**TEMPERATURE MONITORING USING RFID**

**GOWRI PUTCHA**

A Project

Submitted to the Department of Computer Science

In Partial Fulfillment of the Requirements for

The Degree of

MASTER OF SCIENCE

IN

COMPUTER INFORMATION SYSTEMS

PRAIRIE VIEW A & M UNIVERSITY

COLLEGE OF ENGINEERING

PRAIRIE VIEW, TEXAS

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**ABSTRACT**

Temperature Monitoring Using RFID

(December 2009)

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Student Advisor: Dr. Akhtar Lodgher

The goal of this project is to come up with an overall process design for RFID - based temperature monitoring in blood bags and simulate various scenarios to see if the new process design can handle them. Moreover, this system will provide more information in real time regarding how the blood is organized according to its characteristics (Rh, type, date, etc). The device is based on RFID, which is the method that best suits the needs of these types of health materials.

In order to come up with overall process design for RFID, we studied the process design for RFID based temperature monitoring in blood banks, food supply chains, fish logistics chains, ware houses and beer cans. Within this project, we identified the technologies used and compared the pros and cons of each kind of technology. We also completed a comparative analysis of the technologies used in monitoring temperatures in blood bank.

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**SECTION 1**

**INTRODUCTION**

**1.1 Project Background**

RFID based temperature monitoring is gaining importance in various supply chains. There are many factors impacting this, such as legal regulations, growing boundaries, mission critical processes, just to name a few. To understand these various systems, we choose five different systems and studied them thoroughly in order to identify the technology.

The objective of our studies of the Blood Bank was to monitor the temperature of the blood bags, because this temperature data has a direct relationship with the quality of the blood inside the bag. Also, some of the other functions which would be interesting to know are the RH (Rhesus) type of the blood, the donor name, and the collection date. The hope would be that by providing complete information about the origin of the blood bag until it is consumed, better safety would be achieved. The unique information related to the blood bag is provided through the use of the RFID technology, while the real time temperature data is made available by the use of intelligent sensors. These sensors act like a simple “Data Acquisition System,” which collects the temperature data and stores it. This data helps in assessing the quality of the blood in the bag. It uses RFID technology to transfer this information whenever it is required. These sensors can give a complete picture relating to the quality of the blood, from the time of blood collection from donors, through the process of storage and transport, until the blood is finally transfused to the end patient.

The next implication for this technology involves the Food Chain. The “World Health Organization” reports that around 1.8 million people die each year due to food and water borne diarrhea diseases. This clearly suggests that there is an urgent need to monitor the quality of the food consumed, and this should be viable for the end users. With the current trends showing increased consumption of package frozen foods and growth of the food processing and storage industries, the original need to monitor food quality increases dramatically. The quality of the food consumed can never be compromised and we need a technological device ensuring the quality of the delivered food.

In recent years, the food supply chain has become a complex process, due to advancements in food processing technologies. Throughout history, people used to consume fresh foods available locally, but now recent studies indicate that around 70% of the foods consumed by Europeans are frozen foods. These food chains not only involve different locations, but even different countries and continents. As food processing technologies improve, so must the logistical services available to ensure food safety and freshness. The growing trend of frozen foods adds an additional burden to the logistics industry. A majority of the food processing industries are SMB; therefore, they cannot afford to maintain their own logistics. So they use the services of a third party logistics provider. Logistics providers now need to ensure the timely delivery of the food, under proper temperature and humidity requirements. RFID technology provides object identification. So now, with temperature and humidity data, we have sensors which can be monitored to represent the quality of each and every individual food packet, rather than the quality of an entire shipment. This kind of granularity is what is needed in a typical food processing industry, where this data is crucial.

The logistics of transporting fish comes next, with its own problems. With the advances in food processing industry and because of its healthy properties, consumption of sea food is growing rapidly. Despite this growth, there are still lots of challenges to be overcome, as the source of raw materials and the final consumption bridge is growing and increasingly spanning the continents. The logistics chain for cold food is growing more complex because of regulations and mandates by different countries regarding the quality of the food supplied through the cold chain. The quality of such food is directly affected by the conditions of the food during the logistics process, which mainly involves maintaining particular temperatures. Usually the food packages are frozen during intercontinental transport, and they need to remain in that state until they are consumed by the end users. This puts a lot of difficulty and infrastructure barriers at various points during the supply chain, namely, storing, transport, handling, and delivery of the food products.

All such constraints apply to any domain we can think about. A generalized solution does not fit all the industries and domain. The requirements and the needs are totally different and the priorities vary widely in each domain.

The main technologies involved were the smart tag and the ambient tag. An ambient tag is enriched with more features to support different capabilities. So obviously the cost is also higher. In this paper, we analyze the process flow of each of the use cases in detail. Finally, we try to understand the gaps and the possible areas of improvement. From this investigation, we came up with an overall process design for blood bags by complimenting each technology and gaining the best of both worlds.

**1.2 Project Report Organization**

The organization of the project is as follows. **Section 1** provides the project background and discusses the scope of this project and briefly explains the requirements and specifications of the project. **Section 2** discusses the technologies used in five different domains: blood bank, food supply chain, fish logistics, warehouses, and beer cans. This section explains the core RFID technology and compares the pros and cons of the different types of technology. **Section 3** discusses the comparison of the technologies of Smart Tag and Ambient Tag. This section explains the benefits and applications of these technologies and describes their contribution to this project. **Section 4** presents the comparative analysis of RFID based temperature monitoring in blood bags and simulates various scenarios to see if the new process design can handle them. **Section 5** explains the analysis of the project. **Section 6** explains the comparative cost analysis of Smart Tag versus Ambient Tag for different scenarios.

**1.3 PROJECT SCOPE**

 The project scope includes the explanation of the existing system with its limitations, a proposed system with features, and an explanation of the overall process design for RFID based temperature monitoring in blood bag. Additionally, various scenarios were simulated in order to see if the new process design can handle them.

**SECTION 2**

**BACKGROUND REVIEW**

**2.1 TEMPERATURE MONITORING USING RFID IN BLOOD BANK**

The end to end process flow for a RFID based temperature monitoring system can be visualized as shown in the figure 1.As you can see, there are three independent but interacting processes that could be identified in a typical blood bank.

**Blood Collection Process.**

This is a fairly known simple process; an additional step is adding the RFID smart tag.

* Donor registers with the hospital.
* Blood test is done for quality and Rhesus (RH) determination.
* Once the donor is approved for blood donation, donor is taken to the blood collection unit and a unit of blood is collected.
* This blood bag is then tagged with the RFID smart tag, which apart from identifying the blood bag attributes like Rhesus (RH) type, donor information, and date of blood collection, place and monitoring temperature data of the blood bag.
* Once tagged, blood bag sent for storage.

**Blood Storage**

This process interacts with both the blood collection and blood transfusion and acts like a bridge between them. Apart from this, it also interacts with external blood banks for requesting blood bags in case of non – availability.

**Blood Transfusion**

* Patient registers with the hospital.
* Doctor assesses the patient and sees if a blood transfusion is required.
* Doctor sends a request to storage for a blood bag suiting the patient’s need.
* Transfusion process checks if blood bag is available within its storage. If available send the blood bag to the transfusion unit. If not available request the external providers (blood banks) for blood and delivers to transfusion unit.
* Once the blood bag arrives, doctor checks the temperature data of the blood bag, using the RFID receiver and his/her PC.
* If the temperature is within limits, then the doctor approves the blood bag for transfusion. If not, doctor rejects it and requests a new blood bag.
* Finally, the blood bag is transfused to the patient.

No

Donor Registration

Verification

Blood Collection

RFID Smart Tagging

Sent for Storage

Blood Tests

RH determination

Blood Collected from Donor

RFID Smart Tag is attached with Blood Bag

Sent for Storage

Receive Blood Bag

Refrigerated Storage

Request from External Blood Bank

Send Blood Bag

Check Availability

Yes

No

Send Blood Bank

Patient Registration

Request Blood from Storage

Check temperature data

Transfusion

Blood Bag, Good for Consumption?

Check temperature data from Blood Bag

Reject and Request for New

Yes

Blood Collection

Blood Storage

Blood Transfusion

**RFID Based Temperature Monitoring in Blood Bank**

**Figure 1: End to End Process Flow – Blood Bank**

**2.2 TEMPERATURE MONITORING USING RFID IN FOOD SUPPY CHAIN**

A typical food supply chain is shown in figure 2.

Manufacturer

Supplier

Logistics Provider

End User/Consumer

End User/Consumer

End User/Consumer

Distributors

Supply Raw Material

Orders Raw Material

Send Shipment

Distributes to

 Distributors

Delivers to Customers

Delivers to Customers

Delivers to Customers

**Figure 2: Typical Food Supply Chain**

As one could notice from figure 2, there are a lot of interdependent parallel processes involved in a typical food chain, and there are many stakeholders involved, with consumer safety being the important focus here. The core idea is to ensure that the cold chain remains at the appropriate temperature as food travels from the manufacturer to the consumer. This figure illustrates the complexity of the process, and emphasizes the need for RFID technology in the food safety field. The different parties involved in a typical food supply chain are the food manufacturers and the food processing industry, and both have a strong mandate to provide safely cold food for their customers.

**RFID Based Approach**

The main aim is to consolidate and integrate the existing models to provide a scalable, manageable network for transportation without compromising the quality of the transport offered. The main criteria are listing below.

1. Effective control and monitoring temperature during transport
2. Reduce TCO (Total Cost of Ownership) and operational costs for the logistics provider.
3. Flexibility of truck usage.
4. Unified interface for customers.

This is a multi temperature joint distribution system where the transport and storage can handle varying temperature requirements, with the help of temperature controllable storage containers. So now a customer will have a uniform interface for all their different requirements. A simple block diagram is shown in figure 3.

Supplier

Manufacturer

Multi Temperature

Refrigerated Trucks

Refrigerated Depot

Customer

Distributor

Retailer

Food Chain Stores

Supplier

Supplier

Manufacturer

**Figure 3: Simple Block Diagram**

All the four models are unified in a way as shown in figure 3. The customer no longer needs to know about the different service models. They just set the requirements for the package and send it to the logistics providers. Logistics providers take care of assigning these packages to different storage containers and transporting them in general trucks. The benefit to this program is that there is no longer a need to transport food in trucks that maintain only one temperature. By sharing common transport and infrastructure, companies can save money and consumers can be further assured of their food safety.

A simple block diagram of a storage container is show in figure 4. It has a RFID module, which provides a unique identification for the container. There is a configurable temperature controller, which can control the temperature of the container either locally or remotely. This system also has connectivity through GSM (Global System for Mobile) / GPRS (General Packer Radio Service), by which it can communicate with the network. The food packages collected from different suppliers are grouped according to the temperature requirements and assigned to different storage containers. Each of them has their own temperature controller, which can be controlled and monitored centrally. RFID enables unique identification of this container and its contents.

**GSM / GPRS**

**Storage Container**

**RFID**

**Temperature Control**

**Figure 4: Block Diagram of Storage Container**

**Food Processing**

The concept for enabling the monitoring is illustrated in figure 5.It starts at the food processing location. Usually the food processing location receives the raw materials and the quality assurance (QA) also ensures the quality of the raw materials received. A similar approach is followed with the suppliers, but due to the transformation of the raw material into a food product, imposes a discontinuity in the monitoring of the raw material against the end product This is an issue that is up to the quality assurance (QA) of the food processing industry. If the raw material itself is not of good quality, then it imposes constraints on the life of the food products and has to be dealt with very carefully. Here in this process, after the food is processed and packed, the RFID ambient tag is added by the quality assurance process. The real monitoring of the temperature starts, and the ambient tag collects the data every two minutes and stores in it memory. Note that each package may have a different set of constraints, such as temperature, time etc. All of this data along, with the packaging date and the dispatching identifier are all added to the tag and sent for delivery. Even the logistics provider can use this ambient tag data to ensure quality delivery and monitor the temperature during transport.

**Logistics**

The logistics providers pick up the transport packages from the original storage depot, where the manufactures leaver their orders. The logistics provider needs to ensure that the temperature and time constraints are met during the delivery initially. Once they receive the order, they will determine the storage and routing of this package, based on the transport requirements. A priority and category is assigned to each shipment and these packages are transported according to their safety specifications. Once the packages reach the destination depot, the distributor is informed about the package and will be given certain time for pick up of the goods.

The recipient may opt to do a quality check while receiving the package to ensure that the package was transported under the proper temperatures. This is accomplished by a RFID reader and the PC. The reader will gather the temperature data and decide on the quality of the food packet. The distribution process is shown in the below figure 5.

**Food Distribution Process**

This process is a consumer driven process; since it is a food processing chain and the goods are perishable and cannot be stored for a long time, the distributors do not keep a huge inventory. Rather, they order “just-in-time,” based on consumer orders. They only maintain a threshold inventory, which is only large enough to fit in their freezers. When a consumer order reaches the distributor, he/she first checks with his local storage depot for stock. If the stock goes below the threshold inventory, then he/she places an order to the manufacturer for the next delivery. The distributor takes the packages from the depot and does the quality audit to determine the quality of the food package. The food packages collected from different suppliers are grouped according to their temperature requirements and assigned to different storage containers. Each of them has their own temperature controller, which can be controlled and monitored centrally. RFID enables the unique identification of this container and its contents.

Figure 5 describes the various process involved in food supply chain management and describes the relationship between them. From distribution to food packaging and manufacturing to logistics, all the process are interrelated and, in most cases, automated. RFID helps by creating visibility on both the time and quality dimensions of the supply chain.

No

No

Check the Quality (QA) & Process starts

Food Processing

Receive Raw Material

Receive Transport Order

Food Processing

Logistics

Food Distribution Process

**RFID BASED FOOD SUPPLY CHAIN MANAGEMENT**

Raw material available

Yes

Food Packaging

RFID Ambient Tag & Temperature & Humidity monitoring starts

Delivery

Determine Storage

Route to Destination

Deliver to Destination

Receive Consumer Order

Stock available?

QA

Meets Quality Standards?

Deliver to Consumer

Yes

Yes

No

**Figure 5: Overall Process design in Food Supply Chain Management**

The flow chart involving multi – temperature transport is shown in figure 6. Now the food suppliers directly deliver their goods to a nearest storage depot. The logistics provider takes care of grouping these goods and assigning them to proper storage units. The whole set of goods is divided into small packages, with different storage containers for different temperature requirements. Now these storage containers can be transported in any type of truck and stored in any way, since the temperature control is decoupled from the infrastructure. Furthermore, by using RFID and GSM technologies, the temperature data can be monitored anywhere during the life cycle of the transport, ensuring safety and increasing the confidence of customers.

Food Processing

To Nearest Storage Depot

Cold Storage Container

Multi Temperature Truck

Deliver to destination DDestination

Food Processing packages food and send to Nearest Storage Depot

Here Goods are assigned to storage containers, for different Temperature requirements

Storage Container is RFID enabled with GSM and GPRS for Network Connectivity

Multi Temperature Truck carries these Storage containers and delivers to the Destination Store

**Figure 6: Multi – Temperature Transport**

There are five major categories when controlling temperature and monitoring for the food supply chain: hot food above 600 C, fresh food at 18o C constantly, cold food 0 o C to + 7 o C, chilled food -2 o C to + 2 o C, frozen food below - 18 o C, and deeply frozen food below - 30 o C. All of these temperature requirements are taken care of by the ambient temperature depot.

**2.3 TEMPERATURE MONITORING USING RFID IN FISH LOGISTIC CHAIN**

A typical food supply chain for fish transport and logistics is shown in figure 7 in the following figure. It involves various factors involved in the end to end supply chain for fish in a cold chain. Usually the fishing is the start of this process. Fishermen go fishing in the seas, fish is caught using nets and brought to the shore. Fresh fish, thus brought from the sea, is immediately sent to the processing industry. In the processing industry, fish is cleaned and packaged into packages of various types and sizes. All of these packages are put into refrigerated storage and sent as a shipment to various distributors, with the help of the logistics providers. The logistics providers also handle these shipments through refrigerated storage and transport and finally deliver them to the distributors and the wholesale dealers. During this time, the transport involved could be truck or train or flight. But this transport needs to be refrigerated for the safety of the food. Finally, the distributors receive the shipments and deliver the packages to the consumers on a demand basis. Until delivery to the end consumers, the fish packages needs to kept under refrigeration. As understood from the process, there are various parties involved in this supply chain and there are handovers from multiple people who are involved in this chain. Also the quality of the delivered fish package depends on the assurance that temperature was maintained.. Exposure to higher temperatures could result in infection of germs on the food. This could potentially result in harm to the consumers, which is not tolerable. So this is a critical process, where the temperature of the fish packets needs to be maintained at low temperatures. The involvement of various parties and different geographies poses a significant challenge to ensure the safe transport of the package to the end consumer. In such scenarios there is no guarantee that the food packages are safe. The only way to assure the quality is through monitoring the temperatures it has encountered during its lifecycle. Absolute data about temperature and time will directly reflect the quality of the fish package. Here, we propose a concept based on RFID Smart tags to monitor the temperatures in a cold chain, in this case, fish.

**Fisher Man Fishing**

**Process Industry**

**Logistics**

**Whole Sale Distributor**

**Consumers**

**Figure 7: Food Supply Chain for Fish transport & Logistics**

**RFID Based Process Design**

The figure 8 illustrates the process of fish products reaching the end consumer. First, a fisherman catches the fish, and brings his catch to shore to be delivered to the process industry. No monitoring can be done here, since the fish are not yet packed. They are sent in containers to the industry for processing.

**Processing**

A processing industry has lots of sources of fish from various fisher men, and all of them deliver the fish shipments to the industry. The collected fish are sent for cleaning and grouping according to species type. The fishes are now packed into packages of various types and sizes based on the product specifications. To ensure the quality of the fish and to monitor them, an RFID smart tag is tagged on to the package. Now the packages are grouped into shipments and delivered to the third party logistics providers for delivery.

**Logistics**

A logistics provider transports to an industry with the fish held at their required temperatures. They provide refrigerated and non-refrigerated transports. The received package is sent to refrigerated storage. From storage, these are dispatched to the proper end destinations using refrigerated transport using trucks, train or flight. At the destination, these are again stored in refrigerated storage. Either the wholesaler collects it from the warehouse or it is delivered to them directly. In this case, the wholesaler needs to have proper cold storage.

**Delivery**

The distributor gets the fish packages from the logistics providers. Now they check for the quality of the received fish packages, with the help of a RFID reader and computer. The RFID reader will read the temperature data from the RFID smart tag embedded into the fish packet. The data will be sent to the computer and it displays the temperature of the fish in the form of graph. If the temperature is well maintained during its life cycle, the distributor decides to deliver the packet to the consumers. The overall process diagram for RFID based temperature monitoring in a typical fish chain along with the interactions is shown in figure 8.

Fishing

Grouping

Dispatching

Receive Fish

Fish Processing

Send Transport

Receive Package

Refrigerated Store

Destination Store

Deliver

Fishing

**RFID Temperature Monitoring in Fish Logistics**

Receive Package

Check Quality

Package

Deliver to Consumer

Fish Packaging

RFID Smart Tagging

Refrigerated Transport

Processing

Logistics

Wholesaler

**Figure 8: RFID Temperature Monitoring in Fish Logistics**

**2.4 TEMPERATURE MONITORING USING RFID IN WARE HOUSE**

We will discuss the RFID based temperature monitoring in a warehouse. The overall process design using RFID is shown in figure 9. A ware house is a storage space, used by manufactures, exporters, transport logistics providers, importers, wholesaler etc. Goods are stored in the warehouse as packages and stored for certain time under certain temperature constraints and finally removed from warehouse and sent for delivery.

Goods packages are received along with their temperature constraints by the warehouse management. Ambient tags are placed on the packages; these tags are configured to monitor the temperature of the package at certain time intervals as required by the package. There is also a maximum time allowed for the storage of each package inside the warehouse, before which it needs to be shipped out. This is denoted as TTL (Time to Live). This is basically an eviction policy to ensure that goods that enter the warehouse first leave the warehouse first (a FIFO – First in First out Policy). This capability is also provided by the ambient tags. These tags will be configured to alert the warehouse management about the starvation at the end of TTL.

Once the package is tagged and activated with TTL, it will be sent to storage at the required temperature setting. The package stays there until someone picks it up for delivery. The delivery process varies depending on the use case, but all finally boils down to moving out this package from the warehouse. The ambient tag on the package is already monitoring the temperature of the package periodically and updating its memory. Also, the TTL timer is running inside the tag to ensure that the food product is not stored for too long.

Receive Package

Get Temperature Requirements

Add Ambient Tag to Package

Set Time to Deliver

Sent for Storage

If time to deliver exceeded?

Trigger Alert

Yes

No

Pickup Package

Check Temperature

Remove Tag

Send for Delivery

**Figure 9: Ware House Process Design**

For instance, if the package is not picked up within TTL (which means the tag is not deactivated within TTL), the tag will create an alert to the warehouse management, so that the management can arrange for the delivery of this package on a priority basis. But under most circumstances, the packages will be picked up within the TTL; at the time of pickup the ambient tags on the package will be scanned to read the temperature data. The reader will display the accumulated temperature data of the package for the time it has been stored in the warehouse. With this data, the warehouse management can easily find out whether the constraints for the package have been met by the warehouse temperature regulated storage system. After this process, the tag will be deactivated and sent for delivery. This tag can then move to another warehouse or distribution center as needed.

**2.5 TEMPERATURE MONITORING USING RFID IN BEER CANS**

End user consumers care deeply about the temperature of their beer. Temperature monitoring in beer cans, therefore, can successfully monitor beer through the use of temperature sensitive labels or tags. Temperature sensitive tags are adhesive tags which can be placed on any object whose temperature needs to be monitored. These tags display a color change, which is irreversible to indicate the exposure of that object to higher temperatures. These tags can also be preset for some amount of time. The detailed process flow diagram is shown in figure 10.

 The first step in the process is the preparation of the temperature sensitive tag; this step depends on the supplier on the tag. Each tag manufacturer uses certain temperature properties of chemical compounds for temperature monitoring, depending on the ideal temperature for the particular product. Preparation of the tag ranges from refrigerating the tag before usage for about 24 hours or heating up the tag to 40 – 60 degree Celsius and maintaining it in that temperature for about 30 minutes to an hour. This procedure is dependent upon the choice of the tag manufacturer.

Preparation

Tag it on Beer Can

Preparation of the temperature sensitive tag depends on the supplier. Some tags can be directly put on the beer cans, but some tags needs to be heated to certain temperatures before they can be used.

After tagging, Beer cans are sent out through Logistics.

Check for Color change?

Accept

Finally, after spanning across different transports, and warehouses, it reaches the final destination, which is either a distributor or a retailer

Yes

No

This change is also dependent on the Tag supplier. The color changes are specified in the tag manual. It will indicate the Original Color and the color after the exposure to higher temperature for certain time.

Beer Can in Supply Chain

Reaches Destination

Reject

**Figure 10: Beer Cans Process Design**

After the tag is prepared for temperature monitoring, it now becomes ready and can be directly put on the beer cans. After pasting this tag, the beer cans are further grouped into shipments and sent to the logistics provider for delivery. During this period, the beer can goes through various trucks, get stored temporarily in warehouses, and is handled manually or electronically at various places before finally reaching its destination at either a distributor or a retailer. Once the beer cans reaches their destination, the end user checks the color of the tag for any exposure of the cans to higher temperatures for too long of a period of time. The color change is also specified by the tag manufacturer and it is dependent on the tag used for this process. The color changes on exposure to higher temperatures may be from orange to white or from gray to blue. The various color change combinations depend on the underlying chemical compound used by the tag manufacturer.

The distributor checks for this color change specified in the tag. If there is no color change then it means the beer cans have been safely maintained at their proper temperature and hence they accept it. If there is a color change, it indicates exposure to high temperatures, so the end user rejects the can. The number of rejections per area will throw some light on which area in the supply chain is having problems in the transport. This can improve the transport of beer cans with 100% acceptance rate.

**SECTION 3**

**COMPARISON OF TECHNOLOGIES**

**SMART TAG & AMBIENT TAG**

**3.1 SMART TAG TECHNOLOGY**

In this section, we discuss the various technical features and the complete design of the RFID Smart Tag. The smart sensor is the one which can typically do multiple functions, in this case it can monitor temperature and act as a RFID tag. The block diagram of the smart tag is shown in figure 11.

Micro Controller (μC)

In built ADC (PIC 16F)

Data Memory (EEPROM)

2.45 GHz

 (RF Protocol)

125 KHz

LF Transceiver

Temperature Sensor

(PT 100)

Battery Status

Antenna

**Figure 11: Block Diagram of Smart Tag**

With advances in technology and production at the field of application of tag, a new, multi – functional and anti counterfeiting smart label has begun to be widely used. It will bring a new tag system. First, the smart tag features and the application of smart tags (smart labels) was also known as radio frequency identification tags, which tagged the field of high – tech products, which are now packaged in the product and are gradually replacing traditional product tags and bar codes. Smart tags are the tags in the field of New Horizons, which has the tag, and goes beyond the traditional functions. Smart tags contain radio frequency identification technology (RFID) electronic tags, hidden or open indicator or trademark protection situation prompted products sensors. Smart tag with small, thin, flexible (the thickness of the product can be achieved around 0.1mm in size from a few millimeters to nearly 20 centimeters and are free to twist, bend).

**Activation Method**

A PIC16F series microcontroller forms the heart of this tag; this is the microcontroller from PIC. These are 8 bit micro controllers with inbuilt peripherals like ADC, Timers etc. The Microcontroller is interfaced with the Low power temperature sensor (PT100) in the ADC (Analog to Digital Converter Channel). The Microcontroller has an inbuilt ADC channel. The RF interface is provided by the Zig bee (2.45 GHz) and the Low frequency transceiver (125 KHz) for low power control signals. Usually the Zig Bee transceiver is disabled, and the smart tag waits to receive the control signals at Low frequency transceiver (125 KHz). This channel is used for Activation, De-Activation, change data transfer mode control signals. All the data is sent through the Zig Bee transceiver, it can form adhoc network with the nearby tags and provide traceability. Whenever a control signal is received, the microcontroller is interrupted. The microcontroller is interfaced with the external EEPROM (Electrical Erasable Program Read Only Memory) for storing the temperature data. Since the microcontroller has eight different analogs, the sensor can be interfaced with this microcontroller. It is enabled within the hardware timer, which can run even during the sleep and consume very low power. This timer wakes up the microcontroller for measuring and storing temperature data.

**Smart Tag State Diagram**

The smart tag operates in four different states as depicted in figure 12.

Inactive

Active

Initial State

Control Activation signal

Switch to Data Collection Mode

Sleep

Data Collection

On Deactivation Control Signal

Periodically sample temperature data

**Figure 12: Smart Tag State Diagram**

While the initial state of the smart tag is inactive, once the tag is powered up; it remains in the inactive state. In this state, the controller does not do anything. It just sleeps indefinitely, until it is interrupted by any control signal for activating the tag. Once the activation signal is received on the low frequency, the microcontroller is interrupted and goes to the active state. In active state, the microcontroller starts to measure the parameters in periodical intervals and store these parameters in memory. This interval, the tag’s ID, and the time of activation is sent to the tag at the time of activation. Once the tag gets activated, it becomes eligible for data collection at fixed time intervals. The activation parameters are the ID for the tag, activation time stamp and the sampling time. Microcontroller initializes its timers for periodically doing a task at this sampling rate. This timer task performs reading from the temperature sensor and storing it in memory. From data collection state, the microcontroller goes into a sleep state and data collection timer task is completed. It remains in the sleep state until the sample rate timer interrupts the microcontroller for data collection state. When in a sleep state, the microcontroller may receive control signals for data transmission or tag deactivation. During data transmission control signal, the microcontroller enables the Zig Bee module and transmits the collected data to the reader. When receiving a deactivation signal, the microcontroller clears its memory and timers go to its initial state.

**Smart Tag Process Flow – Data Collection**

The process flow diagram for the data collection mode is shown in figure 13. After the activation signal is received, the microcontroller receives the activation parameters: tag ID, activation time stamp and the sampling time interval. Once initialized, it starts monitoring the temperature data in defined sample times. Once the tag is activated, the microcontroller initializes the timers (which will wake up the microcontroller after the sampling time). The timer duration is the sampling time sent during the activation. Microcontroller initializes its timer for the given delay and goes to its low power operating sleep mode. This timer consumes very low power and can run even when the microcontroller is in sleep mode. Once the time overflows after the delay, the timer interrupt is executed, which reads the temperature data and writes to the EEPROM. After the task is finished, the timer is reloaded and the controller again goes to sleep. This process will be repeated until the tag goes into an inactive state.

Initialize

Write ID

Wait for Smart Tag Activation

Start Monitoring

Write Activation Time

Write Sample Time

Read Temperature

Write to Memory

Go to Sleep Mode

Initialize Timers

Processor Wakeup

Yes

No

**Figure 13: Smart Tag Process Flow Data Collection**

**Smart Tag – Deactivation Process**

The deactivation sequence of the smart tag is show in figure 14.

Smart Tag – Functioning

Send ID

Request for Data?

Send Data

Clear Memory

Clear ID

Go to Sleep

Prepare Deactivation

Deactivate or Continue to Collect Data

Yes

Yes

No

No

**Figure 14: Smart Tag Deactivation Process**

During the deactivation signal, the smart tag is already in the data collection / active mode. If the tag is already inactive, then this sequence does not make any sense. During active mode, the tag will continually monitor the temperature of the object and store it in memory. During this operation, a reader can interrupt the tag to read the tag ID and tag data for processing. If the reader thinks that this tag can be cleared up for re use, then it issues a deactivation control signal. On receipt of the de-activation signal, the smart tag starts its process sequence for cleaning it up, so that it could be reused again for different purposes and environments. This sequence involves: clearing its identifier, clearing the memory of the data collected since its activation, and clearing the timers for executing the timer tasks for data collection. After this, the smart tag goes into an inactive state and stays there, until it receives an activation control signal.

**Smart Tag Advantages & Disadvantages**

**Table 1**

|  |  |  |
| --- | --- | --- |
| **S.No** | **Advantages** | **Disadvantages** |
| 1. | Temperature monitoring and RFID in a single tag. | Initial overhead cost associated with the tag. |
| 2. | Low power consumption can be used for 30 – 60 days, depending on the battery life and sampling rate needed. Higher retention rates can be achieved with lower sampling cycles. | Although can be reused, there is still a maintenance cost associated with it, like recharging batteries, antenna life etc. |
| 3. | Provides temperature data along with the accurate time line.  | Data tightly coupled with individual object and hence will be a huge monitoring effort when used in a high volume supply chain scenarios. |
| 4. | Provides data for individual objects. Suitable for monitoring the supply chains where the objects are mostly transferred individually and in mission critical supply chain where the temperature needs to be strictly maintained, like blood bags. | Suitable only for select use cases, for others it is an overhead than of any value it could add. |

**3.2) Ambient Tag Technology**

We will now discuss the various technical features and the complete design of the ambient tag. Ambient tags are advanced active RFID tags, which are self-locating in an ambient network and can monitor the object’s various properties, such as temperature, humidity, CO2, and weight. Hence, the ambient tag enables the following in a RFID based supply chain:

1. Check: - Can monitor the objects by adding sensors like temperature, humidity etc.
2. Track: - These tags are self locating these can be tracked real time in an ambient network (Real Time Location Sensing – RTLS).
3. Trace: - It stores the historical sensor data in its memory so that it can be processed later.
4. Protect: - The data is protected within the ambient network and it has intelligent intrusion prevention.

The tag is also powered with additional processing capabilities so that the users can configure some business rules which can be executed in real time; this is called dynamic event reporting. For example, in the case of a food supply chain, each shipment has a certain life time. If the shipment is lagging in time then a alert can be triggered to the logistics to prioritize the handling of the particular delayed shipment, hence preventing supply chain starvation. The block diagram of ambient tags is shown in figure 15.

**CPU**

**Object Identity**

**2.44 GHz Communication Channel**

**Peripheral Interface – SPI 12C, 1 - Write**

**Temperature**

 **Sensor**

**Humidity**

**Sensor**

**Integrate**

**Other**

**1 MB Storage**

**Figure 15: Block diagram of Ambient Tag**

**Ambient Tag Technical Specifications**

**Table 2**

|  |
| --- |
| **Technical Specification** |
| Operating Range | - 400 C to + 850 C |
| Frequency | 2.44 GHz |
| Battery Life | 3 – 5 years |
| Dimension | 60.0 \* 56.6 \* 14.0mm |
| Antenna | Integrated Omni directional |
| Weight | 44 grams |
| Power | Non – rechargeable 2 \* AAA lithium |
| Storage | 1 Mega Byte Storage with file format system |
| Sensor | Built in Temperature Sensor, humidity, |
| Warning | Low – Battery |
| Range | Typical read range 30 m |
| Locating | Self Locating in a Ambient Network |
| Interface | Support for various peripheral interface – SPI, 12C, 1 – wire interface. |

**Working of Ambient Tag**

 The basic functionality of the ambient tag is that it is providing object identification and temperature monitoring. When the tag is placed on object, the identifier is written onto the tag. The user can also configure some business rules like sampling time, dynamic event reporting and so on. Once these settings are configured, the ambient tag starts to collect temperature data and additional sensors data is configured and stores it in memory. After this cycle, it waits for a business rule to trigger this process again. For example, a user may want to monitor the temperature every 10 minutes. Then, a business rule is configured, asking the tag to store the temperature for every 10 minutes. The processor within this tag executes the temperature measurement. Storage process for every 10 minutes is shown in the below figure 16, also this process is common for any type of sensor.

**RTLS – Ambient Network**

 The main advantage of the ambient tag rather than the dynamic event reporting and monitoring is the ability to self-locate within an ambient network. Ambient tags are capable of forming an Adhoc energy efficient mesh network automatically when they are deployed. An ambient network is actual mesh network formed by these various ambient tags. Since the range of the ambient tag is 30 m, wide coverage may not be possible in a typical supply chain spanning across continents. Hence a micro – router is placed within an ambient tags network, which can by itself form a self controlled network. The micro routers are capable of communicating over long distances and also can form Adhoc mesh networks, so that they can communicate with the ultimate receiver, which is the central administration.

Measure Temperature

Store it in memory

Wait for next cycle

Store sensor data in memory

Wait for next sampling time, based on business rules configured

Time to sample?

Yes

No

Start measuring temperature

**Figure 16: Storage Process**

A typical network formed between the ambient tags with the micro router is shown in figure 17. This network is totally flexible. Ambient tags can communicate to different micro – routers and areas of a self – contained network depends on the location of the tags and the router. The network formation is done automatically by the tag itself using energy efficient algorithms.

Ambient Tag

Ambient Tag

Ambient Tag

Ambient Tag

Ambient Tag

Micro Router

**Figure 17: Network between Ambient tags with Micro router**

**TLS – Ambient Network**

Micro routers to central administration – Adhoc mesh network. The mesh network formed by the micro routers ultimately reach the central administration, which request for information from a tag or receive data from a tag, which is shown in the figure 18, it should be noted that central administration is again a micro router but with additional capabilities to control and receive command and data.

Micro router

Micro router

Micro router

Micro router

Central Administration

**Figure 18: Adhoc Mesh Network**

The process of receiving data from the ambient tag is shown in figure 19. Initially, the ambient tag waits for a signal from the network, either directly from the micro router or from a neighboring ambient tag through the mesh network. The central administration, in this case, may want to check the location of the particular shipment, so they will issue a command to this shipment identifier to the network. The command is delivered to the various micro routers which forms a network in a adhoc fashion and delivers the message to the intermediate receivers which finally reaches the intended ambient tag. Once the tag receives the signal requesting location data, it first finds the strength of the received signal and then computes 3D location information according the signal strength and transmits this data to the neighbor. The destination is of course the central administration. This data traverses the path of the request in a reverse way to reach the ultimate destination. From the traversed path, the central administration will easily identify the location of the tag (shipment) in the ambient network.

Wait for Request

Signal Received?

Measure signal strength

Compute 3D location

Send to micro router

Wait for signal from micro router

Measure signal strength (RSSI)

Send the location information to micro router

Yes

No

**Figure 19: Receiving data from Ambient Tag**

**Ambient Tag Advantages & Disadvantages**

**Table 3**

|  |  |  |
| --- | --- | --- |
| **S.No** | **Advantages** | **Disadvantages** |
| 1. | Temperature monitoring, humidity monitoring, RFID, RTLS in single device | Initial overhead cost associated with the tag. |
| 2. | Provide the accumulated data with the time line | Provides data for a unit of objects (Individual tracking is not available) |
| 3. | Provides data for a whole container, data relevant for all the objects in the container. Example pallets, storage containers etc. | Generalized data can be sometime not applicable for mission critical scenarios, hence these tags also favor only certain kinds of scenarios.  |
| 4. | Self locating and option to integrate various sensors easily.  |  |
| 5. | Automated network formation and secure data transmission.  |  |

**SECTION 4**

**COMPARATIVE ANALYSIS**

The below table 5 show the key features of smart tag & ambient tag.

**Table 4**

|  |
| --- |
| **KEY FEATURES** |
| **Smart Tag** | **Ambient Tag** |
| Individual object tracking | Multiple objects tracking |
| Mission critical scenarios | Bulk scenarios. |
| Temperature data for individual objects | Temperature data for a pallet, container, shipment level. |
|  | Real time tracking (RTLS), configuring business rules (send automatic alerts for starvation time for a shipment etc.) |

Both these technologies have lot of advantages in their domain of use, but some disadvantages when tried to apply it generically. So now we will study about the co – existence of both these technologies and propose a generic concept for overall temperature monitoring using RFID in a supply chain.

**4.1 Envisioned Scenario in a Blood Bag Tracking System**

In blood bag temperature monitoring using RFID, we will try to use both of these technologies and try to find out the feasibility and the advantages it would offer in the existing system. We already studied the RFID based temperature monitoring in a blood bank using smart tags and ambient tag based monitoring in supply chain. Now let us briefly discuss how these two technologies complement each other.

1. The blood bag is not always transported as a single unit; these are collected and transported as one unit, let’s call it as one package. The package may contain one too many blood bags, and each of them can have varying properties, such as like RH or donor hospital.
2. The large volume of blood bags transported makes the monitoring of it difficult. Considering a case where there is hundreds of blood bags processed each day, it means that the reader has to process hundreds of this data (which is already in thousands) and provide a quality view of it. When the volume is high, this process becomes tedious.
3. It could be supply chain starvation. Starvation is defined as the time for which the item is not picked up by any one in a supply chain. Higher starvation time can lead to the expiration of the object, and therefore affect the shelf life of the blood bag. So it would be nice to have some kind of indication to the users, as to which packages are starving.
4. Considering the fact that the blood bags are sent in packages and transported through various transport vehicles, the temperature exposure to various blood bags in a container can be different and largely varies. This kind of scenario will particularly need an individual tracking of the blood bags.
5. Let’s take an emergency scenario where huge volume of blood bags needs to transported immediately, in such cases the emergency protocols come into place and in these situations more caution needs to be taken on the monitoring of the blood bags. These cases also require individual monitoring but we also need to consider that this is an emergency situation, so it would be better to monitor the whole container. In that case one would clearly favor the ambient tag.
6. If we consider another kind of emergency, where the volume of the bag transported is very less, but the time is critical. In such cases, one would clearly favor the smart tag. The reason being the monitoring overhead is little since the volume is lower also the container is not completely full.
7. Real time location sensing (RTLS) is gaining in more attention in supply chains these days. Ambient tags provide this capability. The real time location of an ambient tag can be queried any time in the supply chain; this would be very much necessary in case of emergency cases as well as the normal scenarios.

Let’s only take these scenarios and see how the combination of these technologies will solve these problems and add value to the existing system.

1. By adding an ambient tag to the package or transport container, it becomes possible to track the package as a whole, along with the temperature data and the humidity data. More over the real time data can be fetched using a mobile phone also.
2. As long as the whole package is well within the temperature limits, the individual blood bags inside the package will also be under the limit. So there is no point in monitoring the entire package. This will reduce the complexity in the administration in monitoring. Individual data becomes critical only when the packages temperature is exceeding the threshold limits. In such cases, the individual objects can be read for more details about their exposure.
3. An ambient tag can reduce the supply chain starvation for a package, by automatically alerting the administrator though a SMS. This alert can be configured during the activation itself, saying like after 30 days if the tag is still active and SMS needs to be sent. The tag also stores this information and after 20 days if the tag is still active, it will send a SMS to the administration, so that he/she can look at this and avoid starvation and this leads to efficient resource utilization.
4. This is also a critical problem, as stated in the (scenario ii), because sometimes it becomes necessary to scan the individual blood bags, if the transport nature is not reliable. The ambient tag itself can give a hint about the temperature; in those cases it is necessary that we use the smart tag also. This will help in assuring the quality of the blood bags.
5. This is a special case, where the large volume of blood is transported in very short time. Standards allow the blood bags to be exposed to room temperature (>10 degree Celsius) for about 30 minutes. For example, consider an emergency situation where thousands of blood bags are transported from nearby hospitals in a short time frame, it will not be possible to scan individual blood bags for temperature data. Hence it will be a safe bet only to consider the ambient tag data and proceed with the transfusion process.
6. This scenario also favors the use of ambient tags, but even in an emergency if the transport lead time is slightly higher, it is better to use smart tags along with the ambient tags for ensuring quality.
7. This capability is the core part of the ambient tag, irrespective of the scenario being emergency or routine transport. RTLS will be necessary for providing location information of the blood bags to the hospitals and the logistics provider which will help in planning and estimating the receivable time.

**4.2 Overall Process Before Transport**

We will now discuss the overall process design for the above described scenarios in general. The process before transport is pretty straight forward, as we discussed in previous designs. Initially, blood is collected in blood bags and sent to storage from the blood collection units. These blood bags are tagged with smart tags and sent for storage. The smart tag is activated and they start to monitor the temperature of the blood bag. The probability of error in this process is minimal because mostly this process happens in house or indoors. When there is a request for transport, these bags will be put into a transport container and an ambient tag will be added to the container. After this, the container will be sent for transport. By now, both the ambient tag and all the smart tag inside the container are activated and are monitoring the temperature of the container and the individual blood bag respectively. This is the overall process for blood bag temperature monitoring before transport. See the below figure 21.

Also, it is not necessary that the blood bags should be transported. It is very much possible that they are kept in containers in a local storage. Transportation comes only into the picture, when there is request from an external hospital or in extreme emergency situations. So in any case, the blood bags are collected in a container and kept in storage. Both the ambient tag and the smart tag are monitoring the temperature, the reasons and the scenarios will be discussed in the following sections.

**4.3 Blood Transfusion process**

When there is a need for a blood bag, it is requested from the storage. The storage unit takes care of delivering the blood bag from its own local store and arranges for necessary procurement procedures and ensures they get the blood bag in time to get it safely to the patient..

The received blood bag container will have an ambient tag, which is already monitoring the temperature of the whole container. On receiving the container, the ambient tag is read, to get the temperature information of all of the blood bags inside it. If the temperature of the container is well within the limits (<5 degree Celsius), then it means that the container has met the transport criteria for temperature and hence can be sent for consumption directly. This saves lot of monitoring time and effort on the part of the hospital; instead they would have been monitoring each and every blood bag inside the container for temperature data. This clearly explains the (scenario ii), as we discussed earlier. However, there are some cases, where the temperature of the container is relatively higher than the normal value. In those circumstances, there is a need for individual monitoring. The blood transfusion process flow diagram is shown in figure 20.

Receive Containers

Read Ambient Tag

Read Blood Bag Properties

Get Individual Blood Bag

Accept

Read Ambient Tag to get the Overall Temperature Information

Read Blood Temperature data, RH Type, Donor Information, Date of Collection, etc.

If Info, gives higher value. Check Individual Bags

Yes

No

Receive Containers from Transport

If Temperature is OK

Reject

No

Yes

**Figure 23: Blood Transfusion process**

For example, if the container temperature is shown to be 10 degree Celsius, it does not mean that all the blood bags inside the container are exposed to that temperature. So it is now imperative to check the individual blood bags and analyze the data on a case by case basis.

This also gives information about the individual donor, blood RH etc, so it’s not that this monitoring needs to be done only in high temperature cases, but that it also can be done when the load is not high or when there is a requirement to group the blood bags based on their properties, such as RH type or collection data This explain (scenario i).

For the emergency cases, which we discussed in (scenario v & scenario vi), this holds true. In this cases, the exposure time of the blood bag to high temperatures would be minimal and to avoid the monitoring overheads, it would be good idea to group the blood bags of same RH type and related collection dates together. This would so that it aide the emergency transfusion process. In this case, the ambient tag itself will carry information regarding the RH type of blood bag inside the container and a collection date common for the entire blood bag. For emergency cases, with less volume of different blood bag types, there is not much choice but to use both these technologies to ensure the proper quality and transparent transfusion process.

**4.4 Starvation Alert Process**

This is an interesting scenario described earlier in (scenario iii). This talks about the starvation time for blood bags when they are in storage. Blood bags are kept in storage only for maximum period of 30days. If their storage exceeds the allotted number of days, then the blood cannot be used. So it is very important to check the shelf life of the blood. So we would need to use a first in first out queue kind of distribution process to avoid starvation. But this is typically hard to achieve in a supply chain, because of various reasons.

This kind of first in, first out kind of line can be achieved through the use of ambient tags. If the ambient tags are configured to trigger an alert after certain time after activation, they can be used before they reach their use-by date. The tag will send out an alert if the tag does not get deactivated within that time. Internally, the tag will start a timer for the given time, when the timer overflows (which means the tag is not yet de – activated) then an alert is raised. This alert will be received by administration and they will ensure that this package is processed on priority before other blood bags. By using ambient technology, we can prevent the starvation of the blood bags and hence improve the usage efficiency. The following figure 21 show the starvation process is controlled.

**4.5 RTLS – Real Time Location Sensing**

This is again an important feature of the ambient tag, since they use the adhoc mesh network for location tracking. This location tracking use case was discussed (scenario vii), and this is very important for hospitals as well as logistics providers. Tracking the timely delivery of the blood bags in case of emergency is crucial. Once the ambient tag on the container is activated, it becomes eligible for RTLS functionality. When tag gets activated, the administrator can request information about the tag from the central administration. By the strength of the signal received, the ambient tag computes its location within the mesh network. This data can be collected during the activation lifecycle of the ambient tag. This is one of the key value adds to this system. Putting it all together, the entire configuration and the working of the business rules is represented in the process flow diagram in figure 21. Note that this is the preparation stage or the blood collection and configuring the ambient tag. The blood transfusion is a different process, and as mentioned above, this involves user interaction to make decisions by monitoring the central administration tool.

Collect Blood

Configure Ambient Tag

Blood Collection

Starvation Process

RTLS

**Figure 21: Over All Process Design**

Add Ambient Tag

Transport

Set business rules

Set time for starvation alert

Configure Ambient Tag

Signal received?

Send location data

Yes

No

Determine Storage

Sent for storage

Add bags to transport container

Starvation occurred?

Trigger Alert

Compute location data

No

Yes

**SECTION 5**

**ANALYSIS OF THE PROJECT**

**5.1 Why This Project?**

After studying different technologies and use cases, we identified few gaps in the existing systems due to disparate technologies. We tried to bridge the gap and try to solve the above mentioned problems in section 4.1, which would not have been solved with previous implementations.

**Value Addition**

Having discussed the various scenarios, these complementary technologies provide:

1. Ensuring the quality of the blood bags.
2. Temperature monitoring along the supply chain
3. Reduce starvation
4. Real time location tracking.
5. Individual as well as bulk monitoring capability
6. Reusability & End to end visibility & configurable alerts for starvation.
7. Real time temperature data & Real time Status (GSM)

**5.2 Comparative Cost Analysis**

**Table 5**

|  |
| --- |
| **Normal Scenario** |
| Let’s consider the scenario, assume that 50 blood bags are transported in a single container. This means that there are 50 smart tags plus 1 ambient tag per unit. |
| Cost of Smart Tag | Cost of Ambient Tag | Total Cost | Total Cost per scenario |
| US 4.89 \* 50 Blood bags = US $ 244.50 | US $ 64.49 Per Tag | Cost of Smart tag + Cost of Ambient tag. | US $ 292 per unit |
| So the total cost per scenario is US $ 292 per unit. |

**Table 6**

|  |
| --- |
| **Emergency Scenario** |
| Consider the scenario of emergency case, where it is only necessary to add the ambient tags. Considering a unit of 50 blood bags transported at once. We need one ambient tag per unit. |
| Cost of Smart Tag | Cost of Ambient Tag | Total Cost | Total Cost per scenario |
| \*\*\*\*\*\*\* | US $ 64.49 Per Tag | Cost of Smart tag + Cost of Ambient tag. | US $ 64.49 per unit |
| So the total cost per scenario is US $ 64.49 Per Unit. |

**CONCLUSION**

We studied the various RFID based temperature monitoring systems and their technology. The study led to the identification of the two major variants of RFID based temperature monitoring being used. The basic concept of the operation of both technologies remains the same; however, they vary depending on the cost and the usage of the technology. The two variants are the smart tag and the ambient tag. While blood bags use smart tags for individual identification, the major supply chains where large volumes of goods are transported, such as food chains and the logistics of fish transport use ambient tags. Ambient tags are mainly used for monitoring shipments; they are not suitable for individual monitoring owing to its higher cost. The RFID based blood bag temperature monitoring system uses the both the object identification and the temperature data to improve the quality of the processes in a typical blood bank. This brings great visibility in accessing the quality of the end product in such temperature critical systems. These concepts could be applied in any inventory management systems where the temperature data is critical for assessing the quality of the stored goods.

RFID based temperature monitoring in food chain provides lot of flexibility to the customers and the logistics providers without compromising the quality of the transported goods. Any time monitoring helps with the tracking of quality in real time and ensures that end consumers receive the promised safety and quality. Also, this is a scalable model which can help both the customers and the logistic providers, thus creating a win-win situation for both of them. Both these tags are RFID active tags and are reusable. Smart tags are comparatively cheaper than the ambient tags. Hence, smart tags are useful for mission critical applications where individual monitoring is necessary, like in a blood bank. We did a cost analysis of both these tags and cost of the implementation of such technology in various scenarios.

Based on these studies, we did a comparative analysis of both technologies and identified the pros and cons of each of them. From these findings, we developed the overall process design for use in a blood bank, and identified the added value to the existing system because of the technologies complementing each other. The overall process design covers the various scenarios involved in the real-life usage of the product. Each scenario’s applicability to the technology and where the pros of each technology will help in that scenario were studied and analyzed. Finally, we identified the value addition of this concept to the existing system and, interestingly, there were lot of gaps in the existing system, which could be addressed with this overall process design of both of these technologies. This system has been at least theoretically proven to be of immense value when implemented in a blood bag supply chain.

**REFERENCES:**

[1] “*General RFID Information”,* RFID Journal [online]. Viewed 2009 October 15, Available: <http://www.rfidjournal.com/faq/16>.

[2] A. Abarca, M.de la Fuente, J.M. Abril, A. Garcia, F.Perez – Ocon, “*Intelligent Sensor For Tracking & Monitoring of Blood Temperature & Hemoderivatives Used For Transfusions”.* Available: <http://sciencedirect.com>

[3] R. Glidden, C. Bockorick, S. Cooper, C. Diorio, D. Dressler, V. Gutnik, C. Hagen, D. Hara, T. Hass, T. Humes, J. Hyde, R. Oliver, O. Onen, A. Pesavento, K. Sundstrom, M. Thomas, Design of ultra low cost UHF RFID tags for supply chain applications, IEEE Communications Magazine 8 (2004) 140 – 151.

[4] Ju- Chia Kuo, Mu- Chen Chen, “*Developing an advanced Multi – Temperature Joint Distribution System for the Food Cold Chain*”. Available: <http://sciencedirect.com>

[5] E. Abad, F. Palacio, M. Nuin, A. Gonzalez de Zarate, A. Juarros, J.M. Gomez, S. Marco, “*RFID Smart Tag for Traceability & Cold Chain Monitoring of Foods: Demonstration in an Intercontinental Fish Fresh Fish Logistic Chain*”. Available: <http://sciencedirect.com>

[6] Jackson, V., Blair, I.S., McDowell, D.A., Kennedy, J., & Bolton, D. J. (2007). The incidence of significant food borne pathogens in domestic refrigerators. *Food Control, 18(4),* 346-351.

[7] Chow, H.K.H., Choy, K.L., & Lee, W.B. (2007). Integration of web-based and RFID technology in visualizing logistics operations – A case study. Supply Chain Management: An International Journal, 12(3), 221-234.

[8] Hierlemann. A, Integrated Chemical Microsensor Systems in CMOS – Technology, Solid – State Sensors, Actuators and Microsystems, 2005. Vol 2, 5-9 June 2005 Page(s): 1134 -1137[40] C. Vancura, M.Ruegg, Y.Li, C. Hagleitner, A. Hierlemann, Anal, Chem. (2005) in press.

[9] American Association of Blood Banks. Reference standard 5.1.8A: requirements for storage, transportation and expiration. In: *Standards for Blood Banks and Transfusion Services.* 23rd ed. Bethesda, MD: American Association of Blood Banks; 2005:53

[10] Taoukis PS, Labuza TP. Applicability of time – temperature indicators as shelf life monitors of food products. J Food Sci. 1989; 54:783-788.

[11] Ambient Tag, <http://www.ambient-systems.net>