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ecoSENS System³

FOOD-CARE ANYWHERE

Project Overview Report

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1. Executive Summary

1.1 Background

These years, hunger and poverty have been broadly concerned. Although last food crisis has just passed for no more than 3 years, high food prices have been sweeping around the world again since July, 2010, and there is no sign that the situation is going to be any better. The number of hungry people has recently been increasing widely. A new food crisis may be right on its way.

Hunger has a close relationship with poverty. Whenever a food crisis happens, it is the poor people who bear the brunt of high food prices. However, the food condition cannot be improved a lot only by improving the global crop yields. For the poor people, hunger is directly caused by high food prices and poverty rather than lack of food. It is purported by the Food and Agriculture Organization (FAO) that the world already produces enough food to feed everyone — 6 billion people — and could feed double — 12 billion people[1]. Effective solutions for this strongly unbalanced situation are extremely needed.

1.2 The Problem

While the poor are suffering from hunger, a lot of food is wasted or lost in other parts of the world because of lack of effective monitor. Data shows that the amount of food we lost yearly can feed at least 10 million people. In a way, saving more food means increasing the agricultural production. So, if effective actions were taken to minimize the global food losses, it will be of great help in solving the food crisis.

Despite that various solutions have been proposed and put into practice in response to food crisis, few of them fully focus on or solve the difficulties for the poor. As far as poor people are concerned, food prices are too high to afford, no matter how much the annual crop yields are. What they need are purely cheaper food prices, much more income and more food aid.

Up to now, no single solution has proved adequate to solve the crisis. So, to get rid of the food crisis successfully in the long term, crop yields should be increased, food losses should be minimized, and more aid should be given to the poor.

1.3 Solution

ECOSENS designs an intelligent, multi-zone, global, integrated food-care network – EcoSensSystem (E.S.S.) to solve the food crisis.

Major functions of E.S.S. are to reduce food losses and improve worldwide food scheduling and food aid. Low-cost, low-power and user-friendly, E.S.S. offers a much easier but practical way for both administrators and users to participate in fighting the food crisis.

By keeping wireless sensors in food, E.S.S monitors the complex environmental conditions in food storage and sending timely alarms in emergency situations. The wireless sensors move with food so that E.S.S. can guarantee intelligent lifelong food-care from production, transportation to consumption, and food losses can be minimized as much as possible. At the same time, real-time food information uploaded by the wireless sensors is processed and uploaded to the Cloud Server. A global food distribution and flow map can be accessed everywhere through the Internet. Then, after applying a series of algorithms to the data, an evaluation on the current distribution and finally an optimal suggestion will be offered to the administrators. What's more, suggestions on international food aid will be given to public users according to collected data on food situation.

1.4 Expected Result

Compared with existing solutions, E.S.S. has its unique advantage in solving food crisis. Up to now, no single method has proved comprehensive enough to give lifelong food-care successfully.

If E.S.S. is well acknowledged and widely used all over the world, a global food monitor mechanism of high efficiency will be established, and the whole mankind will benefit from this system. At that time, it will largely avoid unnecessary losses caused by lack of monitor and prevent high prices caused by imperfect food scheduling. Especially for the poor people in Africa or Latin America, bitter sufferings from hunger will come to an end. That is not only the dream of the entire world, but also the ultimate goal that ECOSENS has been pursuing and making efforts for.

2. Situation Analysis

2.1 Food Situation Is Worsening

Although the strong impact of last financial tsunami hasn't gone away thoroughly, a new round of food crisis may be right on its way. Currently, the food prices have kept higher than normal levels for several months. As a result, the number of people in hunger and poverty has been soaring horribly. Our world is really struggling to feed itself these days.

Last food crisis in the year 2007-2008 swept large numbers of countries in the world, making tens of thousands of people in famine. However, the duration of current high food prices has already exceeded that of the last crisis in 2008.

Since mid-June in 2010, global grain prices have been rising with a 56% rise in global wheat prices. By the date of Oct 11, 2010, the number of malnourished population has exceeded 1 billion—about one sixth of the world's population[2]. Up to now, the food price hike drives approximately 44 million people into poverty. Averagely, every 6 seconds, a malnourished child may die from hunger. Experts say that global grain reserves have dropped to historic lows and no signs have shown that the global food situation is going to improve any time soon. At the same time, the global food consumption has kept higher than the food production for the past 10 years. What's worse, it's estimated that the world's food demand will have 30-40% of increase by the year 2030. Global food shortage has already begun!

The world is now going through a very tough period with agricultural recession, rising population, frequent natural disasters and volatile political and economical situations. Once the food prices keep rising out of control and a food crisis break out, its influence will be much more severe than ever before. Thus, effective solutions are strongly needed to alleviate the critical food situation.

2.2 Poor People Bear the Brunt

Take a look at the countries mostly hit by growing food crisis, and it's not difficult to find that they are mainly developing countries.

Therefore, solving food crisis is largely about ending hunger and poverty. Whenever a food crisis happens and whatever harms it may cause, it is the poor people who bear the brunt[3]. Due to high food prices, many poor people will have to spend almost all of their slender income on food. Even so, to make ends meet, they have to buy less, eat less and eat cheaper food with little nutrition which is harmful for their health. When it comes to pregnant women or children, the condition will become even worse.

So, in face of the hunger problems, the hardships of poor people must be taken into consideration. The difficulties of fighting hunger in these regions can be summarized as follows:

- Relatively large population
- Low local crop yields either because of harsh weather conditions or lack of technologies and money
- Relying too much on food import
- Lack of timely and adequate international food aid
- Imperfect food distribution and scheduling mechanism

3. Solution Introduction

3.1 Existing Solutions to Food Crisis

These years, many solutions to food crisis have been proposed with combined efforts from worldwide experts. Most of them have proved to be effective in practice to a certain degree. The following table shows six main solutions to food crisis.

Group One	1. **Increase the world's crop yields with improved technologies.**
	2. **Improve the existing agricultural production mode step by step.** • Ecological agriculture has been introduced to different countries to replace conventional agricultural mode so as to maintain long-term development. • Some kinds of insects are said to be nutritious and can be a substitute for tradition food.
	3. **Control the growth rate of global population.**
Group Two	1. **Minimize the loss and waste of food.** • Most countries possess food monitoring and management department to regulate the use of their food and prevent extra loss.
	2. **Enhance international food aid and improve food distribution and scheduling.**
	3. **Guarantee the transparency of food information.** • Real food information should be available to the public to guarantee the social stability, especially when emergencies or disasters happen.

As is shown, the listed solutions are divided into two groups. The first group focuses on dealing with the food supply and demand problem, while the second group focuses on handling the crisis in a more social and positive way.

3.2 Solution Analysis

3.2.1 Increasing the Production Is A Must But Not Enough

As is known, poor people suffer more in the crisis. Thus better solutions should focus more on the hardships of the poor.

It's well acknowledged that increasing the food supply is a must in fighting hunger. Consequently, more efforts are concerned with increasing crop yields rather than other ways, and many great progresses have been achieved in increasing the crop yields. However, its actual effect in solving the crisis is really unsatisfactory. Two key factors may account for its disappointing effect.

- **It's very difficult for the agricultural production to increase faster than the population growth in the short term.**

On the supply side, crop yields of many main grain-producing countries have decreased because of the continuous abnormal weather conditions in recent years despite of all the efforts in technologies. On the demand side, both the rapid population growth rate and upgrading in food consumption level have added a lot of pressures to agricultural production. Also, growing amount of crops for bio-fuels accelerates the rise in food price.

● **Increasing the production is a must but never enough in solving the crisis.**

As is mentioned above, hunger and poverty are directly caused by high prices in a food crisis rather than global shortage of food. Hunger and poor people still exist in these areas even if worldwide food crisis doesn't break out. So, increasing the global crop yields doesn't guarantee a cheaper and acceptable food supply. Much more detailed work and participation should be involved in fighting the crisis.

3.2.2 Food Should Be Cared Anywhere

Despite the severe food shortage in certain regions, food losses are very common and serious in many other parts of the world. Data shows that the amount of food we lost yearly can feed a total of at least 10 million people. These losses are mainly caused by pests, mildew, pollution, rot, waste and lack of supervision. So, adequate and timely food distribution information is highly needed to ensure an effective mechanism for food aid and distribution.

3.2.3 Combined Efforts Are Needed In the Fight

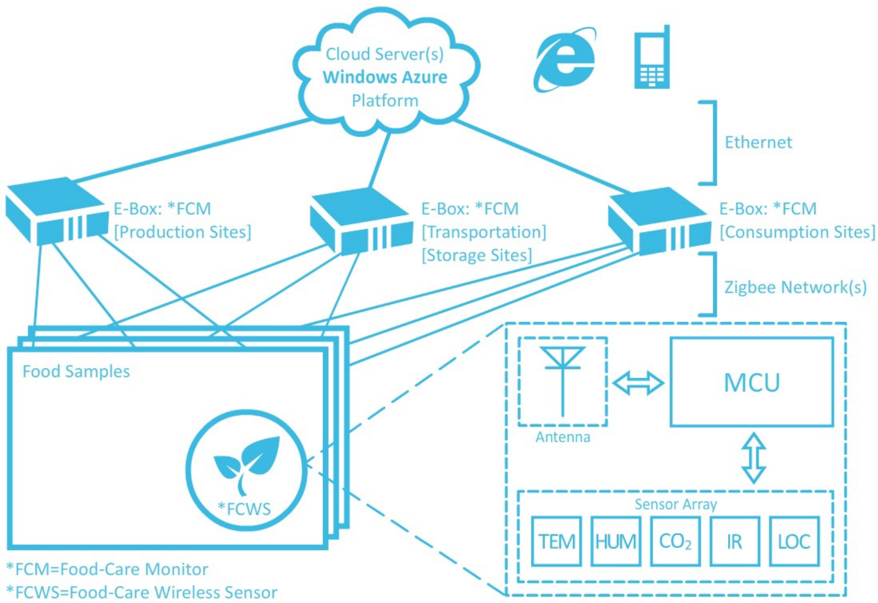
Even if food storage is adequate in the world, hunger and poverty may still exist. This phenomenon can't be changed unless adequate international aid is involved and better food scheduling mechanism is established. It's extremely hard for many poor people to feed themselves without international aid. However, there aren't a lot of wealthy people who will offer to help them. Thus, more actions should be taken to enhance international food aid and improve food distribution and scheduling.

4. Project Introduction

4.1 Goals of Project

As is analyzed above, no single solution has proved to be adequate and more combined efforts are needed. In view of numerous global efforts in agricultural production and its unsatisfactory effect, maybe a lot more efforts should be paid to other solutions that haven't received deserved attention. Thus, ECOSENS establishes the following four goals of the project in response to food crisis:

- Set up a global food-care network to mobilize global positive participation in food-care.
- Guarantee food-care anytime and anywhere to save as much food as possible so that we can minimize food losses in storage.
- Provide a more effective mechanism to help improve the current food distribution and aid.
- The product must be low cost so that it won't add extra cost in food and easy to be widely used.



4.2 Function Overview

This global network monitor system will be mainly installed in food storage positions such as granaries, grain markets and even food freight trucks all over the world. Thus, we can guarantee lifelong care in the whole process from food production, food transportation to food consumption. To realize that goal, wireless sensors will move with the food in transportation to monitor food state. In each storage position, environmental information will be collected, stored, processed and transmitted to the eBox in charge, and finally displayed in the screen connected to the eBox. Then administrators can get access to the food state information timely including temperature, humidity, carbon dioxide, location, etc. In addition, a food health index from each specific position will be calculated and displayed to users as an evaluation of real-time food state. Once the system detects bad conditions for food storage, an emergent alarm will be given to the administrators immediately in the form of audio, message box and SMS.

Besides the direct interface for management in each specific storage position, users can still acquire or manage all these information from the ECOSENS website. Thus, food monitor and management is available anywhere and anytime with network devices. In addition, food distribution and aid information will be displayed on a map of the webpage. The position of each food storage place will be marked on webpage. Real-time grain reserves at each point will also be summed and displayed on the map. Administrators can find out and monitor the current food distribution condition for themselves. Furthermore, according to each region's characteristics, E.S.S. evaluates the current distribution lines and gives an optimal suggestion. Global food situation concerning food aid is displayed on the map, too. People can easily find out the places suffering food crisis and decide what they can do to help the people in famine.

4.3 System Overview

To meet the demands proposed above, we employed proper techniques and designed a 3-layer structure for the E.S.S.. Each layer is in charge of specific part of the entire system. Devices under each layer have different capabilities of calculation, data throughputs and ways of connection. These devices together have become the solution to the food crisis from ECOSENS.

The EcoSensSystem are made up of FCWS (Food Care Wireless Sensor), FCM (Food Care Monitor) and Cloud Sever(s).

FCWS moves with food and can be recycled. It collects useful data concerned with storage condition including temperature, humidity, infrared, carbon dioxide concentration, location, etc. It has two states: When FCWS is in the Online State, which means it is keeping touch with a FCM, the real-time food data will be sent to the FCM through the ZigBee wireless network. When FCWS is in the Standalone State, the real-time food data will be kept in its own memory instead of being transmitted to the FCM.

After receiving data from FCWS, FCM will monitor those key values and decide whether to raise the alarm. FCM can keep and analyze food state data by its own, and display those data and results on its monitor. When connected to the Internet, FCM will upload the real-time data of food to the Cloud Server, and download further information about food health index and history data uploaded by other FCMs.

The Cloud Server collects all the information uploaded by FCM, and stores them in the database. Based on regional food inflows and outflows, food price, economic development level and population, a regional food-supply evaluation model can be established. According to this model, real-time food information in database will be processed and analyzed through cloud computing technologies. Then, a regional food-supply health index diagram can be provided, which is of great help to governments, social welfare organizations and aid agencies. The Cloud Server is also in charge of the EcoSensSystem website to release all these information to users, and the website supports different smart devices.

4.4 Bottom-to-Top Technical Architecture

Accurate Food Sensor

In order to get better real-time state data, we selected the high-accurate, digital, self-calibrate temperature sensor[4] and high reliability, long term stability relative humidity sensor[5] as prime food information source. Taking both efficiency and cost into account, we made the carbon dioxide and infrared IR sensors as optional sensor modules.

ARM Cortex™-M3

To achieve low power consumption and low cost, and to combine both high performance and convenient debugging tools, we selected the MCU with ARM Cortex™-M3[6] core inside. The ARM Cortex™-M3 processor is the industry-leading

32-bit processor for highly deterministic real-time applications. The processor delivers outstanding computational performance and exceptional system response to events while meeting the challenges of low dynamic and static power constraints.

ZigBee[7]

ZigBee is a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for Low-Rate Wireless Personal Area Networks (LR-WPANs). The ZigBee devices are working at 2.4G ISM (Industrial, Scientific and Medical) radio bands, which ensures our system deployed in all major countries without any spectrum authorization problems. ZigBee technology is the best solution for our wireless food sensors. Thanks to this technology, the character of FCWS moving with food finally comes true.

The ZigBee technology means a lot to the E.S.S.:

- **Battery Life:** The power consumption of ZigBee Module is very low (current no more than 30mA with 3-dBm output), which can guarantee a very long battery life.
- **Transmission Range:** The single-hop ranging from 10m to more than 100m is reasonable.
- **Data Latency:** ZigBee can provide latencies as low as 16ms in a beacon-centric network.
- **Network Scale:** The addressing space allows of extreme node density up to 2^{16} devices.
- **Flexible Topologies:** Three types of topologies are supported by ZigBee: Star, Mesh and Cluster Trees, which makes the wireless network flexible and easy to establish.

XML[8]

Different from the binary data, the Extensible Markup Language (XML) is a set of rules for encoding documents in machine-readable form. Data in XML can be decoded easily by the FCM using the C# programming language. Many platforms provide advanced way to access the XML data. The large-scale support for XML makes the development easy and swift. Furthermore, the sensor data can be stretched easily without any pain.

Windows Embedded Compact[9]

Windows Embedded Compact 7 is used as the operating system on FCM, chiefly for these reasons:

- **Connectivity**

For the FCM serves as the core devices of the E.S.S., it should connect both the upper-layer Cloud Server(s) and numerous FCWS through ZigBee wireless network. So the connectivity of FCM should be considered first. The built-in TCP/IP network stack in Windows Compact 7 makes it easy to connect with Cloud Server(s) through the Internet. And with our ZigBee gateway mounted on the serial port, FCM can make the point-to-multipoint wireless data communication with FCWS.

- **Highly-Reliable**

The FCM needs to have the uninterrupted working state. Reliability and Stabilize are two important reference standards. Windows Embedded Compact can assure users a high reliable embedded system.

- **Easy-to-Develop**

With the powerful Microsoft Visual Studio 2008 sp1, it is easy to accomplish from building OS image to develop software using C# or even design the user interface in Microsoft Silverlight, Windows Embedded Compact makes it so quick for us to realize our dream.

- **Extensible UI**

No matter which one the program employ, form or Silverlight, as its User Interface, Windows Compact 7 is in the lead of UI design and develop. The UI design experience on Windows Compact 7 is gorgeous. It is easy to design the form program and the C++ program with Silverlight under Visual Studio 2008.

- **IPv6 Ready**

Windows Embedded Compact 7 is an IPv6 ready operating system. And communication using IPv6 can be handled by socket programming. This can resolve the IP shortage problem in deploying our global-scale EcoSensSystem.

Microsoft Silverlight[10]

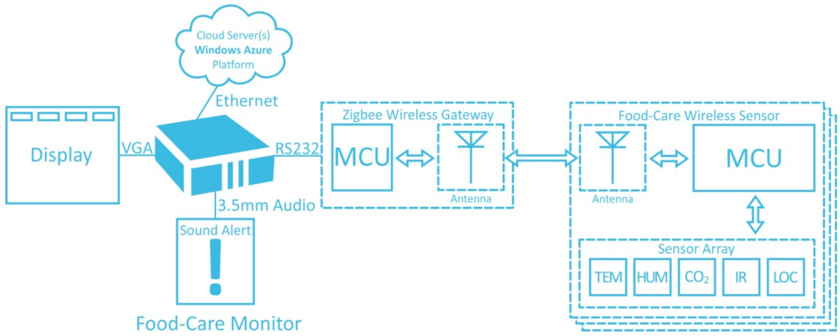
Silverlight is a powerful development platform for creating engaging, interactive user experiences for Web, desktop, and mobile applications when online or offline. Thus, we employ Microsoft Silverlight 4.0 to enhance the user experience on the webpage of E.S.S., and it has an excellent performance.

Windows Azure Platform[11]

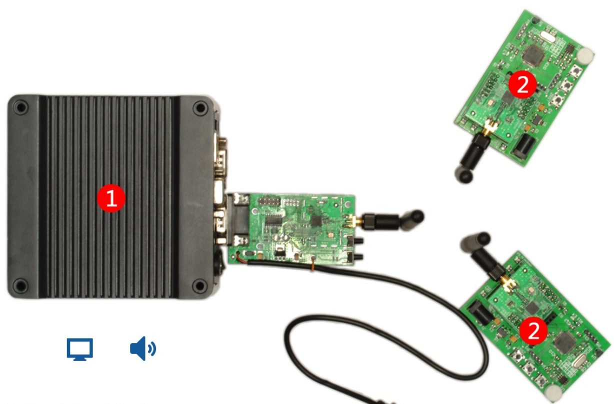
Windows Azure provides developers with on-demand compute and storage to host, scale, and manages web applications on the internet through Microsoft datacenters. By combining the rich user experience with Silverlight with the flexibility and scalability of Windows Azure compute and storage, applications of E.S.S. are more powerful and easy to use. As a global sensor network, E.S.S. should have the ability of huge data throughput and data handle capacity. Windows Azure Platform nicely gives us a chance to open a window for globalizes.

4.5 Embedded System in Detail

4.5.1 Hardware Architecture

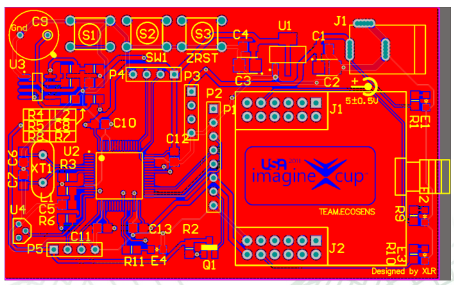


The hardware architecture of E.S.S. can be mainly divided into two parts: the Monitor and Wireless Sensor. There is a MCU with ZigBee Stack both in the Monitor and the Wireless Sensor. The ZigBee MCU serves as a ZigBee wireless gateway. With the ZigBee technology, one Monitor can exchange data with several Wireless Sensors, and Wireless Sensors can switch between networks quickly and intelligently. Thus, as the sensors move with the food transportation, Wireless Sensors can get automatically networked with different Monitors.



1. Food Care Monitor
2. Food Care Wireless Sensor(s)

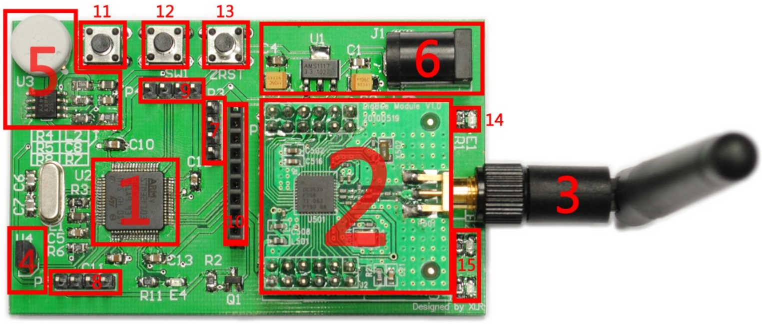
Monitor: The monitor is composed of an eBox-3310A-MSJK, a ZigBee wireless gateway, a display LCD and an alarm device. The MCU with ZigBee stack serves as the wireless gateway in the communications between the Monitor and the Sensors. The monitor communicates with the Server through the Ethernet Interface. A display device is connected through the VGA connector on eBox, and the food state information can be displayed on it constantly. When food is in bad condition, the audio output of eBox will send a voice alarm.



Wireless Sensor: Wireless Sensor consists of a microcontroller and a MCU with ZigBee stack and a food state sensor array.

We choose the STM32F103 as our microcontroller. The STM32 has the high-performance ARM Cortex™-M3 32-bit RISC core operating at a 72 MHz frequency, high-speed embedded memories (128 Kbytes Flash memory and 20 Kbytes SRAM), and an extensive range of enhanced I/Os and peripherals. With powerful core and rich peripherals, it turned to be an easy thing to drive food sensors and deal with the incoming data. The 2-wire SWD debug interface makes it simple to access the register in chip and program. The MCU of the Wireless Sensor can store collected food state data of long period in its own memory.

The sensor array includes temperature sensor, humidity sensor, infrared sensors, carbon dioxide sensors and a built-in ZigBee Location Engine which provides the information of the sensors' relative position. In consideration of cost and accuracy, we choose the DS18B20 digital temperature sensor made by Maxim and HS1101 relative capacitance humidity sensor made by Parallax. The HS1101 relative capacitance humidity sensor needs to work with TLCC555 timer IC and some accurate resistance, and then the microcontroller can get the value of relative capacitance by measuring the frequency of the TLC555's output.

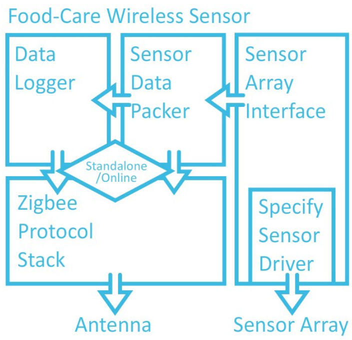


1. Microcontroller (STM32F103Rb)
2. Zigbee Module (CC2530)
3. Zigbee Antenna
4. Temprature Sensor (DS18B20)
5. Humidity Sensor (HS1101 & TLC555)
6. Power Unit
7. UART1
8. UART2
9. Debug Interface (SWD)
10. LCD Interface (Optional)
11. Programmable Button
12. Zigbee Test Button
13. Reset Button
14. Power Indicator
15. Zigbee Workstate Indicators

The ZigBee Module is composed by a CC2530 chip and its RF front end. The CC2530 made by TI provide the telecommunication in IEEE 802.15.4 ZigBee protocol controlled by STM32. The max rate of the wireless communication can reach 250Kbps.

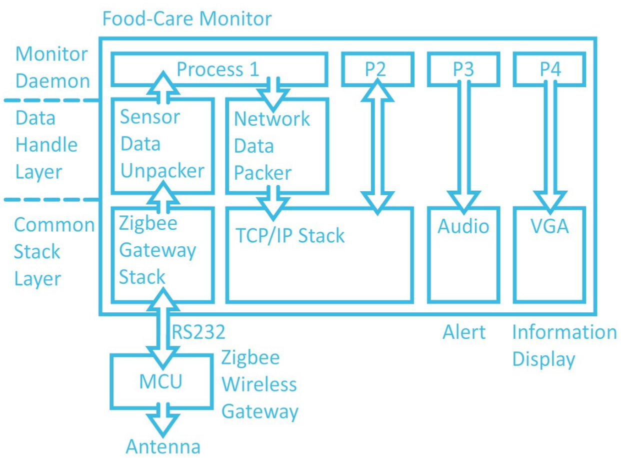
4.5.2 Software Architecture

The software of E.S.S. has been deployed in three places: Wireless Sensor, Monitor and Cloud Server. They are in different system layers and responsible for data acquisition, processing, and interaction.



Wireless Sensor: Wireless Sensors' processing unit is the STM32 MCU, which locates in the lowest layer of E.S.S.. MCU collects all data from the Sensor Arrays, and then makes the raw data unified packages through the Sensor Data Packer. To read the temperature data in DS18B20, we write the specific 1-WIRE Interface Driver. And for the HS1101 humidity sensor, we configured two TIM modules to form a frequency meter, and then translate the frequent to the relative humidity by the formula provided by HS1101 datasheet. All sensor data and the Unique ID (UID) are all tagged on XML label and packed into one package. When Wireless Sensor is in the Online State, the real-time XML data package will be sent to the Monitor through the ZigBee Module. The way of MCU controlling ZigBee module is an UART in CMOS voltage. The data transfer rate can be modulated for energy consumption reasons. When FCWS is in the Standalone State, real-time data packages will be kept into the Data Logger Module. And the package in Data Logger will not be transmitted to the Monitor until the Wireless Sensor is in the Online State again. Thus, the consistency of real-time food information is guaranteed to the largest extent.

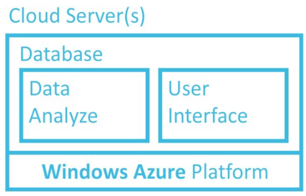
Monitor: The Monitor's main processing unit is eBox-3310A-MSJK, with 1.0GHz processor, 512MB RAM, Ethernet Interface, 2 Serial port, VGA, etc. Software architecture of the eBox can be divided into 3 layers: Communication Stack Layer, Data Handle Layer and the Monitor Daemon. We write our code in C# programming language under .NET framework 3.5.



Layer 1: Communication Stack Layer. It is composed of ZigBee Gateway Stack and TCP/IP Protocol Stack. It controls the transfer of data in the lowest layer. Communication Stack Layer and BSP make up the 1st to 4th Layers in the OSI model. Software designs in this layer are mainly about driver programming. And we have spent time on improving its performance and stability.

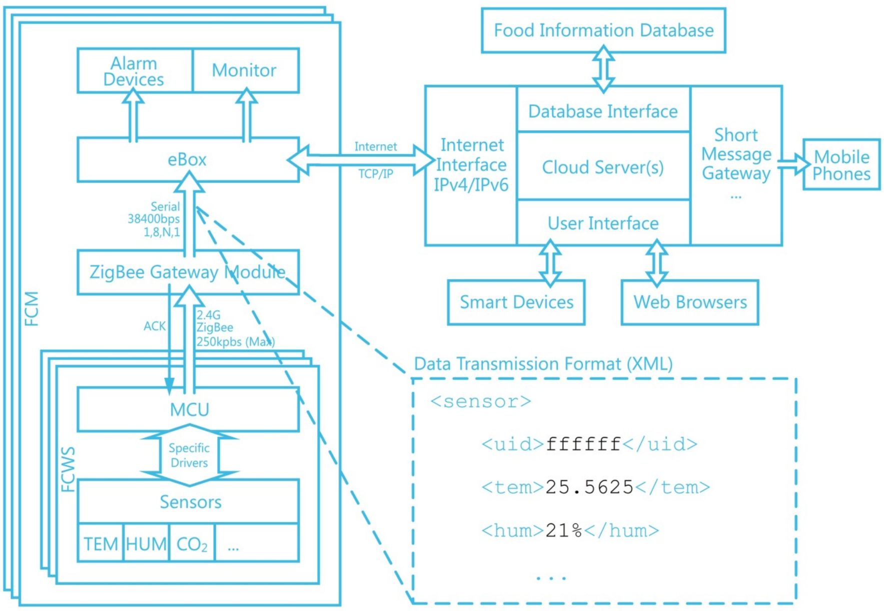
Layer 2: Data Handle Layer. It is composed of Sensor Data Unpacker and Network Data Packer. Sensor Data Unpacker processes the food state data from Wireless Sensors. It unpacks the XML sensor data and then sends the raw data to the Monitor Daemon. In the mean time, the Network Data Packer packages the data from both Wireless Sensor and eBox, and then transfer the package to the Cloud Server through the TCP/IP protocol.

Layer 3: Monitor Daemon. It is the highest layer and has the following four advanced functions: the monitor and alarm of the food state; controlling the sensor and the network data flow; displaying the food and environment state and enquiring the history information of food in its management from the server. The functions above will be achieved in the form of four different sub processes. The food-concerned information will be defined as Shared Data, and thus is available to all sub processes. These designs aim at taking full use of advantages of the Windows Embedded Compact, that is, multi-process, real time and highly reliability.



Cloud Server(s): Cloud Server is the provider of Cloud Service in E.S.S.. It has four main functions: record and analyze the food data uploaded by the Monitor; respond to the Monitor's or users' request for Wireless Sensor's historical information and be the user interface for the data display and generate statistic information in the form of Web. In addition, Cloud Server can warn person in charge of the emergency food storage situation using SMS. We use Microsoft Silverlight as our user interface in order to optimize the way of display and improve the users' experience. The Cloud Service is made up of high-performance network, database and algorithms of Statistics. We employ the latest Microsoft Azure Platform as the cloud-computing platform for E.S.S. to achieve the function of real-time record, processing and enquiries for large quantities of data.

4.6 Data Flow



The figure above shows the entire data flow of E.S.S. including 3 main transmission methods: the ZigBee wireless communication, RS232 Serial communication and the Internet TCP/IP communication. They are just like bridges connecting neighboring layers. Numerous FCWS send their real-time food data to the ZigBee Gateway Module. And the Module translates the ZigBee packages to serial data stream with XML labels. After data processing, the eBox displays the data on its display monitor and decides whether to raise the alarm. The eBox communicates with Cloud Server under the TCP/IP protocol. It is a full duplex way that the eBox uploads the real-time food data and get the statistic information from the server at the same time. The Cloud Server has the best data throughput capability, and it receives data from every FCM and corresponds to their requests. It has the Food Information Database as its storage. And the server provides user interface to display information to end users through webpages. It also connects to SMS gateway to send emergency short messages to the users in charge.

4.7 Data Processing

4.7.1 Data Processing in eBox

1) Emergency Detection

Once the detected temperature, humidity or other index of food are far from the normal level, eBox will release alarm in the form of message box, audio or SMS, etc. Thus, timely treatment is guaranteed to prevent unnecessary losses.

2) Calculation of Real-time Food Health Index

Food health index gives an integrated evaluation to the food status in storage, which will make it easier to monitor. In E.S.S., Food health index is given according to an AHP[12] (Analytic Hierarchy Process) model.

As is shown in Figure 1, temperature, humidity, carbon dioxide and other factors have different influences on food status. According to 1-9 measurement standard presented by Satty, the Pairwise Comparison Matrix is as follows:

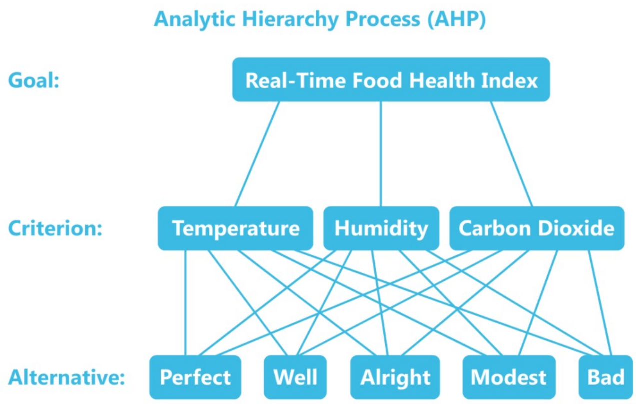


Figure 1

$$A = \begin{pmatrix} 1 & 1/3 & 5 \\ 3 & 1 & 7 \\ 1/5 & 1/7 & 1 \end{pmatrix}$$

Assuming that t, h and d represent actual detected temperature, humidity and carbon dioxide index of the food, and T, H, D represent corresponding normal level. Then according to AHP, the FHI (Food Health Index) can be calculated as follows:

$$\mathrm{FHI} = 0.2790 \times |t - T| + 0.6491 \times |h - H| + 0.0719 \times |d - D|$$

According to different FHI value, we divide the food status into different levels: “Perfect”, “Well”, “All Right”, “Modest”, “Bad”.

Meanwhile, FHI can also be defined using other models, such as FCA (Fuzzy Cluster Analysis), ANN (Artificial Neural Network), Grayscale Model.

4.7.2 Data Processing in the Server

1) Food Comprehensive Health Index (FCHI)

Food health condition will naturally worsen as time goes on. The current food health has a lot to do with its historic status. Thus, a food comprehensive index is greatly needed. In order to simplify the processing process, discrete mathematics is used.

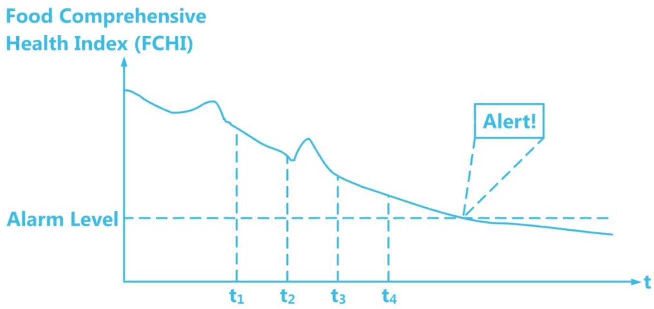


Figure 2

Assuming that there are totally N records between t_2 and t_3 stored by data base. As we can see in Figure 2, then FCHI can be calculated as follows:

$$\mathrm{FCHI}_{t3} = \mathrm{FCHI}_{t2} - \sum_{i=1}^{N} |t_i - T| \times P_{ti} - \sum_{i=1}^{N} |h_i - H| \times P_{hi}$$

Where FCHI_{t3} represents the food comprehensive health index at t_3, FCHI_{t2} represents the food comprehensive health index at t_2, P_{ti} represents temperature’s influence on food comprehensive health at t_3, P_{hi} represents the humidity’s influence on food comprehensive health at t_3.

2) Food Life Prediction

According to historic food status data in the SQL Database, the temperature, humidity and carbon dioxide concentration variation curve can be drawn easily. Through these curves, besides figuring out historic variation of the food status, we can also predict future status and food life by using interpolation fitting. These predicted food information will be of great use for the buyers.

3) Food Distribution and Scheduling Optimization

- The Amount of Food In Specific Region

  Data uploaded from FCWS contains real-time position and amount of food distinguished by a unique ID of FCWS. Thus, these data will make sense until all these food are finally consumed. So, we can calculate the food distribution in different regions.

- Food Scheduling

  Based on current food distribution carried out by E.S.S., a more economic and optimal fitting scheduling project will be offered.

  As for food importers, they can identify the most proper food provider to minimize transportation expenses or transportation time.

  As for food providers, they can choose an economic transportation scheme by solving an optimal model. The object of this model is to minimize the amount of transportation cars and the distance of transportation. An ant colony algorithm[13] is needed to solve this model.

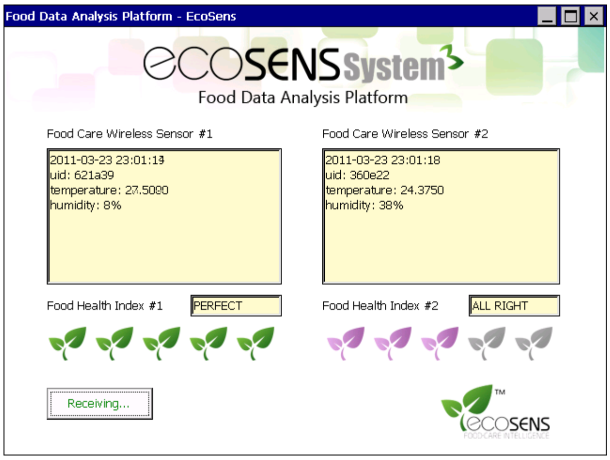
  Imitating capacity of ants searching shortest path between nest and food, we make use of artificial ant leaving a certain message when finding out optimal solution and its memory function will adjust the message next time it pass this path. At last, when the superiority of solution does not evolve, we will get the needed solution.

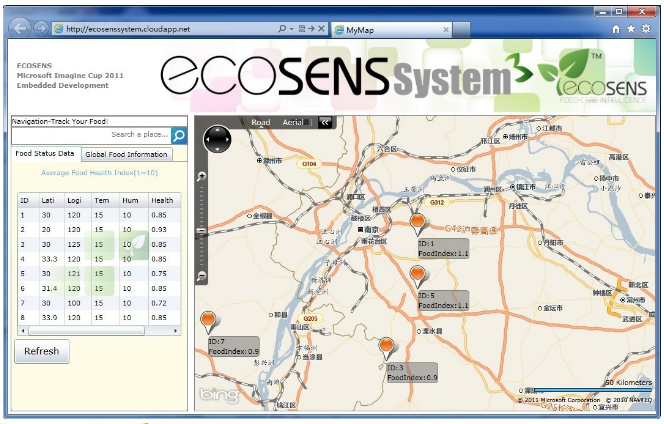
4.8 User Interface

The actual users of E.S.S. can be divided into two classes: administrators and ordinary users. To meet the demand of different users and be user-friendly, ECOSENS designs two different interfaces for different occasions. These two interfaces combine to make it easy and convenient to manage the whole system and to participate in the global food aid.

4.8.1 Interface Through eBox

The interface through eBox is available to administrators only. Major functions of this interface are to display real-time food storage information and give alarms when food is in bad condition. Through a screen connected to the eBox, administrators can get access to real-time food storage information from all the sensors within its communication coverage, including temperature, humidity, carbon dioxide, location, etc. Meantime, a food health index from each storage position is calculated and displayed on the screen. The eBox monitor the real-time health of food within its coverage. Once any part of food is detected in bad condition, an alarm message box will appear on the screen and a SMS will be sent to administrators in charge at the same time.





4.8.2 Interface Through Internet

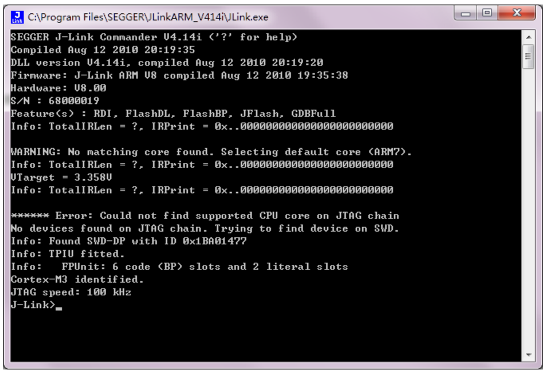
The interface on web is open to people all over the world, but only the administrators can do some operations and management through the web page. With a network device, everybody can acquire food information of the world and help in the fighting for food crisis.

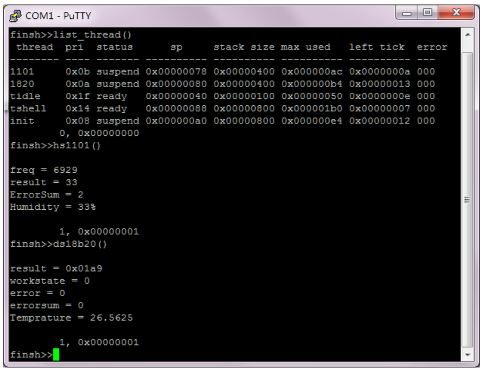
The function of this web page is more systematic and complex than the previous one. Besides food storage information display, the Bing map in the webpage plays more important role in food distribution and aid.

The position of each food storage place will be marked as a point on a map of the webpage. Real-time grain reserves at each point will be summed and displayed on the map. Through the map, administrators can find out and monitor the current food distribution condition for themselves. Also, according to each region's characteristics, E.S.S. evaluates the current distribution lines and gives an optimal suggestion on food distribution. Besides, dynamic global food situation is displayed on the map, which will make it easier for people to participate in solving the crisis.

4.9 Testing and Performance Analysis

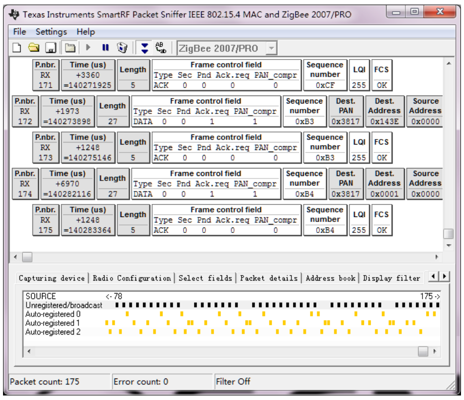
White Box Testing[14]

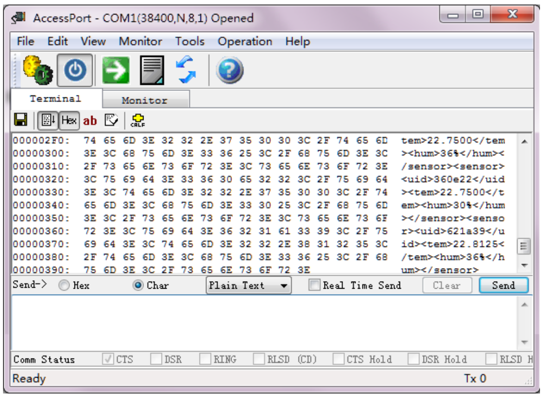




White box testing in E.S.S is performed through the ARM SWD debug interface and the debug & remote tools for Windows Compact 7. We use the JLink debugger for ARM to monitor specific registers including the Data Register of UART, Systick Clock and several interrupt status. We also check the contents of the variables and buffers to affirm that the sensor data can be achieved and transmitted as is programmed. And with the KITL (Kernel Independent Transport Layer) build option enabled when building OS image, we observed the VS2008 IDE's Output of the eBox to prevent the process crashing and memory leak. We also make remote debug in VS2008 to locate the mistake of program.

Black Box Testing





Black box testing in E.S.S is performed by the PC through many monitor softwares. The first one is the SmartRF Packet Sniffer. With RF hardware (another CC2530 and a CC debugger) connected to the USB port on PC, it allows us to sniffer the wireless ZigBee package in the air. Then, we can check the ZigBee function packets and the unsecured data in payloads. The second software is AccessPort. It is an advanced serial monitor, simulation and RS232 data analysis tool. We can monitor the serial data sent to the FCM eBox by using the AccessPort, finding whether the data is transferred successfully or not. We also use it to stimulate normal and abnormal data packs to test the reliability and robustness of the FCM.

Performance Analysis

After testing all the transmitting procedures, we made several conclusions: The ZigBee transfer has been proved stabilized in sufficient level for we have monitored its transference for a week and find no mistake (thanks to the error correction mechanism provided by the ZigBee standard). The network entry delay of FCWS can be controlled within 3 seconds. The delay of refreshing data in SQL Server is about 5-6 seconds depending on network status and the server load. That means the data from the sensor array can be transferred to the user in a very short period of time. And we believe, with further optimizations, the efficiency of E.S.S. will be improved to a higher level.

4.10 Cost Analysis

The Cost of Each FCWS

Component	Model	Price	Accuracy
STM32 Microcontroller	STM32F103Rb	$2.3	
MCU with ZigBee Stack	CC2530	$3	
Temperature Sensor	DS18B20	$1	±0.5℃
Humidity Sensor	HS1101	$1.5	±5%
Timer for HS1101	TLC555	$0.5	
PCB and Electronic Components		$2	
Totalize		$10.3	

Cost Comparison between the Food and FCWS

Grain Categories	Food Quantity	Food Price	$ FCWS/food
Rice	93.75t	$48450	0.021%
Wheat	97.5t	$28275	0.035%
Corn	101.25t	$31387	0.032%
Estimated detection volume: 5×5×5 （m³）			

The Cost of Each FCM

Component	Price
ZigBee Gateway Module	$5
eBox-3310A-MSJK	$275
Alarm device	$10
Totalize	$290

5. Market Analysis

5.1 Target Customers

Main buyers of E.S.S. range from food producers, transporters and sellers to relevant food monitor and management institutions, organizations or governments.

5.2 Competitive Analysis

Traditional solutions to food crisis focus more on increasing agricultural production. These solutions do increase the crop yields to a certain degree. However, it's really hard for the rate of food production growth to exceed that of the population growth in the short term. Although a lot of money and time have been taken in this area but its effect is still unsatisfactory. At the same time, increasing the crop yields is not adequate in solving the crisis.

There have been some products focusing on food storage and minimize the food loss. But these products can't give food care anywhere as well as E.S.S., and they are mostly fixed in one place and can't move with food. Also, they don't build a systematic network and they can't get food distribution information nationwide or worldwide as easy as E.S.S.. What's more, the cost and power consumption of current products is usually high.

Seldom products are found to help solving the food distribution and food aid problem with the combination of hardware and software in practice partly because these products haven't succeeded in building a global food-care network.

5.3 SWOT Analysis

Strengths	Weaknesses
• Low power consumption and low cost • Multi-zone network system, food-care anywhere and anytime • Friendly user interfaces, easy participation and Easy management • Integrated multi-functional solution to food crisis	• Recycle of wireless sensors will cause extra work.
Opportunities	**Threats**
• Hunger and poverty has been a global social problem, many governments or organizations are investing on the problem. E.S.S. has a bright market prospect. • New development in technologies will make the hardware and software function more and more powerful.	• Long-term test and further research on E.S.S. is needed. • It's unknown that whether or not the battery of wireless sensors will cause secondary pollution.

6. Project Status & Next Stage Overview

As the ECOSENS team has already released the EcoSensSystem Beta, including the FCWS PCB board, the FCWS program on microcontroller, ZigBee Module and Gateway, Food Data Analysis Platform application on FCM, EcoSensSystem Database and EcoSensSystem website. And next stage we will do the following things according to the timeline.

7. Conclusion

High food prices have been sweeping around the world and the current food situations are extremely critical. Numerous poor people are suffering from famine without timely and adequate food aid. Meanwhile, large amounts of food are being lost because of the lack of effective monitor in other parts of the world. Though, hunger has been broadly concerned, and no solution has proved to have handled it effectively.

E.S.S. will be a better solution than previous ones because it is an integrated solution which will not only reduce food losses but improve food aid and scheduling as well. It establishes a global intelligent food-care network, which guarantees comprehensive and effective food-care from production to consumption. Unnecessary food losses can be minimized as much as possible. Also, after data processing with specific algorithms, E.S.S. will help a lot in food aid and food scheduling and will raise more social awareness of food aid. Thus, it will be of great help for the poor to get rid of hunger in practice.

Besides saving more food, improving food aid and optimizing food scheduling, E.S.S. is also low-cost, low-power, environmentally friendly and easy to use. It can attract investments from social organizations, governments or merchants of food industry and have a bright market prospect. Once put into actual use, with more detailed feedback from users, E.S.S. will have unlimited potentials and perform more excellently in solving the food crisis.

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