID (Jedermann et al., 2006). Laniel et al. (2008) focuses on the 3-D mapping of RFID signal strength inside a 12m (40') refrigerated marine container. Three different types of radio frequency configurations were tested: 2.4GHz, 915MHz and 433MHz. Tests were performed with an empty container and the main goal was to find a frequency and configuration that would allow real time reading of the temperature in a shipment of perishable products using RFID. Results obtained in this study showed that wave propagation inside a closed marine container is significantly higher at 433MHz than at 915MHz or 2.4GHz, with attenuation averages of 19.57 and 18.20 versus 36.49 and 35.91 and 29.91 and 29.78 dBm respectively (Laniel et al., 2008). At 433 MHz the wavelength is approximately a meter, enabling signals to diffract around obstructions. The level of diffraction depends on the size of the object versus the signal wavelength. At

2.4GHz the diffraction is very limited and therefore not recommended for most cold chain applications which are in crowded environments (Technologies, 2008).

3.1 Pharmaceutical applications

Most of the top pharmaceutical companies are running RFID cold-chain pilot projects but results and details are not published. The typical application is RFID loggers or active tags are placed inside test packages to record temperature and sometimes also humidity at specified intervals and wirelessly download the data to a web-accessible database when they pass a reader. For example, CSL, Australia's biggest pharmaceutical company, is using an RFID-based temperature sensing system that features a read-write, credit-card-size, 13.56 MHz active tag, which can be attached to or inserted in shipments (Forcinio & Wright, 2005). Also some specific RFID devices for monitoring some products like for example blood were developed. The system helps track the blood in space and time from extraction to transfusion. In this way, the blood is monitored according to certain parameters: the time elapsed and the temperature that could determine its state before transfusion (Abarca et al., 2009).

Another interesting application in high value products is to integrate the RFID tag together with the sensors in paperboard packaging. Smart packages with temperature and tamper sensing capabilities for the pharmaceutical industry have been reported (Figure 2) (CYPAK, 2009).

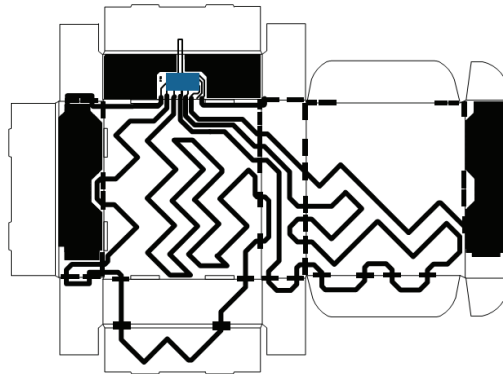


Fig. 2. Smart package (Source: SecurePak)

Any commercial application of RFID in the pharmaceutical cold chain must include anti-counterfeit mechanisms such as ePedigree, providing means of authenticating legitimate product together with temperature information (Ames, 2006).

4. Challenges and limitations

RFID has limitations and its implementation involve multitude of challenges. A significant proportion of RFID deployments remain exploratory. There is a need to know the long-term behavior of the systems. Most of the applications reported have short experimental periods. Longer testing and experimentation is necessary for validate some of applications presented. One limitation might be that these monitoring systems create huge volumes of data that are difficult to manage, causing a huge increase in the daily volume of data in a corporate

information technology system. Database administrators need to be able to deal with the potential stresses on the databases, both in terms of speed and volume. Even so, data volume can be overwhelming to the network. If a product have 1,000 bytes of data associated with it, the RFID monitoring system would generate 10 terabytes of data per year. If the data of five years is stored, that means a database of 50 terabyte. Thus, the solution lies in implementing a decentralized data management system. Data can be pre-processed and duplicate information eliminated close to their point of origin by intelligent systems, which could be sited at the level of the tag or reader (Roberti, 2003; Ruiz-Garcia, 2008).

An important research topic that must be faced is fault detection and isolation. In a remote sensing application is essential to detect the erroneous measurements. False reads can be done as a result of radio waves being distorted, deflected, absorbed, and interfered with. Wrong information provided by the monitoring system should be identified and skipped. Also the implementation of artificial intelligence in the core of the system can block the transmission of erroneous data (Angeles, 2005).

RFID data loggers are available in high quantities, but they require manual handling because of their low reading range. Another disadvantage is that temperature loggers are only available for the 13.56 MHz HF-Range. The major drawback of this band is the limited reading range of about 20 cm. If a gate reader scans items automatically upon arrival at the warehouse, the reading range has to cover several meters. Also these tags take around five seconds to transfer recorded temperature values over the RFID interface (Jedermann et al., 2009). A higher data rate is required according to a normal flow of goods in a warehouse.

Another important issue is to deal with the physical limitations of RFID. Metals and liquids inhibit the propagation of electromagnetic waves. This is particularly true for UHF and microwave frequencies (2.4GHz). Some temperature sensitive products such as fruits, vegetables or juices have high water content, sometimes more than 90%. As a result, performance can be affected by the item on which the tag is attached (Angeles, 2005; Ruiz-Garcia, 2008). However, reflections and product dimensions is important for liquid and dielectric materials as well since much of the power loss occurs at the interfaces between air and the medium (Fletcher et al., 2005).

The lack of uniformity in global standards makes the RFID implementations more difficult. Managing multiple readers and related hardware can be a challenge, especially across multiple facilities. There is practically no part of the spectrum available worldwide because governments have assigned different uses for the various parts of this spectrum, with the exception of the ISM (industrial, scientific and medical) bands. In order to solve this problem, the Auto-ID Center has explored the concept of "agile" readers that will allow the network to operate at different frequencies in a wide variety of geographical locations (Haller & Hodges, 2002).

The level of granularity is a limitation in most of the applications. Normally three levels of granularity are considered: pallet, case or item-level. The primary advantage of case or item-level tagging over pallet-level tagging is more detailed and accurate information, since each pallet in a load and each carton on a pallet can experience temperature variations. Instead of reject an entire shipment goods can be considered on a pallet-by-pallet or case-by-case basis. But high granularity also means much more tags to handle with, higher costs and huge data to be processed. Pharmaceutical cold chain is the leading candidate for RFID tagging at item level. The high relative value of pharmaceutical products relative to the price associated with RFID-equipped make it possible (Angeles, 2005).

5. Conclusions

The use of RFID in cold chain monitoring provides new features that have the potential to be an economically viable. RFID and sensor technology is evolving rapidly and enabling greater capabilities at lower costs. The value of technology can be best realized when integrated with decision support systems. Also improving operations by providing early warning of equipment failure and a predictive maintenance tool, improving energy management, providing automatic record-keeping for regulatory compliance, eliminating personnel training costs or reducing insurance costs. Growers, shippers, processors, distributors and retailers that can establish the continuity of the cold chain have a powerful advantage in a highly competitive marketplace. The collaboration and synergy of sensing, processing, communication and actuation is the next step to exploit the potential of these technologies.

Another important benefit of the systems is the visibility that it can give along the cold chain. This kind of systems can be used in a warehouse, container or vehicle for remotely monitoring and tracking environmental characteristics. Measurements obtained are consistent and provide valuable information on the conditions encountered during the life cycle of the products. It is possible to address, at regular time increments, what is happening with the product, whether it is temperature, humidity, acceleration, etc. Another advantage is providing effective support in legal situations as well as safety inspections.

The suitability of this technology for monitoring refrigerated cold chain is clear. RFID has the potential to be a revolution although the adoption of RFID in the industry is at an early stage. However, this technology, as any other, has limitations that have been explained in this chapter. A lot of work remains to be done on overall approaches involving harmonization of standards, long term experimentation and hardware and software improvements.

Sharing information is crucial for an effective cold chain but also privacy. To protect data of unjustified access there are methods in information technologies but in addition an agreement has to be found, that opens the possibility of a fast and detailed rebuild of the trace of a product along the chain, without giving sensitive information to the public or competitors.

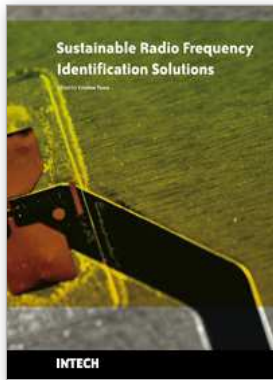
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Sustainable Radio Frequency Identification Solutions

Edited by Cristina Turcu

ISBN 978-953-7619-74-9

Hard cover, 356 pages

Publisher InTech

Published online 01, February, 2010

Published in print edition February, 2010

Radio frequency identification (RFID) is a fascinating, fast developing and multidisciplinary domain with emerging technologies and applications. It is characterized by a variety of research topics, analytical methods, models, protocols, design principles and processing software. With a relatively large range of applications, RFID enjoys extensive investor confidence and is poised for growth. A number of RFID applications proposed or already used in technical and scientific fields are described in this book. Sustainable Radio Frequency Identification Solutions comprises 19 chapters written by RFID experts from all over the world. In investigating RFID solutions experts reveal some of the real-life issues and challenges in implementing RFID.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Luis Ruiz-Garcia and Loredana Lunadei (2010). Monitoring Cold Chain Logistics by Means of RFID, Sustainable Radio Frequency Identification Solutions, Cristina Turcu (Ed.), ISBN: 978-953-7619-74-9, InTech, Available from: <http://www.intechopen.com/books/sustainable-radio-frequency-identification-solutions/monitoring-cold-chain-logistics-by-means-of-rfid>

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