# Wireless Sensor Monitoring Combined with RFID Networks

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## Abstract

To further enhance students' learning, the EET/TET Program developed a new win-win partnership with two industry partners, AXCESS International who is a leading provider of Radio Frequency Identification (RFID) systems and Hisco, a specialty distribution company. AXCESS has provided its ActiveTag™ on-demand, semi-active RFID technology to the RFID/Sensor's Convergence Laboratory for students to research and develop applications for business projects. We expect that students not only learn new technology, but also perform larger scale of work than typical classroom projects.

This paper describes the development of a RFID/Sensor chemical monitoring system; provides details of the system operation and offers results from the operational evaluation. The problem at hand is to provide a well monitored temperature environment to chemical in a storage warehouse. The specific chemical considered for the project is used for creating photo-resist for semiconductors and requires a highly stable temperature environment for storage. The RFID/Sensor based system developed clearly demonstrates the effectiveness of RFID technology to provide an automated temperature monitoring and alert system to meet this requirement. This system is built using RFID tags with temperature sensors, a RFID receiver and a backend computer to collect, store and analyze temperature measurement data. This system is efficient, saves time, money, provides real time data that can be accessed 24/7 on a standalone laptop or via internet and definitely less tedious compared to the previously employed manual data collection system using temperature recorders.

## Introduction

The Texas A&M Engineering Technology and Industrial Distribution Department strives to give its students hands-on experience with today's technologies. In spring 2006, a Radio Frequency Identification (RFID) [1] pilot project was launched at Hisco's chemical warehouse in Carrollton, Texas using active RFID equipment from AXCESS Incorporated [2], [3], [4]. RFID is becoming a new standard because of the ability to monitor thousands of asset tags to track inventory from the supplier to consumer. It is utilized by supplier and distribution centers as well as warehouses to track assets using specially designed RFID tags that help uniquely identify every item in inventory automatically.

Active RFID tags can be fitted with specialty sensors that can monitor temperature, humidity, ammonia or radiations in a warehouse, on a real-time basis, to protect assets and personnel. These tags emit a burst of very high frequency signals in regular intervals that include the ID of the tag, its status, and any additional tag information (such as temperature, humidity, ammonia, etc.). The emitted signals can be read by an active RFID reader that sends the information using an RS232 serial communications interface to a computer running inventory management software to interpret the data. This real-time data is analyzed and presented with a user friendly program interface to the user. This entire process is illustrated in Figure 1.

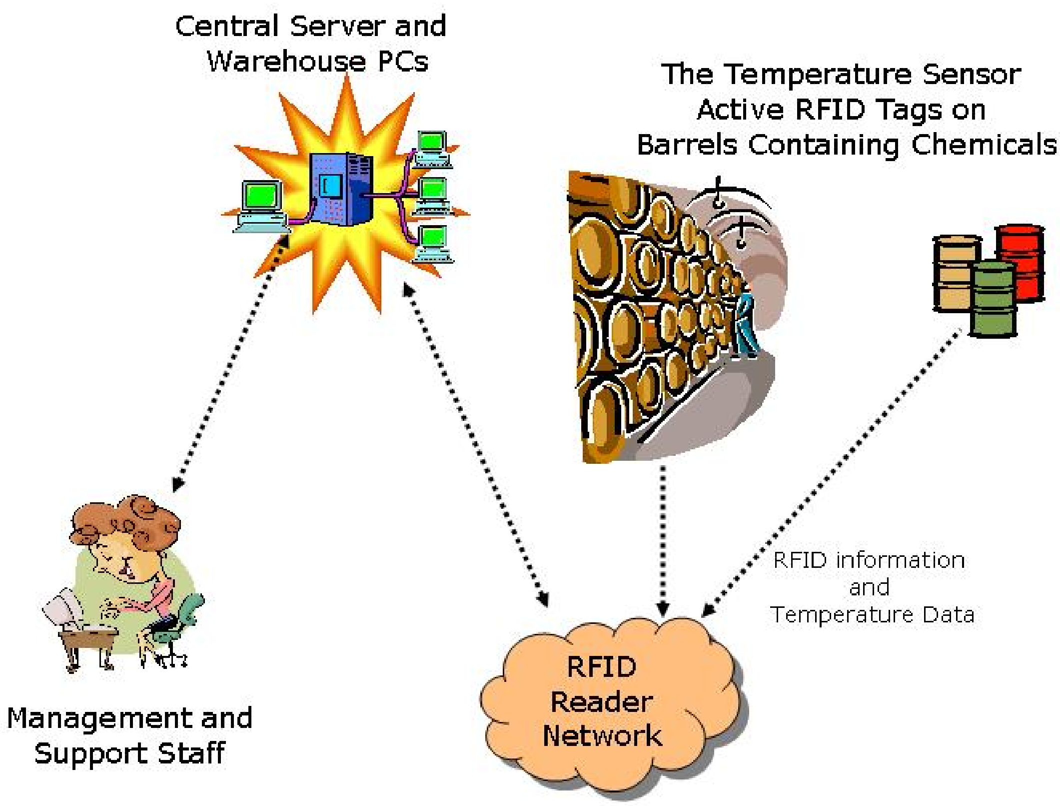



Figure 1: The Schematic of the Complete System

The system created by Texas A & M monitors temperature, creates log files for each day, and alerts the appropriate personnel if the temperature in the warehouse is approaching an unviable limit. The process begins with personnel placing a tag on an individual barrel that will be placed in the warehouse. The tag is then activated for temperature recording and the tag ID is then added to a database with other attributes like chemical name, location, and acceptable temperature range. Once the barrel is inside the warehouse, the tags continually transmit the temperature data to an RFID receiver. The receiver sends the data from all the tags to the backend computer. This computer runs the RFID Warehouse Manager software created by the Texas A&M research team to collect, analyze, and store the data. The temperature data is then compared to the limits set when the tag was placed on the barrel. The upper temperature is a few degrees below the unviable temperature to alert someone before it is too late.  If the temperature does reach the upper or lower limit, an alert is sent via and alarm as well as via an e-mail to a number of people that could fix the problem. The data collected by the system is also displayed on a webpage.

**Manual Temperature Monitoring Process**

Prior to the Texas A&M RFID/Sensor system, a manual process using temperature recorders was used to monitor the temperatures. DeltaTrak mechanical temperature recorders shown in Figure 2 were used for this purpose at the Hisco warehouse. These recorders were placed on the barrels and recorded the ambient external temperature of the chemical. The recording itself is done by tracing a line on a scrolling sheet of paper. The sheet of paper could only be examined if the box was opened. So, to examine the temperature, someone had to physically go to each temperature recorder, open the box, get the paper of the data, make sure the temperature was stable, and replace the temperature recorder to continue data collection. Obviously, this becomes a time consuming task if there are 25+ recorders in the warehouse.


Figure 2: DeltaTrak Temperature Recorder

As the barrels go in and out of the warehouse, the DeltaTrak recorders attached on them were checked to make sure the materials were kept at a proper temperature during their transport to the warehouse, and during their storage in the warehouse respectively. Further, the exact inventory counts were had by first hand counting all the barrels, and then looking at the invoices to find out the chemical content of each barrel.

Clearly, an automated temperature and inventory monitoring system is highly desirable keeping in mind the tediousness of manual effort. This demonstrates of the necessity of the RFID/Sensor system.

**Texas A&M RFID HAZMAT System**

As explained previously, the main objective of this system is to automate the temperature monitoring and alert system and also an automatic inventory system. RFID tags equipped with temperature sensors along with a receiver and a backend data processing computer achieve this objective. In this section we outline the tracking process, basic setup and details about the hardware and software utilized to build this system.

RFID Asset beacon tags are placed on barrels of temperature sensitive photo resist stored in the Hisco warehouse. When the barrels arrive at the warehouse, employees enter the tag number and the chemical properties (name, acceptable temperature range, storage location) into the RFID Warehouse Manager software and place the barrels in their proper storage location. Once within range of the receiver, the tags send out the data to the receiver once every hour. If the temperature read by the receiver violates the upper or lower bounds of the acceptable temperature range on any tag, an alarm is shown on the user program interface and an email is sent out to all email addresses listed on the notification tab giving the tag ID number and the status of the tag whether it be above the specified range or below it.

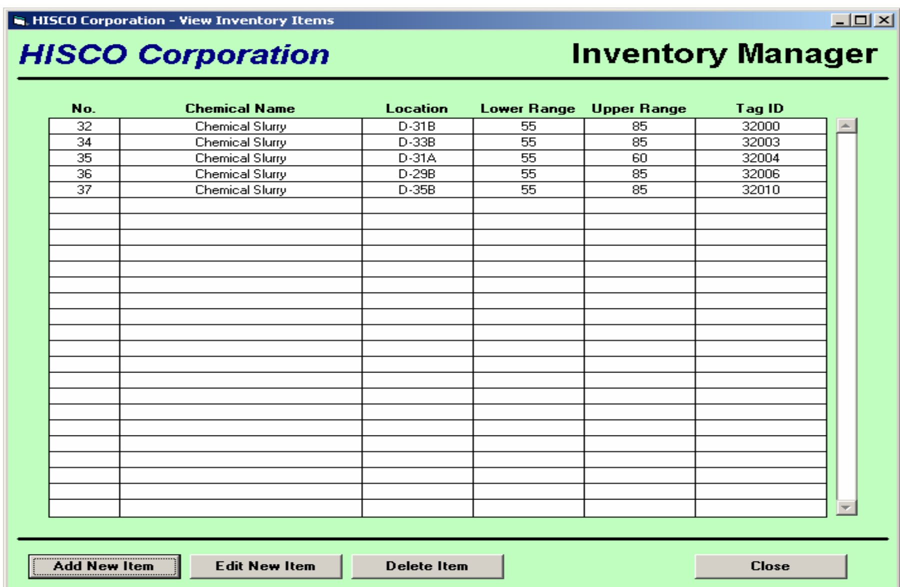



Figure 3: Tag Manager Window

If the workers needed an inventory, they need only to count the tags listed on the RFID Warehouse Manager Software interface. The interface also provides the location of the tag as an attribute, so that if a tag is out of range, the workers can go directly to the location detailed on the interface and check for problems. The tag manager window in the program interface also allows the user to add tags, remove tags, and change tag temperature information any time it is needed. Figure 3 shows the tag manager window.

A Xitami web server has been set up to host a webpage designed to allow an offsite employee or customers to check the temperature of the chemicals at any time of the day. Along with the complete temperature data, present and past, the web-server also contains other features like:

1. The complete project description, sponsor and team information.
2. A notifications page that displays all previous out of range notifications.
3. An FTP server to enable quick file transfer to and from the remote PC.
4. MS Remote Desktop capability.

The screen shot of the user interface are shown in Figure 4.

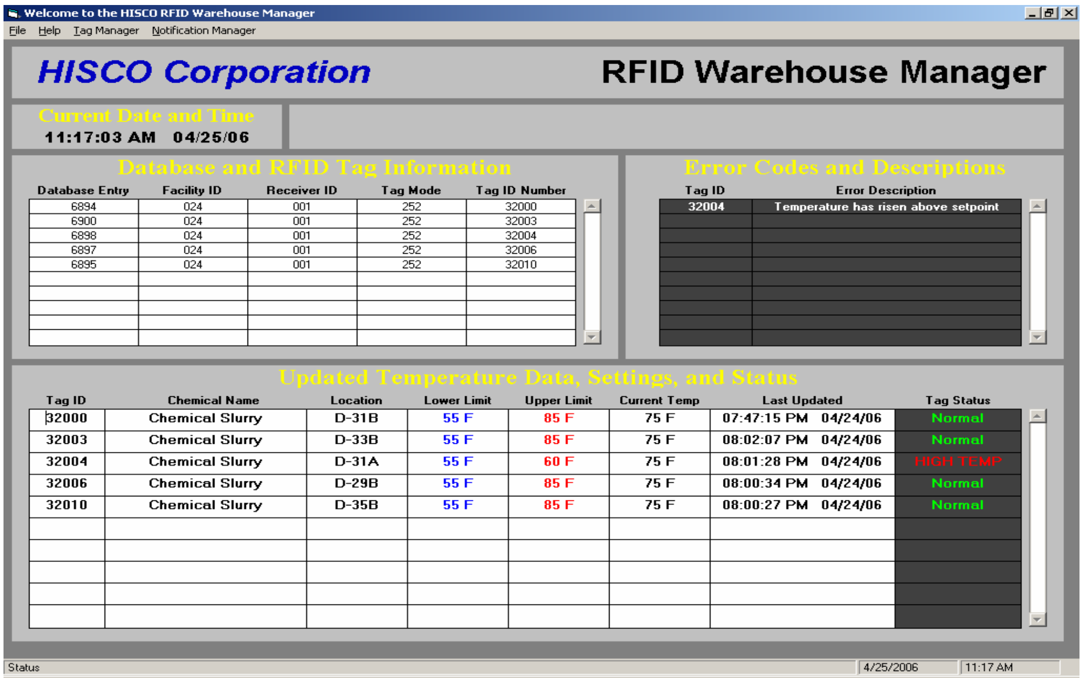



Figure 4: Hisco Warehouse Program Interface

## Hardware Components

The hardware used to implement the system consisted of the following parts:

1. AXXESS ActiveTag Standard Asset Beacon Tag AT-132A: These active tags are used for reading the temperatures inside the warehouse. The tags are programmed and activated to record temperature readings according to instructions included with the RFID tags. The temperature asset beacon tags transmit a temperature reading once every hour under normal operating conditions [3]. If an error occurs, the error message is sent once every 10 minutes. The tags were placed on top of the barrels in the system. The tags have a wake up frequency of 126 kHz and a transmit frequency of 315 MHz. The operating temperature ranges from 0 degrees to 185 degrees Fahrenheit. The tags have an operating life of 1 to 3 years, depending on application.

2. AXXESS ActiveTag Network Receiver AT-132-NR-IP: The receiver collects the data being transmitted from the tags and sends it to the hazmat database through a serial link. The receiver was mounted on the racks where the chemicals are stored. It has a range of about 35 feet, i.e., it can read the tags at a distance up to 35ft. with great reliability. The receiver has a wake-up frequency of 125 kHz and a transient frequency of 315 MHz [4].
3. AXXESS ActiveTag Activator AT-132-AT: The activator is used to activate the tags to operate in temperature mode. Under normal conditions he tags do not emit anything, to save power. To activate them to enable transmission, a 126 KHz [2] field is generated by the activator. HyperTerminal was used to set the activator to activate the tags. The tags were put in the activator field for 5 seconds to become activated.
4. Backend Computer: As a proof of concept, a Compaq Evo laptop loaded with Microsoft Windows XP, Outlook Express, Access and Visual Basic is used for the backend data processing. The temperature measurement data received from the receiver is processed and presented using a user-friendly interface. The computer also executes the RFID Warehouse Manager software as well as the Xitami Web and FTP Servers.

**Software Components**

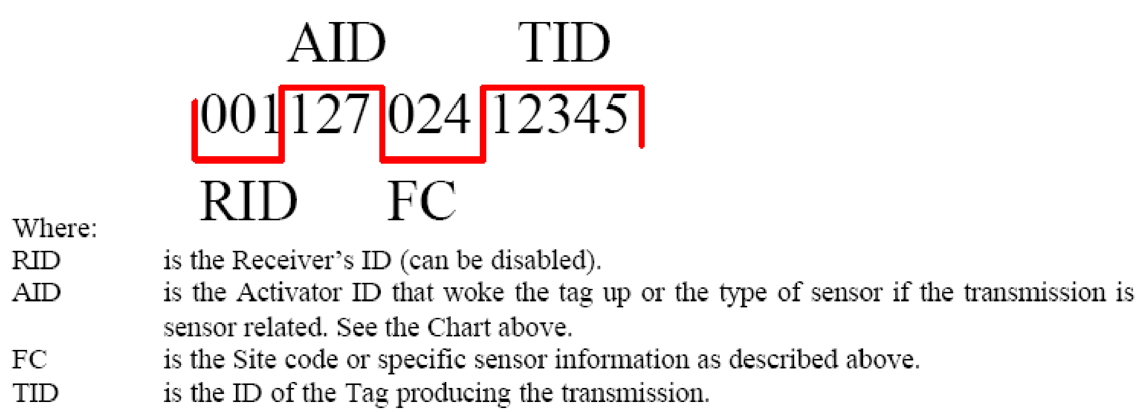



Figure 5: ActiveTag Data Format

The RFID Warehouse Manager software used for this project has been developed using Microsoft Visual Basic 6. It is capable of taking the strings of data from the receiver and parsing it into separate data fields for activator IDs, tag IDs, receiver IDs, and facility codes which can be represented as either errors codes or current temperatures. It is these fields that are used when interpreting the data from the tags. The tags use a 14 digit packet to send data to the receiver. This packet consists of 4 different fields. Figure 5 shows the packet and contents of each field in the packet.

The FC for the sensors we use represents the temperature measured in Fahrenheit plus forty. These fields are then stored in various Microsoft Access databases for querying and interpretation. The Hisco Manager interface displays all of the tags, the time, date and temperature reading of their latest temperature recordings, and any notifications that are currently valid for tags above or below their respective temperature restrictions. The pull down menu at the top also allows for the editing of tag information such as the addition of new tags as well as the removal of old tags from the interface.

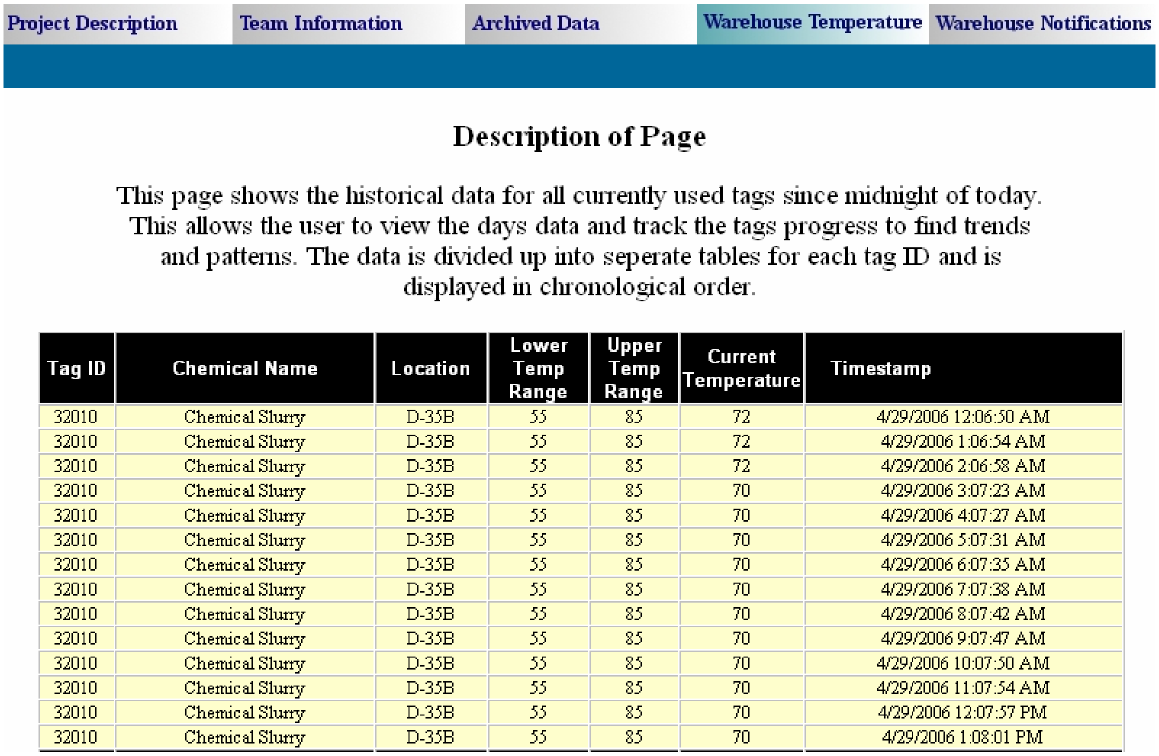
A user can alter the email addresses that receive notifications through the Notifications Editor menu. Up to 5 different email addresses can be entered into the fields. If the RFID Warehouse Manager software detects a temperature outside of its acceptable temperature range, a pre-written email is sent out, using Microsoft Outlook Express and the speedymail.org SMTP server, and includes the tag number of the tag violating its range and a brief explanation as to the nature of the violation. The RFID Warehouse Manager software assumes that any email address entered into the Notifications Editor already exists as a contact in Outlook Express. The default SMTP port (25) is commonly used by spammers and email worms; this port had been blocked by the ISP. Hence we use an alternate SMTP port offered by speedymail.org and then correspondingly change the default port for outgoing mail used by Outlook Express. Since Outlook Express is being used to send the emails automatically, it must run in the background at all times.

The Xitami web server hosted the webpage for this project. The webpage has been created using Macromedia Dreamweaver. CGI is used to allow for the querying and displaying of objects directly from the Microsoft Access databases to the webpages.

**Data Collection and Analysis**

This pilot project demonstrates use of RFID as a viable method of tracking temperatures of sensitive chemicals on a larger scale throughout an entire warehouse. The system has been running at the Hisco warehouse for over eight weeks without any significant problems encountered. The Visual Basic and website codes have been updated several times to include new features using Microsoft Remote Desktop. The Hisco Monitor Software performed without error for the entire pilot project and did not miss any transmissions during the time that the program was being executed.

The webpage allows the user to view the current status of the temperature in the warehouse, the temperature archives, and any errors that might have occurred. Each tag that is entered into the database transmits a temperature reading every hour and every ten minutes if the temperature is out of range. This transmitted data is displayed under the Warehouse Temperature section on the webpage. Figure 6 is a screen shot of the current temperature reading of the tags.



Project Description | Team Information | Archived Data | Warehouse Temperature | Warehouse Notifications

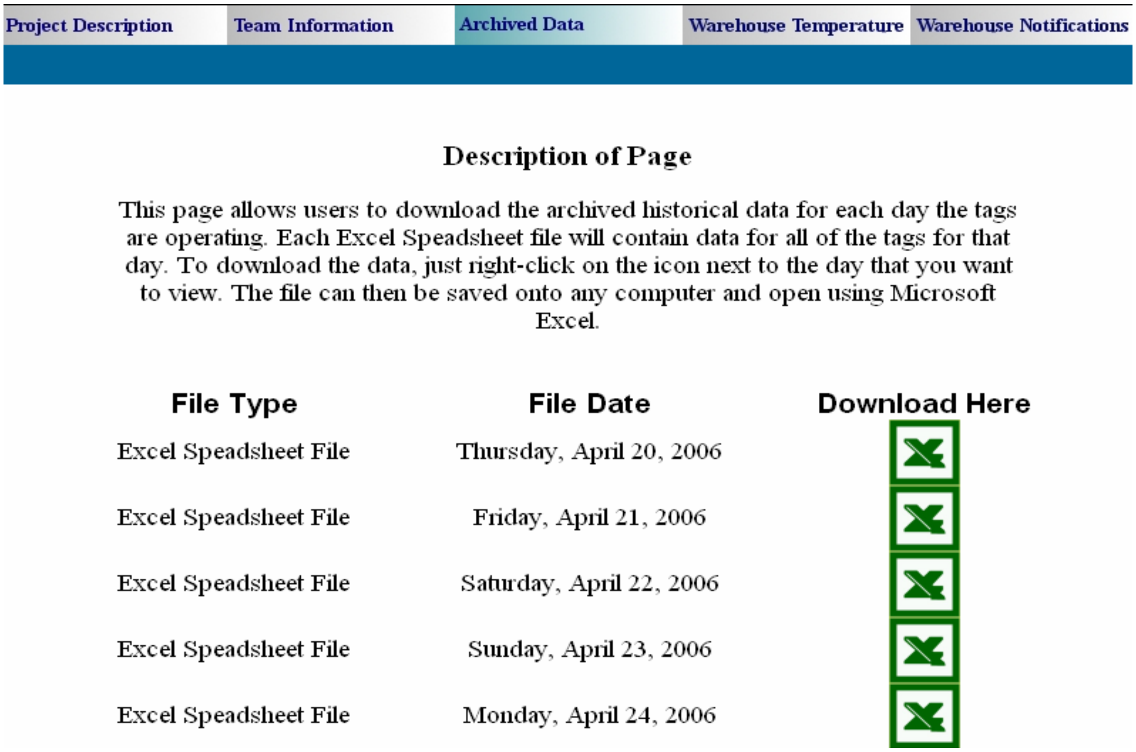
**Description of Page**

This page shows the historical data for all currently used tags since midnight of today. This allows the user to view the days data and track the tags progress to find trends and patterns. The data is divided up into seperate tables for each tag ID and is displayed in chronological order.

| Tag ID | Chemical Name | Location | Lower Temp Range | Upper Temp Range | Current Temperature | Timestamp |
|---|---|---|---|---|---|---|
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/29/2006 12:06:50 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/29/2006 1:06:54 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/29/2006 2:06:58 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 3:07:23 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 4:07:27 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 5:07:31 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 6:07:35 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 7:07:38 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 8:07:42 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 9:07:47 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 10:07:50 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 11:07:54 AM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 12:07:57 PM |
| 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/29/2006 1:08:01 PM |

Figure 6: Current Temperature

Each tag's data is logged on the computer. The webpage displays the current day's temperature data. When a new day begins, the previous day's data is saves as an excel file and a new entry is entered into the Archived Data section of the webpage. The archived data is a record of the warehouses temperature divided into days. Figure 7 is a screen shot of what the user will have access to. The user can select which day they want to look at to check the temperature. An excel file will be opened displaying the tag ID, chemical name, location, temperature range, and status. An excel file of the logged data can be seen in Figure 8. Each tag is placed on a new spreadsheet. Figure 9 is the same file, but sheet2 is selected which displays the data for tag with the ID 32006.



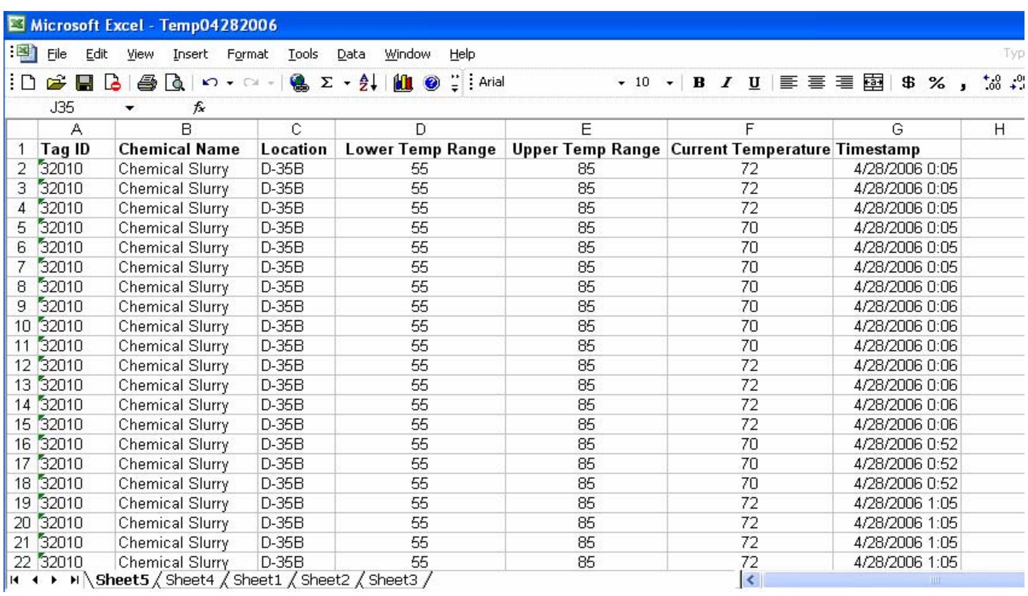
Project Description | Team Information | Archived Data | Warehouse Temperature | Warehouse Notifications

**Description of Page**

This page allows users to download the archived historical data for each day the tags are operating. Each Excel Speadsheet file will contain data for all of the tags for that day. To download the data, just right-click on the icon next to the day that you want to view. The file can then be saved onto any computer and open using Microsoft Excel.

| File Type | File Date | Download Here |
|---|---|---|
| Excel Speadsheet File | Thursday, April 20, 2006 | |
| Excel Speadsheet File | Friday, April 21, 2006 | |
| Excel Speadsheet File | Saturday, April 22, 2006 | |
| Excel Speadsheet File | Sunday, April 23, 2006 | |
| Excel Speadsheet File | Monday, April 24, 2006 | |

Figure 7: Archived Data



Microsoft Excel - Temp04282006

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Tag ID | Chemical Name | Location | Lower Temp Range | Upper Temp Range | Current Temperature | Timestamp | |
| 2 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:05 | |
| 3 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:05 | |
| 4 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:05 | |
| 5 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:05 | |
| 6 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:05 | |
| 7 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:05 | |
| 8 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:06 | |
| 9 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:06 | |
| 10 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:06 | |
| 11 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:06 | |
| 12 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:06 | |
| 13 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:06 | |
| 14 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:06 | |
| 15 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 0:06 | |
| 16 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:52 | |
| 17 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:52 | |
| 18 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 70 | 4/28/2006 0:52 | |
| 19 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 1:05 | |
| 20 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 1:05 | |
| 21 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 1:05 | |
| 22 | 32010 | Chemical Slurry | D-35B | 55 | 85 | 72 | 4/28/2006 1:05 | |

Sheet5 / Sheet4 / Sheet1 / Sheet2 / Sheet3

Figure 8: Archived Temperature Download for Tag 32010

|  | Tag ID | Chemical Name | Location | Lower Temp Range | Upper Temp Range | Current Temperature | Timestamp |
|---|---|---|---|---|---|---|---|
| 2 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:05 |
| 3 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:05 |
| 4 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:05 |
| 5 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:05 |
| 6 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:05 |
| 7 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:05 |
| 8 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:06 |
| 9 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:06 |
| 10 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:06 |
| 11 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:06 |
| 12 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:06 |
| 13 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:06 |
| 14 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:06 |
| 15 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 0:06 |
| 16 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:52 |
| 17 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:52 |
| 18 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 70 | 4/28/2006 0:52 |
| 19 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 1:05 |
| 20 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 1:05 |
| 21 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 1:05 |
| 22 | 32006 | Chemical Slurry | D-29B | 55 | 85 | 72 | 4/28/2006 1:05 |

Figure 9: Archived Temperature Download for Tag 32006

## Challenges

This pilot project was filled with challenges and obstacles. Some of them were

1. Attenuation due to Liquids: The liquids stored inside the barrels have very high attenuations for RF transmissions.
2. Attenuation due to Metals: The tags were being placed inside a warehouse filled with metal racks, supports and gratings for holding the barrels. RF waves are attenuated in the presence of metallic objects.
3. Tag Placement and Orientation: The placement and orientation of the tags on the barrels within the racks with respect to the receiver antenna became a very important aspect. Certain tag locations caused high miss rates while others were highly successful.
4. Error handling on Misreads: With the correct tag placement, there were extremely few misreads. Even if there were any, they were accounted for by error-handling modules within the software. The most common misread was caused by the buffers of the receivers sending only a portion of the data received followed by a small delay of a few seconds and then the remaining portion of the data.

## Conclusion

This project has proven RFID temperature monitoring as a reliable automated method of monitoring the storage temperature of chemicals in a warehouse. RFID tags with temperature sensors, receiver and backend data processing and user interface program developed using Visual Basic achieve this objective. The webpage developed for this project is very effective at presenting the data from the warehouse in a readable and efficient manner and also allows a person offsite to check for any recent notifications without checking their email. The email feature of this project is critical for expensive sensitive chemicals that must be kept on tight temperature restrictions. By alerting an employee or supervisor that the ambient temperature at a certain location in the warehouse is too hot or too cold for a given chemical, adjustments can be made before the integrity of the chemical is surrendered. Some basic employee training would be required, to train them on the software. The employees would also need to be informed that tags should be placed as close to the receivers as possible with as little metal grating or other barrels between the tag and the receiver as possible to ensure minimum interference.

The investment required to support the cost of RFID equipment for such this system can be easily justified by the savings achieved through prevention of losses of chemicals under unacceptable storage temperatures and by the elimination of the time consuming manual interventions.

**Acknowledgement**

This project was done by three electronics engineering technology students, Bryan Crisp, Tim Hinkle, and Jack Culberson. The complete project can be accessed at http://12.134.79.242 .

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**Biographies**

BEN ZOGHI is currently a Professor and Director of RFID/Sensor Lab at the Engineering Technology and Industrial Distribution Department at Texas A&M University. He has served the department as Industrial Distribution Program Coordinator, Executive Director of Thomas and Joan Read Center and Associate Department Head for Research since he joined Texas A&M in 1987. His research activities include RFID/Sensors and engineering leadership development.

JAY PORTER joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 1998 and is currently the Program Coordinator for the Electronics and Telecommunications Programs. He received the BS degree in electrical engineering (1987), the MS degree in physics (1989), and the Ph.D. in electrical engineering (1993) from Texas A&M University.

STEVE THOMPSON joined the Department of Engineering Technology and Industrial Distribution at Texas A&M University in 2002 as an Associate professor after being with high-tech industries for over twenty five years. Steve worked as a scientist for Motorola, Fab Operation Manager for TI and the director of quality for Applied Materials. He received the Bachelor of Science, Chemistry, University of Dundee, Dundee, Scotland, the MS degree in physics (1989), and Ph.D., Chemistry, University of Dundee, Dundee, Scotland.

YONG-KYU JUNG is an Assistant Professor at Texas A&M University in College Station, TX. He received his B.S.E.E. from Korea University (Seoul) in 1985, his M.S.E.E. and Ph.D. from Georgia Institute of Technology (Atlanta, GA) in 1997 and 2001 respectively. His research interests include reconfigurable embedded computing system design.

RAINER FINK received the BS degree in biomedical engineering (1988), the MS degree in biomedical engineering (1992), and the Ph.D. in biomedical engineering (1995) from Texas A&M University. In August 1996, he joined the Electronics Engineering Technology faculty at Texas A&M University. His research activities include mixed-signal testing, analog circuit design and biomedical electronics.