ISSN 2234-3075(Print)
ISSN 2288-7806(Online)
Http://dx.doi.org/10.14771/AIM.6.2.2

Status of ICT Convergence Smart Quality Distribution Technology for Food Quality and Safety Management

Jong Hoon Kim · Ji Young Kim · Byeong Sam Kim

Abstract The world is in the process of a structural change related to ICT convergence knowledge industries. ICT is leading to the creation of new products and services, and is making our lives more convenient, safer, and more efficient. In advanced countries, many studies have been conducted with the goal of developing new business models converged with ICT, and this is also the case in the food industry. Korea possesses world-leading ICT, and if this ICT is applied to the food industry, a world-class new business model can be developed.

The u-Food System, which is in the process of development in Korea, is a next-generation food system that can allow food providers, consumers, and distributors to access various types of information about food products, including traceability, distribution, safety, quality, and freshness, and manage this information. It is a future food system that converges ICT, biotechnology and sensing technology with food.

Based on the u-Food System, this paper will introduce the status of current smart quality distribution technologies that converge ICT (such as sensor tag, sensor network, LBS, GIS, and CDMA) with food technologies (such as traceability, quality, distribution management) to manage the safety and quality of fresh food in the distribution process.

Keywords ICT Convergence, Smart Distribution, Food Safety, Food Distribution, u-Food, Sensor Tag

1 Introduction

The world is currently in the midst of a structural change due to ICT convergence knowledge industries. ICT will bring about new products and services that make our lives more convenient, safer, and more efficient. Across the automobile, shipbuilding, aviation, health care, construction, and national defense industries, new convergence products and services involving ICT have been developed. In advanced countries, many studies have been conducted with the goal of developing new business models converged with ICT, including in the food industry. Korea possesses world-leading ICT, and if this ICT is applied to the food industry, a world class new business model can be developed.

Major countries around the world are creating added value through the promotion of their food industries, and are pursuing employment and economic growth through export expansion. The Korean government is following this global trend and has been promoting the domestic food industry. In 2011, the total food market size of the top 20 countries was 2,199 billion dollars, accounting for 82% of the world market. Korea was ranked 15th, accounting for 1.2% of the world market. (Food distribution yearbook of Korea, 2013)

Food accidents in the food distribution process increase

J. H. Kim · B. S. Kim · J. Y. Kim
Food Distribution System Research Group, Division of Platform Technology Research, Korea Food Research Institute

J. H. Kim
e-mail : jhkim@kfri.re.kr

B. S. Kim
e-mail : bskim@kfri.re.kr (✉)

J. Y. Kim
e-mail : jykim@kfri.re.kr

every year. The refuse and loss rate of processed food because of a lack of distribution management amounts to 4%, and is estimated to be worth around 1,200 billion Korean won a year (Moazine, 2005.5). As well, the refuse and loss rate of fresh food amounts to more than 25%, which is estimated to be more than 7,000 billion Korean won of economic loss per year (Korea Postharvest Management Association, 2009). Recently, the food industry has been shifting to a new paradigm of LOHAS (lifestyle of health and sustainability), which pursues health and sustainability. In order to satisfy consumers' consumption desires for fresh and safe food, a food distribution system based on IoT that converges a system quality management system, formerly limited to the microorganism field, with system engineering, ICT, and BT is required.

For the safe management of food, a Food Chain Approach is suggested that provides comprehensive management throughout the entire process from production to consumption, to provide consumers with foods that are safe from various hazards including chemical substances and microbes. The Food Chain Approach is a method to systematically manage the whole process from production through consumption and open the process transparently. GAP (Good Agricultural Practices) should be adopted for ingredient production, GMP (Good Manufacturing Practices) and HACCP (Hazard Analysis of Critical Control Point) for processing and GHP (Good Hygienic Practice) for food consumption. Technology for monitoring, bidirectional controlling, and tracking of traceability, quality, stability, and various environmental information of food (temperature, humidity, gas, real-time route, and so on) is needed. Moreover, in order to secure food safety and reduce the refuse and loss rate of food, a system is required that can monitor and control the status of food products and the distribution status throughout the processes from production, to processing, distribution, sales, and consumption, in real time.

Advanced countries including the United States, Japan, and the EU have introduced ICT to food production, food safety management, and the food distribution industry to secure transparency in food distribution and utilize it in production management, quality management, and distribution and logistics management. Regarding the trend of ICT technology for the safe distribution of food, these days, safety/quality management utilizing RFID/USN, real-time management of distribution information, and recently the use of quality management technology during the distribution process by utilizing smart sensors are attracting interest. In the 1980s, Temptime/3M (US) introduced IT for the purpose of freshness management of food. After the 1990s, Infratab (US), Cool Chain Group (Germany), Stepac L.A. (Israel) and more companies proceeded with the development of technologies involving RFID and sensor network solutions for the safe distribution of food. Like other industries, the food distribution industry has also been significantly changed by ICT, the materials industry, environmental changes, the development of human engineering, and social changes. Recently, food e-commerce has been active and new concepts such as e-pedigree standard, universal design, and sustainable distribution have been introduced and become more common.

Also in Korea, the Korea Food Research Institute launched the u-Food project, converging ICT technology on the basis of food. Since then, core source technologies including food quality management sensors, intelligent food distribution, environmental control systems, smart storage, and food quality monitoring have been developed. u-Food System is a next generation food system to provide various information about food including traceability, distribution, safety, quality, and freshness to providers, consumers, and related people involved with distribution, and manage the information. It is a future food system converging ICT, biotechnology, and sensing technology with food. This study will discuss the status of smart quality distribution technologies that converge ICT with food technology to enable the management of the safety and quality of fresh food in the distribution process based on the on-Food System.

2 Patent Trend

Since the year 2000, a total of 160 applications for overseas patents related to smart quality distribution of food have been made. Highly relevant patents started to be submitted in 2003, and there was a significant growth trend in this area between 20011 and 2013. When it comes to the number of patent applications, China has shown the highest patent share with 60 patent applications (43.75%) and the United States has 42 patent applications (26.26%), Korea has 17 patent applications (10.63%). Priority countries are China with 64 cases (40.63%), the United States with 54 cases (33.75%), and Korea with 16 cases (10%). As for the number of patent applications by inventors, Kim Byeong Sam (Korea Food Research Institute) applied 4 of the most relevant patents and Ying and Zhang of Zhejiang University of China applied 2 patents each.

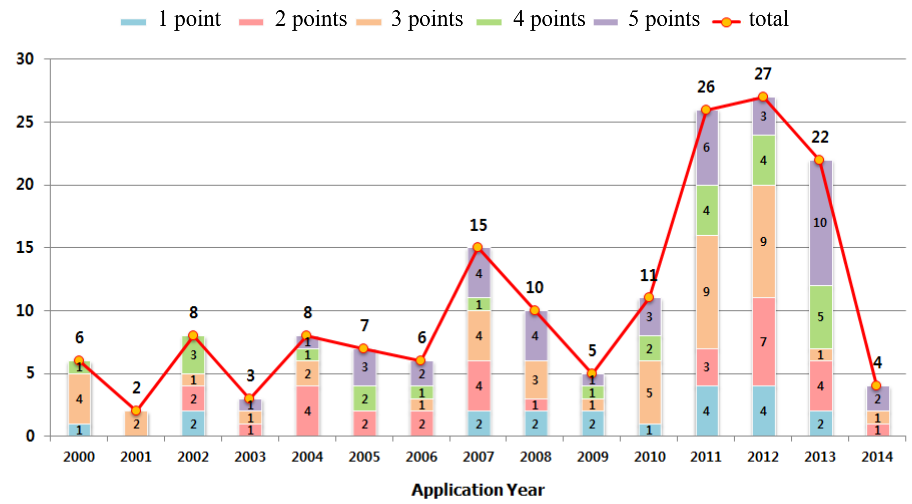

Fig. 1 Status of overseas patent applications and disclosures, by year

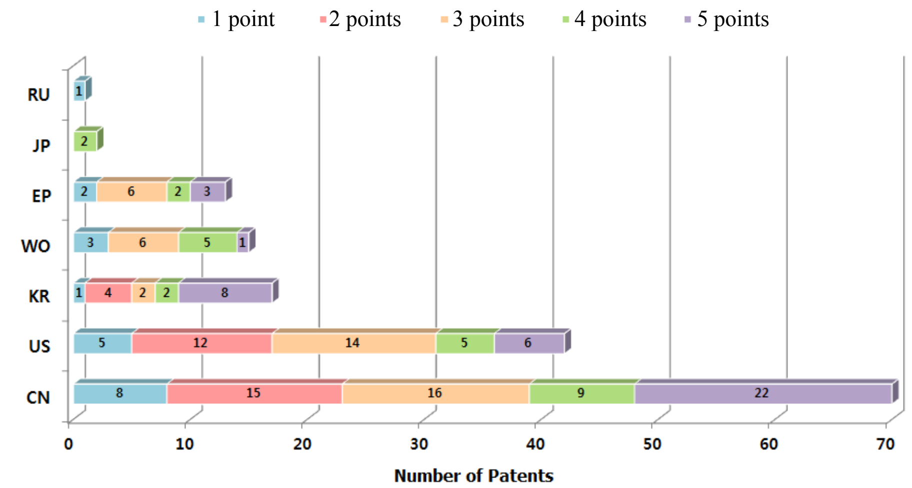

Fig. 2 Relativity and the number of patent applications, by country

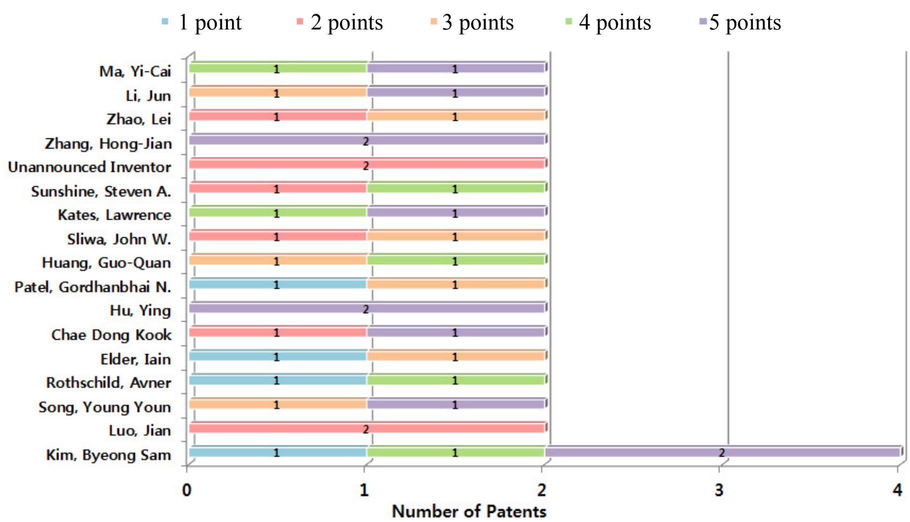

Fig. 3 Status of patent applications by the world's major inventors

Valid data of patents and theses based on patent application dates from the United States, Japan, and Europe were analyzed through data mining, and from each cluster 15 element technologies were derived reflecting keyword frequency, relativity, and expert opinions. Table 1 has 15 technologies. These are technologies with a frequency of more than 30% (frequency means the number of patents and theses in which the keywords of each technology appear) and a relativity of 7 or higher (relativity means the number of patents and theses in which 2 keywords or more appear.)

Table 1 Food smart quality distribution element technologies through clustering

	Related keywords	Relativity	Element technology
1	customer, item, service, order, food, order, food, RFID	10-24	Remote order using RFID
2	customer, item, service, order, food, order, food, RFID	15	Automatic cooking system
3	shelf life, food, management, check	9	Food expiration date management system
4	beverage, preparation, capsule, operation	15-18	Food provision system using capsules
5	information, storage, retrieval, hand-held, food, temperature, collection, service, facility, safety	17-20	Food storage temperature auto search system
6	production, monitoring, traceability, quality	20-21	Food production record tracking system for quality management of food
7	product, information, search, distribution, system, grocery, item, sale, GUI	8	Food information provision method based on GUI
8	sales, retail, business, food, restaurant, touch, screen	18-21	Food sales support system using touch screen
9	refrigerator, temperature, user, interface	17-22	Smart refrigerator using user interface
10	ubiquitous, sensor network, food, information, kitchen, appliance	7	Food hygiene management system based on USN
11	RFID, food, delivery, management, monitoring, temperature, distribution	15	Quality management system of distributed food using RFID sensor tag
12	barcode, cooking, food, information, identification, traceability	21-24	Food examining machine using RFID and QR code
13	restaurant, kiosk, customer, quality, traceability, manage	14-18	Food quality information and traceability management kiosk
14	sensor, biosensor, pH, diagnostics, food, feed, quality, control, foodstuff,	10	Quality management sensor
15	environmental monitoring, system, food, circulation	15-20	Smart food distribution environment control system

From the recent patent ratio[1] and PFS[2] of each element technology of food smart quality distribution, it is analyzed that technologies 6, 12, and 14 have higher than average recent patent ratios and PFS, meaning that technology development has recently been active and the number of family patents is high. Technologies 2, 3, 4, 8, 11, and 13 were analyzed to have lower than average PFS and recent patent ratio. As for Technologies 9, 10 and 15, it was found that they have lower than average PFS, and the number of patents is relatively low but the recent patent ratio is higher than average. Technology 7 has a lower than average recent patent ratio, but PFS was higher than average and the number of family patents was high.

1 Recent patent ratio: international patents and official patents granted after 2008
2 PFS : computing the number of family patents to present the level of advancement into overseas market

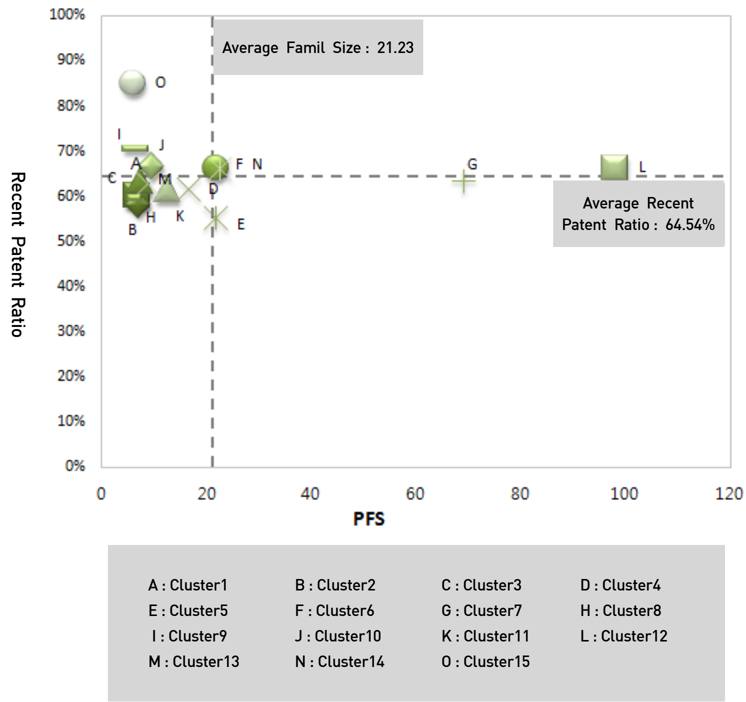

Fig. 4 PFS/recent patent ratio by element technology

Technology level analysis was conducted using average CPP and average TS, the patent citation relationship appeared in the United States patent to analyze the technical competitiveness and originality by major IPC. As a result, it was found that technologies 5, 6, and 14 have higher than average TS and CPP, meaning that they have high technology competitiveness and originality. Technologies 3, 4, 7, 8, 9, 10, and 15 have lower than average PFS and recent patent ratios. Technologies 11 and 13 have lower than average TS, meaning that their competitiveness is relatively low, but their CPP is higher than average, showing that their originality is high. Technologies 1, 2, and 12 have lower than average CPP but higher than average TS, meaning that their technology competitiveness is high.

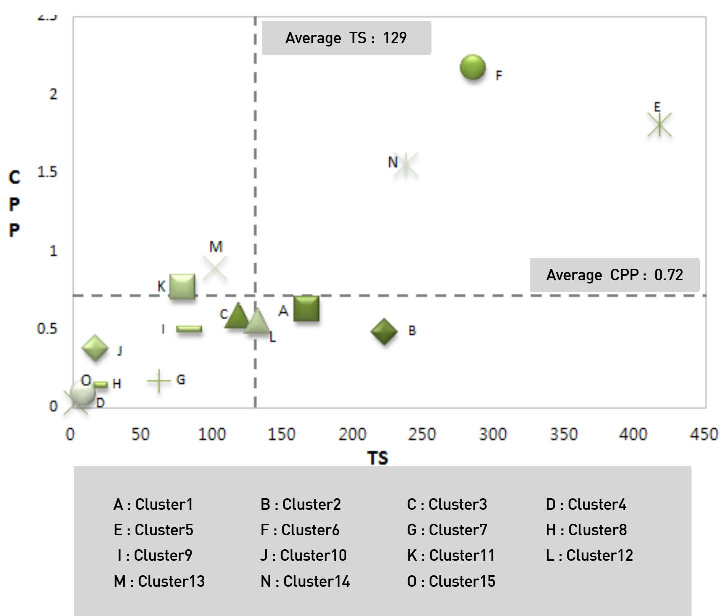

Fig. 5 CPP / TS by element technologies

Technology barriers for international patents were analyzed. Through the analysis on technology barriers by major IPC using patent approval rate and number of claims, it was found that technology 5 has higher than average values for all the items. Technologies 3, 9, 10, 11, and 14 have lower than average numbers of claims and higher than average approval rates. Technologies 6 and 13 have lower than average approval rates and higher than average numbers of claims. Technologies 1, 2, 8, and 15 have lower than average approval rates and numbers of claims, meaning that the patent barrier of the technology is low and they are a candidate group for strategic products that small and medium-sized companies can easily attempt.

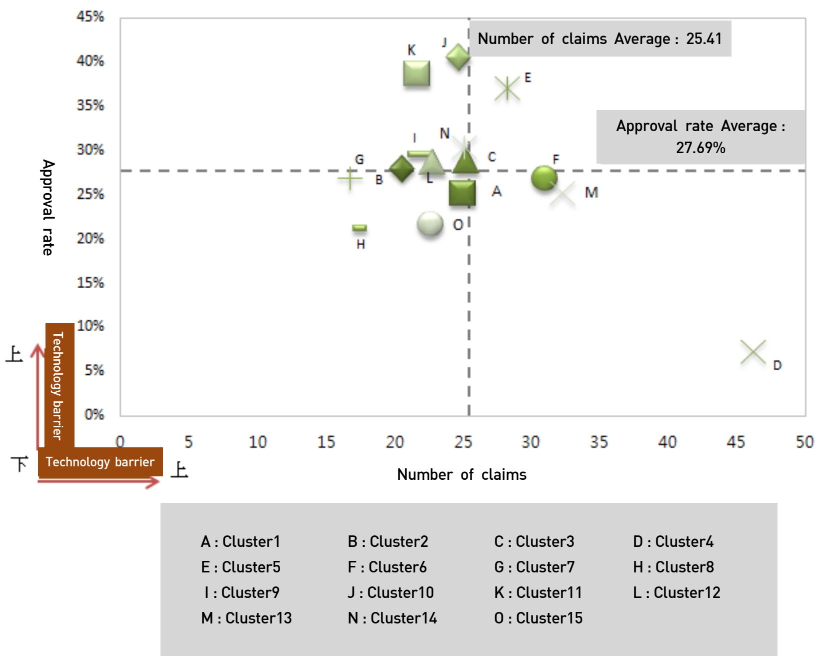

Fig. 6 Technology barrier analysis by element technology

3 Food smart quality distribution system

The food smart quality distribution system converges IT (such as sensor tag, sensor network, LBS, GIS, and CDMA) with food technologies (such as traceability, quality, distribution management). RFID sensor tag, communication unit, real time sensing and communication and food quality prediction technologies were applied. This system is capable of managing quality throughout the distribution process of fresh foods, from production to transportation, storage and sales.

Fig. 7 Food smart quality distribution system converges IT with food technologies

The conventional food quality management focused on the fastest way to respond to an emergency. But now, the focus has shifted to a system capable of preventing quality problems before they occur. The food smart quality distribution system is capable of managing quality throughout the distribution process of fresh foods, from production to transportation, storage and sales. The distribution processing center monitors the storage facilities and workplaces. During distribution, the system sends temperature, humidity and location information collected from sensor tags in real time through WCDMA. In the situation room, we can respond to any emergency in the distribution environment in real time.

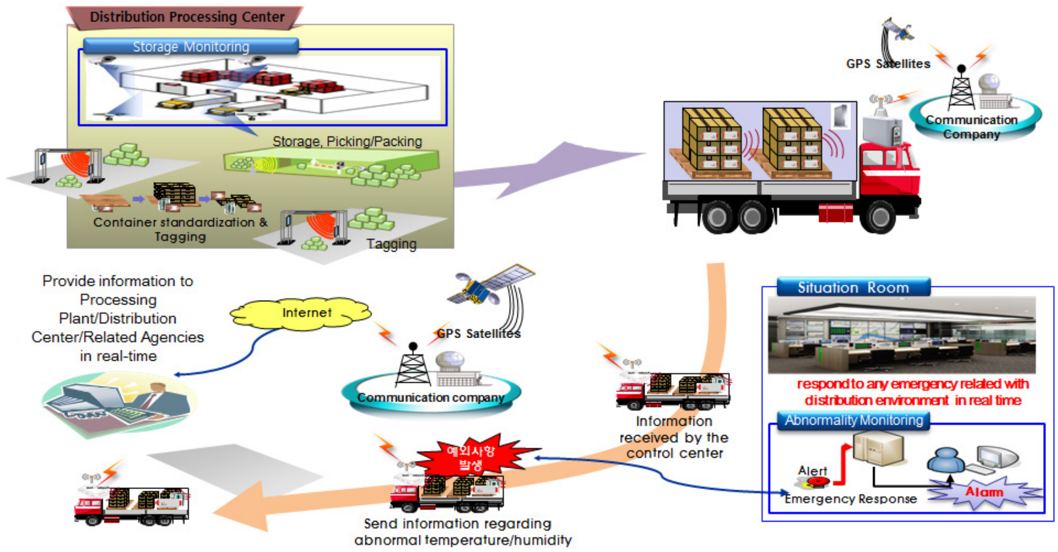

Fig. 8 u-Food based food smart quality distribution system

4 Technologies

4.1 RF Sensor Tag

The Sensor Tag for food quality management is an end-device of the smart quality distribution system that collects and stores information on the food distribution environment to transmit it through RF in real time. It includes the sensors needed for food quality management such as temperature sensor, humidity sensor, and gas sensor. Sensor tag consists of antenna, sensor, MCU, and battery. It was developed to collect food distribution environment data, including information on temperature, humidity, gas, and so on. The collected data is transmitted to the RF reader to be sent to the server through the network in real time.

The RFID sensor tag board consists of RF block and digital block hardware of RFID sensor tag board. The digital block of the RFID sensor tag board is realized using a low-power high performance MCU, and it is in accordance with the transmission standard of EPCglobal Class1 Generation2. Also, the NFC sensor tag for food quality management was developed, enabling consumers and managers to check the data on-site using the NFC (Near Field Communication) function of smart equipment.

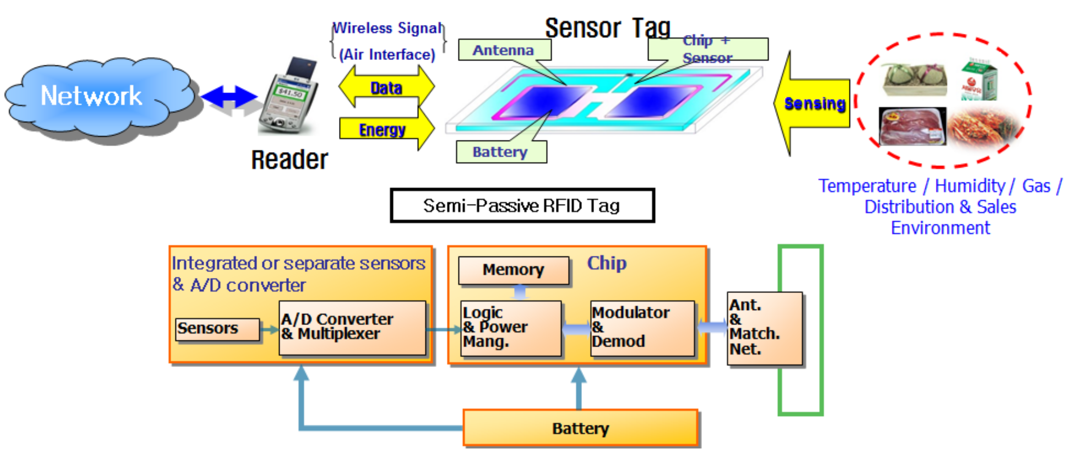

Fig. 9 Sensor tag for food quality management

4.2 Real time sensing and sensor network

In order to build an IoT-based smart quality distribution system, sensing technology is needed to manage the quality factors including decomposition and freshness of food by quality control lots such as separate packaging of food, box, or palette. Recently, smart sensor development using IT and MEMS (Micro Electro Mechanical System) technology has been ongoing in many industries, and smart sensor development for food quality management has also been attempted in the food industry.

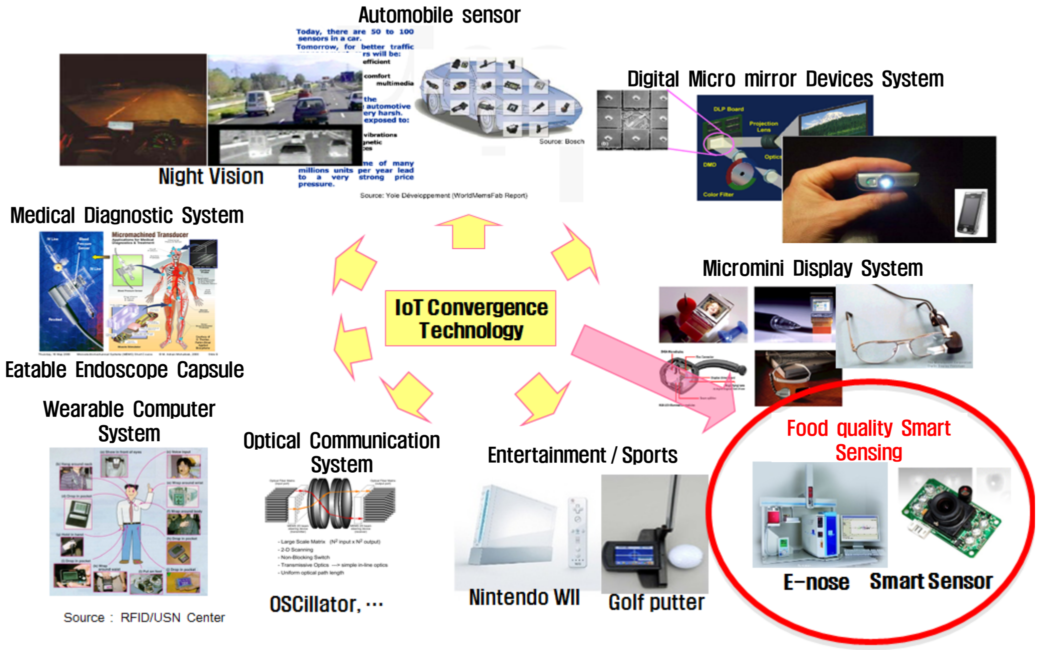

Fig. 10 IoT based smart sensing system

For the smart sensing technology for food quality management, technology to detect quality abnormalities during the distribution process using non-destructive quality analysis technologies such as E-nose and NIR (Near Infrared Response) should be developed first, and then sensors for food quality factors should be developed using the technology. For the smart sensor to detect decomposition factors in the production, storage, and distribution processes of food, smart sensor node technology of 30ppb detection level within 1.2 hours is in the process of being developed, by combining sensor node with gas sensor array based on sensing technology for decomposition gases by food item group.

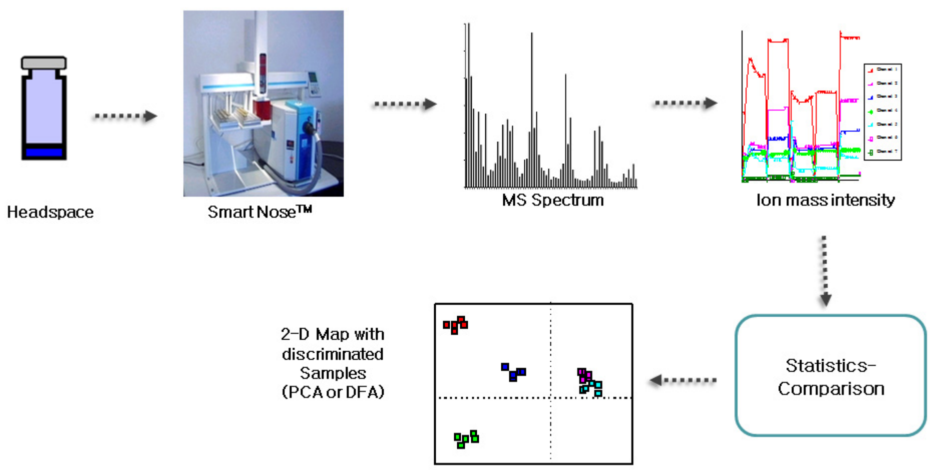

Fig. 11 Food quality factor sensing using E-nose

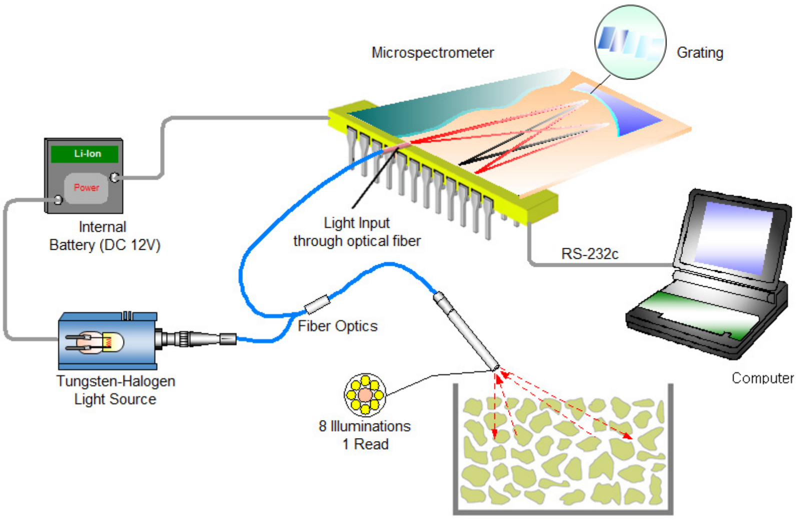

Fig. 12 Food quality factor sensing using NIR

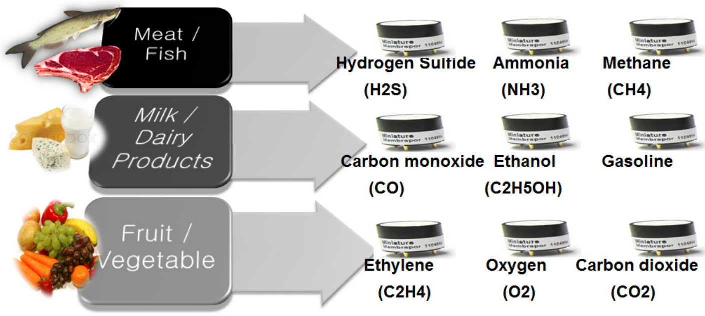

Fig. 13 Sensor factors by food item group available to use for smart sensor

Also, in order to monitor the quality changes in real time during the food distribution process and pre-emptively address any potential quality abnormality, information of temperature, humidity, and quality factors collected at the sensor tag should be transmitted to managers or consumers in real time. To this end, a communication unit was developed for this research. A communication unit is a device to transmit information collected at the sensor tag and the location information of fresh food to the server in real time. It consists of sensor tag reader, GPS, and WCMA modem. Since the communication unit uses WCDMA, real-time data transmission is available wherever a mobile phone is available. One communication unit can control 200 sensor tags in real time through a mesh network.

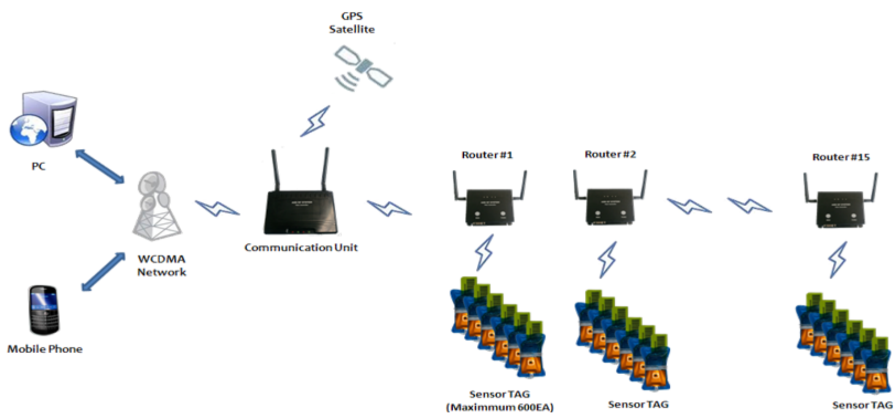

Fig. 14 Real time sensing and communication

4.3 Food quality prediction technology

Food quality prediction technology is one of the core technologies of the smart quality distribution system. It predicts the freshness of food based on factors in the distribution environment, including temperature and humidity. We developed a kinetic model that considers chemical reaction, which is capable of calculating a freshness index and controlling freshness.

The food quality prediction model is developed in four levels. First, TTT (time-temperature-tolerance) data of enzyme reaction, pigment destruction, nutrients destruction, and microorganism propagation that occur inside the fresh food because of the external environmental changes are analyzed. Second, a quality index for each food group that considers factors such as general bacteria, fatty acid value, titratable acidity, and sensory preference is selected using the analyzed database. Third, a mathematical model with which quality can be predicted is selected from among Arrhenius model, Kinetic model, Baranyi & Roberts model, Hills & Wright model. Fourth, model parameters that show the minimum error between real value and estimated value are determined using a repetitive operation program and the estimated accuracy level of the model is verified (accuracy factor, bias factor, r2) using the quality factor data analyzed in the environment of changing temperature, which is the real distribution environment, and finally a prediction model for various food groups is developed.

$$t_{\text{remaining shelf-life}} = t_{\text{total shelf-life}} - t_{\text{current}}$$

$$N(t) = \frac{N_{\max}}{\left[\dfrac{(N_{\max} - N_0)\left(\dfrac{1+s_0}{\mu_{\max}(T_{MK}) - k_n s_0} k_n + 1\right)\exp(k_n t)}{N_0\left(\dfrac{1+s_0}{\mu_{\max}(T_{MK}) - k_n s_0} k_n \exp((k_n + \mu_{\max}(T_{MK}))t) + 1\right)} + 1\right]}$$

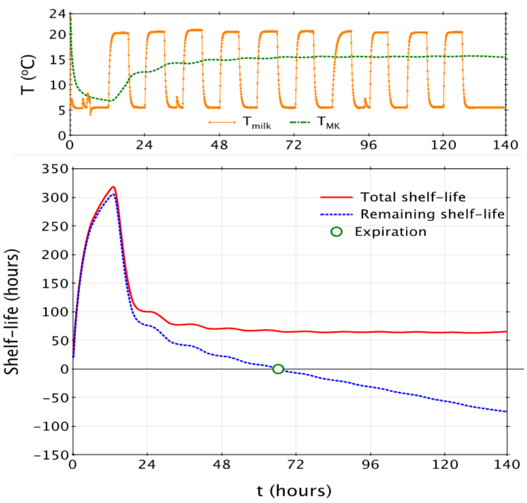

Fig. 15 Mean kinetic temperature (MKT) model to estimate the remaining shelf-life

4 Conclusion

The world has evolved through agricultural, industrial, and information societies into an IoT society. The IoT society is a new society in which physical space and electronic space are combined. As with any other period of social change, in the IoT society, it is those who adapt well who will succeed. For the food industry, the time to ask "Should we introduce ICT?" is long past. Now, it is time to think about "How we can introduce ICT." Regarding ICT, while technology development is important, convergence with other industrial technologies and creating a useful business model is critical.

The u-Food System, which is in the process of development in Korea, is a next-generation food system that can allow providers, consumers, and distributors to access various types of information about food products, including traceability, distribution, safety, quality, and freshness, and manage this information. It is a future food system that converges ICT, biotechnology and sensing technology with food.

This paper introduced the status of the current smart quality distribution technology that converge ICT with food technologies to manage the safety and quality of fresh food in the distribution process based on the u-Food System. The smart quality distribution system is a system that enables quality control throughout the whole distribution system, from production to transportation, to storage and sales. As the smart quality distribution system is a system in which IT including sensor tag, sensor network, and LBS is converged with food technologies to manage the traceability, quality, and distribution of food, it is expected that the introduced technologies will be applied to the food distribution industry to help the domestic food distribution industry develop to the world's highest level.

Reference

Ayers, J. et al., (2010). “An Ultralow-Power Receiver for Wireless Sensor Networks”, IEEE JSSC.

Cho, S. I., Ki, N. H., Chung, C. J., KIm, J. I. & Cheong, B. H. (1995). Development of modeling technique for land re-arrangement using GIS, Journal of the Korean Society for Agricultural Machinery, Vol. 20, No. 2, pp. 173-179.

Chong, K. W., Kim, J. C., Kim, J. I. and Lee, W. J. (2008). A System for Analyzing Data Transmission Time in a Ubiquitous Sensor Network, The Journal of Society for e-Business Studies, Vol. 13, No. 2, pp. 149-163.

Heo, D.H., Kim, J.H. & Kim, B.S. (2011). Dynamically switched low-phase-noise LC VCO with harmonic filtering, Electronics Letters, 47 (14).

Iniewski, K. (2013). Smart Sensor for Industrial Applications. CRC Press.

Jung, J., Heo, D.H., Kim, J.H., & Kim, B.S. (2013). Wide Tuning Range LC VCO with Parallel Coupled Negative gm Cells, IET Journals, Electronics Letters 49 (9).

Kim, B.S. & Kim, J.H. (2010). u-Food System. Food Science and Industry, 9. pp. 32-43.

Kim, B.S. et al., (2012). Development of u-Food System. Korea Food Research Institute E0122500.

Kim, B.S., Kim, J.Y., Hong, B.H., Lee. K.J., Park, J.K., and Lee, J.W. (2012). Real-time Detection Information Management System and Method for Distribution Management. Korea Patent 10-1180810.

Kim, B.S., Kim, J.Y., Kim, J.H., Kim, O.W., Kwon, K.H., Park, Y.K., Kim, Y.S., Cha, H.S., and Koo, J.M. (2012). Method for Monitoring Food Quality. Korea Patent 10-1180809.

Kim, B.S., Kim, J.Y., Kim, J.H., Kim, O.W., Kwon, K.H., Park, Y.K., Kim, Y.S., and Koo, J.M. (2012). Method and System for Monitoring Food Quality. Korea Patent 10-1198845.

Kim, B.S., Kim, J.Y., Kim, J.H., Kim, O.W., Kwon, K.H., Park, Y.K., Kim, Y.S., Cha, H.S., Koo, J.M., and Jung, J.Y. (2013). Sensor Tag and System for Quality Index Monitoring of Product used Sensor Tag. Korea Patent 10-1226105.

Kim, B.S., Kim, J.Y., Kim, J.H., Kim, O.W., Kwon, K.H., Park, Y.K., Kim, Y.S., and Koo, J.M. (2013). Method and System for Monitoring Food Quality. Korea Patent 10-1315902.

Tanenbaum, A. et al., (2010). “Computer Network”, Prentice Hall.

Kim, J. S., Lee, K. C. and Lee, S. H. (2009). Establishment and Promotion Strategy of Lifetime Tracing (Traceability)System of Agricultural Products using RFID, Korea Society of IT Services.

Kim, J.Y., Kwon, K.H., Gu, K.H., & Kim, B.S. (2011). Selection of Quality Indicator to Determine the Freshness of Muskmelon (*Cucumis melo L.*) during Distribution. Korean J Food Preserv. Vol. 18, No. 6, pp. 824-829.

Kim, J.Y., Kim, J.H., & Kim, B.S. (2011). Selection of Quality Indicator to Predict the Shelf-life of Milk during Distribution. Korean J. Dairy Sci. Technol. Vol. 29, No. 2, pp. 37-42.

Lee, E. J., Lee, K. I., Kim, H. S. and Kang, B. S. (2010). Development of agriculture environment monitoring system using integrated sensor module, The Journal of the Korea Contents Association

Lee, H.Y., Lee, Y.J., Kim, J.Y., Kwon, K.H., Cha, H.S., & Kim, B.S. (2013). Choosing Quality Indicators for Quality Prediction of Frozen Green Pumpkin in Distribution. Korean J. Food Sci. Technol. Vol. 45, No. 3, pp. 325-332.

Liu P., Heo, D.H., Kim, J.H., & Kim B.Y. (2011). Current-reuse and gate-modulation techniques for sub-1 mW QVCO, IET Journals, Electronics Letters 48 (2).

Oh, K.H., Ahn, Y.H., Koo, J.M., Kim, J.Y., Kim, B.S., and Jung, J.Y. (2011). A Cold Chain Food Quality Monitoring System for Ubiquitous Food Logistics Management. Journal of Information Technology and Architecture. Vol. 8, No. 4, pp. 381-386.

Xu M., Heo, D.H., Kim, J.H., & Kim, B.S. (2013). ECPC:Preserve Downtime Data Persistence in Disruptive Sensor Networks, International Journals of Distributed Sensor Networks.