WSN BASED INTELLIGENT COLD CHAIN MANAGEMENT

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Abstract

This paper presents a cold chain monitoring system which is implemented by using ubiquitous computing technologies, Radio Frequency Identification (RFID) & Wireless Sensor Network (WSN). In this paper, we discuss how cold supply chain works and how we can monitor and control cold supply chain by using wireless tracking and sensing technologies. We propose a prototype design which will provide a well controlled and transparent cold chain system, which could help the users to manage their products' environmental data in real time during the life cycle. Moreover, we highlight how the availability of product trace data in combination with historical condition-monitoring data can facilitate decision-making processes enhancing supply chain's performance. Finally we discuss the integration works of these two technologies together in the cold supply chain management system. Hardware and software platform of WSN used in this system are also described in this paper.

Keywords: Cold Chain, RFID, WSN.

1.0 Introduction

A cold chain is a temperature-controlled supply chain. An unbroken cold chain is an uninterrupted series of storage and distribution activities which maintain a given temperature range. Cold chains are common in the food and pharmaceutical industries and also some chemical shipments. One common temperature range for a cold chain in pharmaceutical industries is 2 to 8 °C. But the specific temperature (and time at temperature) tolerances depend on the actual product being shipped [1]. Cold chain is very important for the supply chain management of the food and pharmaceutical industries because a good cold chain can reduce the risk and cost. The loss of a trailer of temperature sensitive products due to improper transportation or inventory will cost thousands of dollars; a pharmaceutical shipment, in millions [2]. Perishable food products must be continuously monitored for safety concerns throughout the whole supply chain. A breakdown in temperature control at any stage will impact on the final quality of the product [3]. The key to managing the cold chain is to measure product temperature at each stage. Currently, food, dairy and pharmaceutical companies are already tracking their environmentally sensitive products using temperature data loggers placed in their transportation vehicle, containers or even pallets. However, this technology only provides information for a certain part of the cold chain [4]. But for the whole life cycle tracking is still under research. To achieve the capability of monitoring and controlling of every link in a cold chain, real time data should be communicated via data retrieval devices.

Radio Frequency Identification (RFID) technology has been available for decades but it has only recently risen to prominence. Increasing competitiveness between tag manufacturers has lead to significant reductions in the cost of the technology, which in turn drives industry sectors' attention on RFID for adoption. Current RFID systems, however, lack intelligence on their operational environment such as temperature, humidity, etc. In order to tackle this problem, we have been investigating the possibility of integrating RFID with a relatively new technology, WSN. WSN are made up of many small devices with processing and sensing abilities [5].

Integrating RFID systems with condition-monitoring systems will enhance existing track and trace applications, not only the location, but also the condition of perishable and valuable products. Moreover, the availability of product trace history data in combination with historical condition-monitoring data can facilitate numerous decision-making processes [6]. In this paper, we aim to discuss the benefits that such integration could provide, whilst also paying close attention to the implementation view. In our research, we used a sensor network system based on Nano-Qplus platform which is composed of NANO HAL for abstracting the hardware part sensing and actuating, task management, power management, and message handling module. In addition, the Nano-Qplus platform includes ATmega128 MCU and CC2420 Zigbee, IEEE802.15.4 RF communication module. Based on Nano-Qplus platform, we developed the integrated system which have the functionalities of both RFID and wireless sensor network system [7]. Overall, this paper focuses on the design and implementation of the WSN based cold chain management system which monitors the condition of temperature sensitive objects during their supply chain processes.

2.0 Wireless Sensor Network Platform

2.1 Hardware of Nano-Qplus Platform

The sensor hardware which is called Smart Sensor Node focuses on low-cost, low-power, and high-modularity. The sensor node is composed of four blocks: Main, Base, Sensor, and Actuator. The main block has ATmega128 microcontroller and CC2420 IEEE802.15.4 compliant RF transceiver. The base block is used for Anchor node with RS-232 serial I/F, parallel I/O and external power source. For sensing of physical environment, the sensor block has several sensor entities, such as light, humidity, temperature, and ultra sound. The actuator block is made up several electrical switches and can be combined with electric appliances in order to turn Off/On power. In case of normal application, the sensor node is power-supplied by two AA3.3 batteries [7].

2.2 Software of Nano-Qplus Platform

The architecture of the Nano-Qplus resembles as classical modular and layered design and consists of dynamically-loaded modules included in hardware, Nano-OS, and application parts respectively. The hardware part is composed of MCU using ATmega128, RF module, which is CC2420 for wireless communication, and Sensors/Actuators. The Nano-OS part has a role as kernel scheduler and network protocol stack for handling RF messages, and it have a device driver modules, called as nHAL, for abstracting the hardware part. Furthermore, the Nano-OS part also offers the system APIs for convenient developments of WSN applications to sensor networking programmers. In the end, the application part consists of one or more modules interacting via system APIs with Nano-OS part [7].

2.3 RFID Reader Embedded Sensor Technology

As the name indicates RFID is used to identify objects using radio communication. Different applications have different demands on range, power consumption and so on. The most commonly used carrier frequencies are 125 kHz, 13.56 MHz, 868 MHz and 2.4 GHz. The tags can be either passive or active, this system uses 13.56 MHz carrier with inductive coupling, has ability to read from and write to the tag and read multiple tags simultaneously [8]. The normal reading range for the RFID system used in this system is about 5-10 cm, which means that reader and tag cannot be physically separated more than this distance in order to function. The nodes in the network include an RFID reader and RF transceiver as we have mentioned before. When the RFID reader read the tag, it will transmit the tag's information from the sensor node to the sink node, and the distance between the sensor node and sink node could be 10-30 meters [9].

3.0 Analysis of the Cold Chain

3.1 Typical Cold Chain Process

From the factory to the consumer, products follow complex logistic circuits that are subjected to intrinsic constraints. First, the required chilling time between harvest, or the end of cooking, and loading, is a constraint encountered by the producer and the carrier. The carrier's liability comes into play from the moment the products are taken over, and it is up to him to check the temperature manually during loading products, then reach the temperature-controlled distribution hub and send to the customer via supermarket or store. Temperature control needs to be improved throughout the cold chain, to ensure food safety and hygiene and to maintain the product quality [10].

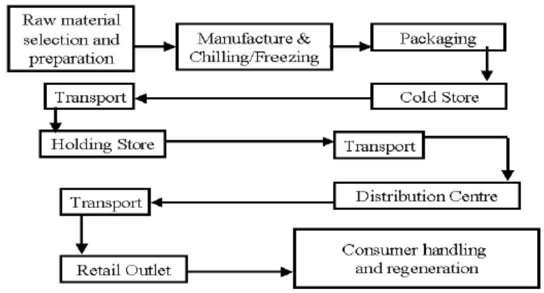

Fig.1. The sequence of events within a typical cold chain [11]

3.2 Hazard Analysis and Critical Control Point (HACCP)

A cold chain can be managed by a quality management system: it can be analyzed, measured, controlled, documented, and validated. The food industry uses the process of Hazard Analysis and Critical Control Point (HACCP) as a useful tool. Its usage continues into other fields [1]. HACCP is an important element in the control of safety and quality in food production. When properly applied, it provides a management tool aimed at complete commitment to product quality and safety. HACCP is useful in identifying problems in food production and works well for simple products and processes. There are 7 principles of HACCP as follows: 1)Identify hazards, assess risk, and list controls; 2) Determine critical control points (CCPs); 3) Specify criteria to ensure control; 4) Establish monitoring system for control points; 5) Take corrective action whenever monitoring indicates criteria are not met; 6) Verify that the system is working as planned; 7)Keep suitable records [12]. Therefore according to these principles, it is clear that we need to define the control points to monitor and keep the time-temperature history throughout the chain for products' safety and quality.

3.3 Lot Traceability and Expiration

Many process industries, notably those involving food and beverages, drugs, cosmetics, and medical apparatus, are subject to government regulation, and must maintain records that detail the lot identification of materials used in the manufacture of these products. Many businesses follow this practice to protect themselves against liability. Shelf life or lot expiration tracking systems also require supporting inventory record subsystems. Typically, they track lot creation dates and expiration dates and provide for first-in, first-out (FIFO) use of material as well as periodic aging reports used to predict material that is potentially expiring [13].

3.4 Advanced Planning Systems Adopting Cold Chain Management

Advanced planning system incorporates long-term, mid-term and short-term planning levels. With the support of effective information flows among these levels make it a coherent software suite. APS do not substitute but supplement existing Enterprise Resource Planning (ERP) systems. APS now take over the planning tasks, while an ERP system is still required as a transaction and execution system. APS are intended to remedy for the inefficiency of ERP system through a closer integration of modules, adequate modeling of bottleneck capacities, a hierarchical planning concept and the use of the latest algorithmic developments. APS is seen in its ability to check whether a (new) customer orders with a given due date can be accepted. By adopting cold chain management functions into the APS could help us to track not only where the product is but also the temperature information around it. To adapt the sensing based APS, in our cold chain management system, we can define the environmental parameters to record and transmit those in every process of the cold chain system and send back to APS and ERP system which could help us to better manage the forecast, inventories, resources, orders and distribution information [14].

4.0 Proposed System Description

4.1 RFID&WSN in Cold Chain

The monitoring of the cold chain should be from the birth of the product to its' destination with its whole life cycle. When the product is ready to be palletized, an RFID and temperature (or humidity, etc) sensor node is activated and placed on the product stack, each product item will be packaged with the RFID tag containing information such as description, destination, and date of departure etc. This information is stored in a secure database [4]. So during the whole life cycle of the cold chain from the plant to the hand of customer will be traceable by using the RFID and Sensor Networks. As RFID record the individual information of an item and sensor network could detect the environmental status, by combining the two domains we can check the status of every product in real time. The system will automatically integrate new nodes which are placed in the range of the network. RFID sensor nodes in the network will have the ability to read RFID tags of a certain type and pass that information to the sink node. The sink node will connect to a PC or Internet from which the user can collect and analyse the data. In every critical points of cold chain we deploy wireless sensor networks in which sensor node should communicate with each other (Fig .2).

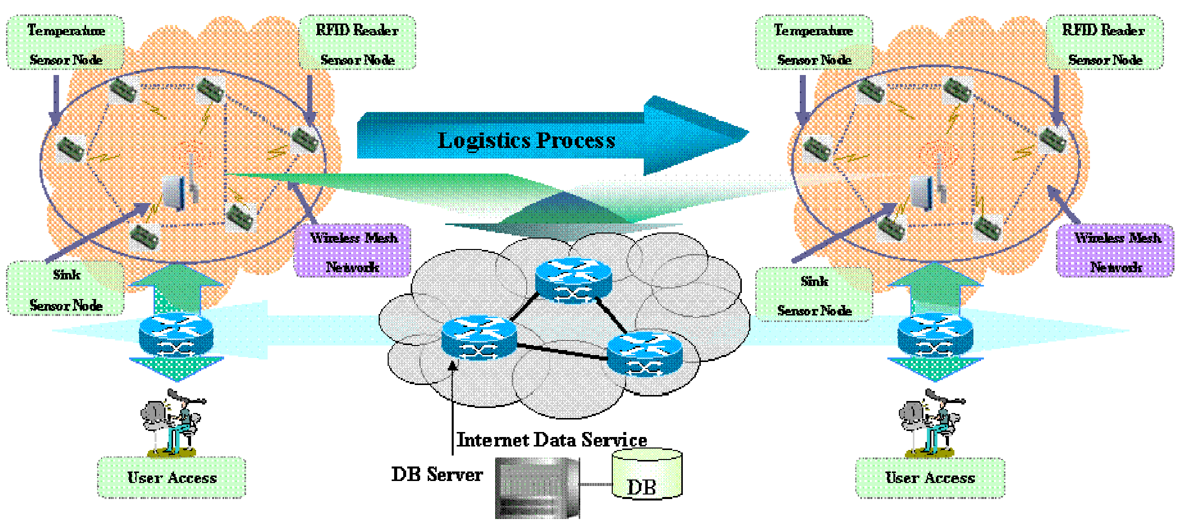

Fig.2. Integrated RFID&USN Cold Chain Management System Design

One or more RFID reader sensor is being clustered with some of the temperature sensor node. When the product have been read from the RFID reader node, the temperature data being detected from the same cluster by the temperature sensor node will be sent to the database and build up the product environment history information. By combining the RFID data and temperature sensor data in the data logger, we get the real-time temperature information of products. Also by using the web server we can make the web application in which remote users could monitor and access the cold chain data. Whenever the temperature is out of the control range in the part of the cold chain, the system could sent the SMS message to the administrators' mobile phone to give the alert by using the CDMA server and SMS service.

4.2 Supply Chain Planning and Execution

Supply chain planning refers to a set of supply chain activities that focus on: evaluating demand for material and capacity; formulating plans; and scheduling to meeting the demand and company goals [15]. Supply chain execution means set of supply chain activities that focus on fulfillment rather than planning-raw material delivery, manufacturing operations and shipments to customers. Execution functions receive requirements from the planning cycle and provide the actual data for actual measurements [16]. Obviously, supply chain planning is an important factor for the success of a company. Poor planning will result in loss of profits and revenue while accurate planning allows a company to operate smoothly and to minimize expenses. The question then is how to more effectively create business forecasts for supply chain activities and control supply chain execution [17]. In our research, the prototype system will not only act as a monitoring tool but also could be used as a planning and execution tools of the supply chain control points. As an easy example, it is easily provide the gap between planning and execution during the cold chain processes.

5.0 System Implementation

5.1 Programming Tool Description

Our prototype system is implemented by LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) which is a platform and development environment for a visual programming language by National Instruments. LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various flavors of UNIX, Linux, and Mac OS [18]. VISA is a standard I/O language for instrumentation programming. VISA by itself does not provide instrumentation programming capability. VISA is a high-level API that calls into lower level drivers [19]. In our system, the sink node is connected to the computer by serial connecter, in order to get the data easily by using NI-VISA module. For our prototype system, we use Microsoft Access database to store the records.

5.2 Cold Chain Management System

As a part of cold chain execution tool, RFID tag should be assigned to a product and it will represent the product during the whole life cycle. For example, we assigned an RFID tag for product 'ice-cream' and its attributes (e.g. Product ID, Product Quantity, Customer, Preferred High and Low Temperature, Due Date etc.).

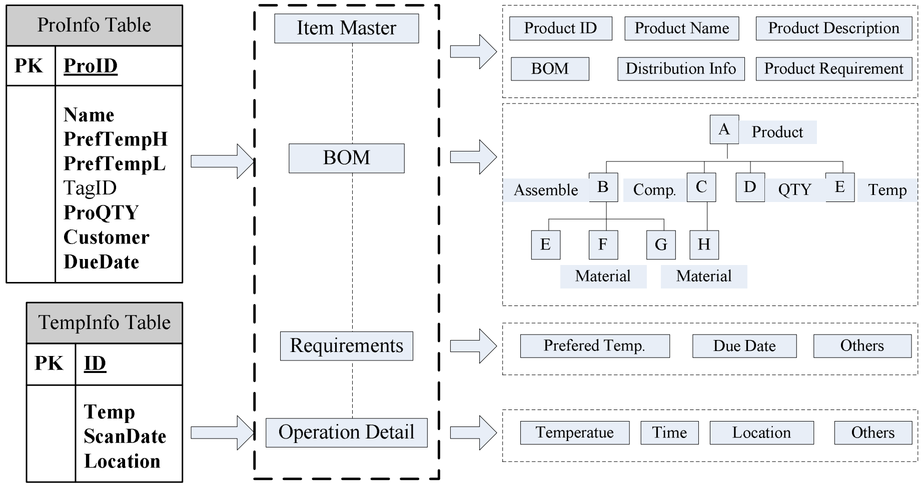

Fig. 3. Data foundation for cold chain management

Fig 3. shows example data foundation for cold chain management. After assigning the tag with product information, the next step is to identify the location of a product in the cold chain. When we scan the RFID tag using the wireless RFID reader sensor node, the system can show us the location information where the tag has been read. In monitoring point of view, we include four steps in the cold chain such as Manufacture, Inventory, Transportation and Retailing which simulate the whole life cycle of a product. In each step, there is a monitoring window that clearly shows the function of each step. We placed LED indicators to indicate whether the sensor node is working well or not, and to alarm whether the temperature is out of the range from preset interval. By using waveform chart we could clearly see the changes of temperature during monitoring process. We also designed a user interface which could help us to monitor the process visually. If the temperature is out of the range, it will also give the alarm for enabling proactive measures for our cold chain (Fig 4).

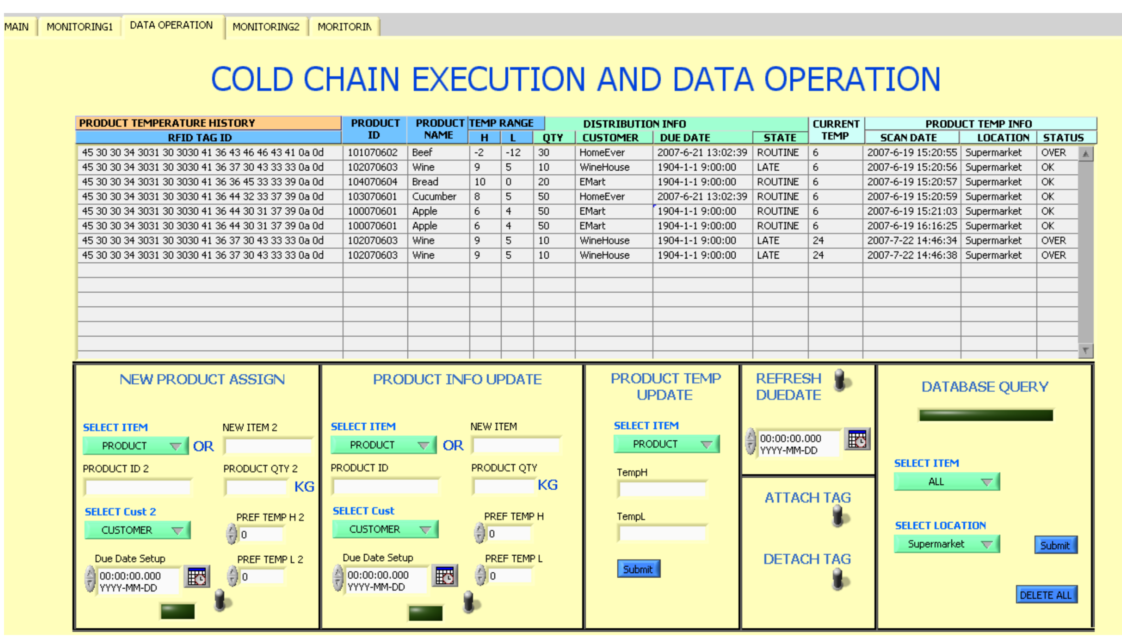

Fig.4. Cold Chain Monitoring System User GUI

6.0 Conclusion

Highly integrated and inexpensive smart nodes network is much cheaper and more flexible compared with heterogeneous network. Smart nodes read fewer tags and can be deployed densely as self-organizing WSN. They run autonomously and translate data information to the sink node. The gathered information is transmitted through multi-hops. Energy constraint is an extremely crucial problem when smart nodes are applied in industry because of battery consumption. Currently ZigBee protocol is considered as the best candidate as it satisfies reliable, low cost, low power consumption requirements [20]. For a large scale application, collecting a huge amount of data from the sensor nodes is also an issue to consider. Although we use one temperature sensor in each location, it is also possible to deploy more than one temperature sensor for multi-temperature modeling. We have presented a design model for the cold chain traceability and the concept of the cold chain. After that, the hardware and software architecture for WSN and RFID integration platform is described. Then, we have mentioned a prototype of a traceability system using Nano-Qplus wireless sensor networks and user friendly LabVIEW working environment. RFID/WSN integration works are also introduced as a challenging area of research.

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