Sensor Networks and the Food Industry

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ABSTRACT

Over the past decade there have been a myriad of scandals and incidents involving contamination of the Food Supply Chain which has drained consumer confidence and has had untold financial, political and health costs. Despite this, much of the processes in the Food Industry are still manual. This paper examines the role that Sensor Networks can play in providing the industry with an automated software solution that will help prevent repeats of the contamination of the food supply chain that is occurring on a seemingly regular basis.

1. THE FOOD INDUSTRY AND ITS SCANDALS

Over the past decade there have been several incidents that have shaken consumers' faith in and perception of the Food Industry. In Europe, BSE is probably the most well known scandal to affect consumer confidence. Unfortunately however, this is one of many incidents that have occurred. Each incident has impacts in terms of health, financial and even political costs.

European Union countries have suffered several high profile scandals in recent years. The presence of cancer-causing dioxins in farm animal feed led to the banning of pork, beef, chicken and egg products by the Belgian authorities in 1999 [1]. This scandal cost the country's farm industry €1 billion and contributed to the electoral defeat of the outgoing government. In 2002, an Irish Oyster Farm was forced to close after consumers in Hong Kong suffered from the Norwalk-like virus [2]. This was traced to the oysters feeding on a sewage outflow containing industrial waste from a local hospital that had suffered an outbreak of what is commonly termed the 'Winter Vomiting Bug' (a loose term embracing viruses classified in the "Norwalk-like virus" genus of the family Caliciviridae).

These incidents are not limited to food producers. Retailers and distributors have also been indicted in a number of incidents. In 2002 NorgesGruppen, the leading Norwegian food service conglomerate, attracted unwanted publicity when it was found that 5 of its Meny supermarkets were selling meat well past the expiration date. Indeed, one of these shops was expelled from the chain after health inspectors found that staff was making forcemeat from expired products.

These and other incidents have had a critical influence upon consumers.

Table 1: Food Industry Scandals

Year	Incident	Loc.	Industry
2005	160 ill after eating in a UK restaurant.	UK	Retail
2005	Sudan 1 Cancer-linked colorant in Food Chain.	UK	Food Proc.
2004	Fake infant formula causes baby deaths	China	Food Proc.
2004	Raw meat found to be injected with water and additives to retain moisture.	UK	Food Proc.
2003	Fish found to be laced with mercury and PCBs	USA	Fishing
2002	Cheap and standard meats mixed and sold at premium prices.	Japan	Food Proc.
2002	Altered expiry dates on butter products.	Japan	Food Proc.
2002	Wheat containing cancer-linked nitrofen herbicide fed to chickens in organic farms	Germ.	Farming
2002	Eggs contaminated with salmonella	UK	Farming
2002	Oysters contaminated, 'Norwalk-like' virus.	Ireland	Fishing
2002	Expired Meat Products sold to consumers.	Norw.	Retail
2001	GM corn found in Taco Bell products.	USA	Food Proc.
2000	Mass food poisoning caused by bacteria-ridden milk produced in unhygienic conditions	Japan	Food Proc.
2000	Kellogg plant closes down, as it could not source corn guaranteed to be GM free grain.	USA	Food Proc.
1999	Illegal steroid hormones found in animal feed, meat and soft drinks.	Europe	Farming Food Proc.
1999	Dioxins in feed for poultry & pigs.	Belg.	Farming
1991	Food poisoning outbreak from consumption in a Fast Food Chain linked to kidney failure.	UK	Retail
1990	BSE/CJD ('Mad Cow Disease')	Europe	Farming
1985	Wine laced with antifreeze	Aus.	Wine

Table 1 illustrates that the examples cited above are just a sample of the many events that have shaken consumer confidence.The consumer group is now much more conscious of the product they purchase and consume and even companies and restaurants not directly implicated by scandal have been forced to adjust to reflect the new reality of the health-conscious consumer. Witness the recent marketing campaign by McDonalds to re-brand their image as a provider of 'healthy' meals.

Food Authorities throughout the world have responded to the growing concern among consumers and lack of legal framework for the Food Industry. The European Union has introduced much legislation in recent years regarding food product traceability, the maximum permitted levels of colorants and dioxins and food hygiene[3]. It should be noted that many of these directives apply throughout the food chain i.e. growing, production, transports and distribution.

However, there is still much work to be done as evidenced by the recent recall of products containing the carcinogenic Sudan Red 1 food colorant[4]. From the perspective of those in the food industry there is a requirement for the timely supply of information. This information includes temperature, the presence of agents and airflow. This paper addresses the potential for Sensor Networks to aid in the provision of a software solution.

While the incidents in Table 1 can be attributed to a variety of factors including human error, carelessness, irresponsibility and fraud, the incidents could n future be prevented or managed through the judicious use of wireless intelligent sensor technology. For those affected by the careless or irresponsible actions of participants in the food chain the deployment of a sensors that can detect pathogens, bacteria and other potentially harmful agents. On the other hand, those who act less than ethically can be policed more effectively by health and food safety inspectors through the ad-hoc set-up of an intelligent sensor network during site visits.

2. TECHNOLOGY IN THE FOOD INDUSTRY

Woodworth[5] outlines how the Food industry is generally receptive to the use of information systems. Traditionally the principal use of Information Technology by Food Processing companies has been in Enterprise Resource Planning (ERP) Software. However, in recent times companies have started using mobile devices such as PDAs and wireless technology such as 802.11 to provide solutions in areas as diverse as traceability and logistics. Indeed, the incidents outlined in the previous section have led to increasing interest in Product Life Cycle Management Software which, in conjunction with RFID (Radio Frequency Identification Technology), is being mooted as a solution for addressing food safety [6].

As pointed out in Friend[7], ERP software is designed for managing operations within the enterprise only. However, given a typical food processor's dependencies on external suppliers and the external environment this is no longer adequate for today's food industry. Indeed, many of the key tasks in food production are still carried out manually, For example, growers still manually measure temperature and food scientists often have to manually carry out tests to detect ingredient composition and check for the presence of contaminants. Mobile technology is one factor in providing an automated software solution for the food industry but the solutions offered today only cater for the tagging and labelling of products. Granted, these are key components of a good traceability system and are vital for the post-auditing of food contaminations but they don't prevent the actual problem. It is in addressing that intelligent sensors can provide a vital role.

3. SMART SENSOR NETWORKS

The potential applications for Smart Sensor Networks is diverse with current uses ranging from vineyards to equipment maintenance. The communication potential for Smart Sensor Networks with external systems is cited in Hac[8] where Bluetooth is proposed as a possible communication standard between Sensors. Given the protocol's suitability for smaller electronics products such as mobile phones and digital camera one would expect it to be a feasible option. The Zigbee Wireless Technology has also been proposed for intra-sensor communication.

External interfaces such as those provided by Crossbow [10] enable the Sensors to communicate with electronic devices such as PCs, Laptops and PDAs. Once the data reaches these devices it can literally be transmitted to any network. Support is provided for detecting this data transmission through the Java API provided by the TinyOS open source forum [11].

Sensor Networks are recognised as one of the fastest growing segments in the technology industry. Part of the reason for this is their wide applicability. Good[12] illustrates the many uses of sensor networks for security purposes while Harbor Research estimates that the market size could be US$1 billion by 2009[13].

4. SMART SENSOR NETWORKS & THE FOOD INDUSTRY

Good[12] raises an interesting point in its illustration of the use of sensors for detecting biological and chemical agents. While security is certainly a pressing issue and an obvious application for sensor networks the technology can also be put to other uses, in particular the detection of contaminants in the Food Supply Chain. The 1999 Belgian crisis could certainly have been averted if technology existed for the detection of dioxins in the production of animal feed.

As is clear from a perusal of EU sources[3], the EU has imposed heavy duties upon food manufacturers. One key requirement for manufacturers is Regulation (EC) No. 178/2002 requiring manufacturers to keep detailed records of their supply chain. Despite the fact that this legislation has been effective since the 1st January 2005 the manual processes still practiced by many companies has made it difficult for them to comply with this legislation.

Among the requirements are labelling and barcodes for product batches so that 'problem' batches can be easily recalled. Not only is this good for the consumer it is also good for the producer and retailer as products can be recalled in a more timely fashion. This is a key point the legislation does not mandate the publicising of product recalls if this process occurs before the product enters the consumer market so companies can avoid the attendant adverse publicity and damage to their reputation.

However, there are issues with labels and barcodes, which can reduce their effectiveness. Barcodes and labels are line of sight only and are unreadable if they are damaged or soiled. The emerging solution to this problem is the use of Radio Frequency Identification (RFID) tags. RFID tags are essentially sensors that contain unique ID for a product or product batch.

The tags are long range and since they are a radio technology can be embedded in plastic. Of course, since they are Sensors they can form a part of an overall Sensor Network. Roberti[14] demonstrates how the US Navy used RFID as part of an overall Sensor Network to monitor pressure, temperature and humidity in shipping containers for aircraft parts.

The point raised in Roberti[14] can also be applied to the Food Industry. Many products require constant monitoring throughout their supply chain. This is not only for compliance purposes but also to ensure that the basic quality assurance requirements to retailers are met. For example, the chill chain requires that chilled products are stored at a constant temperature throughout the delivery and storage of the product. Typically each product batch is examined by the retailer on arrival and is rejected if it does not meet the required temperature. Up to now, the only solution to this problem for many smaller companies was to take periodic manual temperature readings. With the advent of Sensor Networks it is now possible to devise a solution whereby the producer is notified virtually instantaneously if the temperature failed outside acceptable parameters.

5. SENSOR NETWORKS & FOOD GROWERS

Of course, food processing companies are only one segment of the Food Industry. Growers also have requirements that can be met by sensor networks. The most well know example is that of the ‘smart vineyard’. The Australian Cooperative Research Centre (CRC) for micro technology and Motorola have devised a Sensor Network solution for the Australian Wine Industry[15]. The devices used in this project can measure wind speed and direction, temperature, light, humidity, soil moisture and leaf wetness. Given that weather conditions and the anticipation of same is a key factor in the production of quality wine it is obvious that the use of a Sensor Network can be of great benefit to vine growers.

Such a system also has the potential to give vine growers better information for monitoring the crop and can ultimately play a role in anticipating problems such as the presence of pests such as phylloxera, an insect that sucks fluid from the grape vine which results in the rotting of the plant.

The ubiquitous nature of the radio transmission of Sensor Networks is also important here. By its nature agricultural land can vary widely and the same applies to vineyards. The Sensors can be deployed virtually anywhere in a vineyard as long as they are in requisite range of each other. The other key advantage here is cost. Traditionally climate sensors are expensive which precludes their use from most growers and even then only on a limited scale.

The above characteristics of sensor networks are not just useful to vine growers. Any fruit grower will have similar requirements, as indeed will growers of cereals, vegetables and sugar beet. Once again the potential use of Sensor Networks is wide ranging.

Monitoring of crops is at present performed manually and on a somewhat ad-hoc basis. At times, this is a very onerous task given the very specific requirements of a crop. Mushrooms growers, for example, have very specific requirements in terms of light, temperature and airflow and have to manually measure these attributes. The deployment of a Smart Sensor Network would greatly increase the efficiency of this process.

6. CASE STUDIES

6.1 The Wine Industry

One of the most popular early deployments of Sensor Networks is in the Wine Production Industry[15]. However, there are other successful examples in different parts of the world, such as how Pickberry Vineyard in Sonoma, California was able to manage its crop growing problems through the use of a Sensor Network provided by Accenture Labs[16]. From the perspective of vine growing sensors can be used to monitor soil moisture, rainfall, wind velocity and direction, and air and soil temperature. The monitoring of these factors can be critical in the cost management for a vineyard. For example, detecting frost in a timely manner can prevent loss of a crop, all the more important since, to take the Pickberry example, each ton of grapes can be worth US$1000 to US$4000.

However, while all the focus is currently on using Sensor Networks for the growing of grapes this is merely one of the stages in wine production for which intelligent sensors can play a role. For example, temperature must be strictly controlled during the vinification process (i.e. the conversion of grape juice into wine). This is so that yeasts attached to the grape can feed on the sugar to produce alcohol – for white wine the temperature must be between 15°C to 20°C for fermentation, for red wine fermentation requires a temperature of between 25°C and 30°C. Furthermore, for this controlled fermentation process the presence of Sulphur Dioxide must be added but this is monitored in accordance with strict European Union guidelines.

Intelligent Sensors can clearly play a role in the fermentation process whether it is in temperature or Sulphur Dioxide monitoring. However, these two examples are just one of the many potential uses for Sensor Networks in vinification – intelligent sensors play a role in everything from detecting the presence of malic acid to tannins.

The final step in the production process of course is storage. Once again sensors can be used here to detect levels of humidity and temperature in a cellar. Randomly deployed sensors could also be potentially be used to detect what is commonly termed ‘corkage’ (air contact with the wine due to inadequate corking) in wine bottles or batches.

6.2 The Chill Chain

One of the greatest challenges for the Food Industry is for the manufacturers of frozen foods, in particular meat and poultry. Temperature must be maintained at a constant level from initial processing to final display by a retailer. However, given the steps from production to sale this has up to now been an onerous though essential requirement for frozen goods producers. This term coined for this issue is the Chill Chain.

As implied above the Chill Chain consists of a number of steps. Primary chilling relates to removing the heat from the carcass before it can be further processed or shipped. However, there can be startling differences in the surface temperature of a carcass and its deep temperature[17]. Once a previously chilled produced has been cut, minced, wrapped or cooked secondary chilling must take place. This is vital for ensuring that a product remains at a constant temperature during transportation.

Studies have shown that primary and secondary chilling are vital for maintaining potential shelf life. In studies[17] it was found that vacuum packaged beef on average achieved only 25% of its potential shelf life, 2 weeks instead of 8 weeks. This is due to a number of factors including loading the meat for transport at too high a temperature and the incomplete cooling of boxed meat due to weak air movement.

There is an obvious opportunity for sensor networks in primary and secondary chilling, not only to monitor temperature but also to monitor airflow. Currently, despite the best intentions of manufacturers the possibility of error is very high. Not only is this a risk for the consumer but there is also much wastage if shelf life is being reduced to a quarter of its potential.

Primary and secondary chilling take place in plant but these are only two steps in the Chain. Refrigeration when transporting the goods much provide an adequate air distribution. It should be noted that the refrigeration unit does not cool the goods. Rather it maintains them at the temperature at which they were loaded. There are similar requirements for Off-site Cold Storages, Central Distribution Centres and Wholesalers and, of course, Retailers.

While primary and secondary chilling are the responsibility of the processor, essentially manufacturers have no control once the goods leave their premises particularly if they do not have their only transportation. Ultimately, any fault in the chill chain will damage a frozen goods manufacturer's reputation even if this fault is caused by a third party. However mandating the use of a sensor network to monitor temperature and air flow in the other steps in the process can play a critical role in the monitoring of food quality and can help prevent spoiled goods reaching the end consumer.

7. FOOD INDUSTRY SYSTEM REQUIREMENTS

The Food Industry involves complex processes and detailed regulation. By contrast, the typical Information Systems department wants software that is easy to use [5]. Any Sensor Network System that is targeted for the Food Industry will have to be easy to deploy. Food Processors are uninterested in configuring sensors, their interfaces and the attendant software for analysing the data. The system will literally have to work from 'out of the box'. While this is admittedly a difficult goal for any emerging technology it is critical to the success of Sensor Network Systems in the Food Industry.

However, while deployment is a challenge, smart sensors already monitor the actual measurements required. Critical measurements such a temperature, wind speed and humidity are already catered for and there is little that is new. One open research topic is the development of Sensors that can measure not only the presence of a particular ingredient or characteristic but also the quantity or percentage of that characteristic. For example, it would be useful not only to whether there is limestone in the soil but also the percentage composition of the soil that is limestone. Similarly, while the presence of dioxins can be tested with current sensor technology the *level* of dioxins in products such as milk cannot currently be tested using smart sensors. Such information is important for quality assurance programs and has to be carried out manually for the most part.

The other point of interest regarding the Food Industry is its use of relatively few and relatively generic software systems. The output from any Sensor Network System must be easily transferred to third party software such as MS Excel and SAP. Thus, any system must be open and have easy to use or even automated export functionality to other software.

8. FAILINGS OF SENSOR NETWORKS FOR THE FOOD INDUSTRY

From the authors' experience, there are a number of factors that act as serious barriers to entry for the use of Sensor Networks in the Food Industry:

- Reliability
  A recent deployment of Sensor Networks in two redwood trees in Sonoma, California found that 65% of the nodes never returned data [18]. Similar problems were recorded when using Sensor Networks for habitat monitoring[19]. The former statistic would be unacceptable in any commercially deployed food monitoring network and it would be very difficult to make a business case for a network where a significant proportion of the nodes never work.
- Ease of Use
  Food processing organisations tend to be technology agnostic. Microsoft based technology prevails as it is easy to use and install. For the non-technical user Sensor motes are intimidating to deploy and use. Indeed, implementing a Sensor Network lies outside the range of the average Food Industry Information Systems Professional.
- Data gathering and Data Interpretation
  While Sensor Networks undoubtedly can play a significant role in improving the availability of update data on a physical environment there is currently no standard way for gathering and interpreting the data. The Food Industry relies heavily on standard reporting tools such as Crystal Reports and Brio and would be loathe to use non-standard Java-based reporting GUIs.
- Organising Networks and Clustering

There is at present no mechanism by which end users can organise their sensors for reporting purposes. Granted, group IDs are available but there can be limited – for example, two sensor groups might be monitoring the same area and would be effectively the same sensor group from a reporting perspective. What is required is a means by which users can organise their groups into clusters that make sense to them.

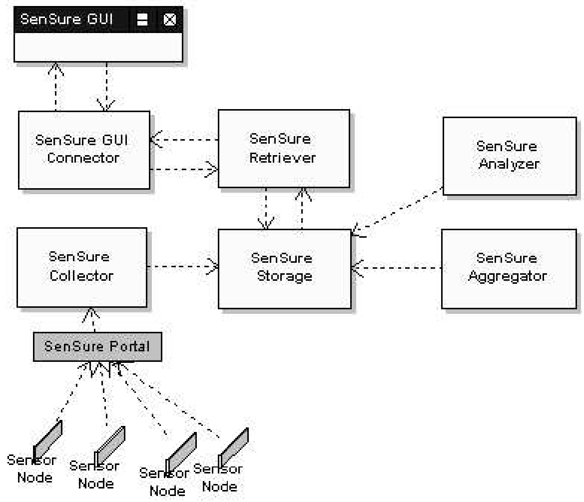

Figure 1: Sensure Sensor Portal

9. THE SYKOINIA SOLUTION

The above issues effectively preclude any commercial use of Sensor Networks in the Food Industry. Sykoinia's SenSure solution aims to bridge this significant gap in Sensor Network technology, by providing a means for end users to organise their networks, providing integrated Crystal Reports functionality and enabling users to add different types of sensors easily and quickly.

Data produced by the sensors is collated by the SenSure portal Figure 1, and is then forwarded to the server system for analysis and storage. The server system can be accessed through a user interface that can organise the Sensor Groups and can also request and schedule reports.

10. CONCLUSION

Sensor Networks have a myriad of potential uses. The Food Industry provides ample opportunities for both hardware and software providers given its need for monitoring software – a niche that a sensor network consisting of diverse smart sensors can fulfil.

However there are a number of caveats – a complex and hard to use system will not succeed in this industry nor will a 'closed' system where data is difficult to export, interpret and analyse.

11. About the Authors

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12. REFERENCES

[1] van Larebeke, Nik, Hens, Luc, Schepens, Paul, Covaci, Adrian, Baeyens, Jan, Everaert, Kim, Bernheim, Jan L, Vlietinck, Robert, and De Poorter, Geert, "The Belgian PCB and Dioxin Incident of January-June 1999: Exposure Data and Potential Impact on Health, *Environmental Health Perspectives Volume 109, Number 3 March 2001*

[2] Cassidy, Eddie, "Norwalk-like Virus Outbreak in Hong Kong Forces Closure of Irish Oyster Farm*", The Irish Examiner 26/03/2002*

[3] *Official Journal of the European Union*

[4] Food Safety Authority of Ireland, FSAI Alert Notifications, http://www.fsai.ie/alerts/fa/index.asp

[5] Woodworth, Simon. "Track and Trace: An opportunity for Information Systems Deployment and Supply Chain integration", Food Traceability Seminar, NUI Cork, February 2005

[6] Sullivan, Laurie, "PLM Software Has A Role In Food Safety", *InformationWeek, Jan. 12, 2004*

[7] Friend, Bill and Thompson, Olin, "Managing Software: Is the food industry ready for Product Life Cycle Management?", *Food Industry Magazine March 2003*

[8] Hac, Anna, "Wireless Sensor Network Designs",Wiley Press 2003

[9] The ZigBee Alliance http://www.zigbee.org

[10] Crossbow Technology Inc. http://www.xbow.com

[11] Tiny OS http://www.tinyos.net/

[12] Good, Barbara G, "Sensors for Security", *Sensors Magazine, July 2004*

[13] Harbor Research, Inc http://www.harborresearch.com/

[14] Roberti, Mark, "Navy Revs Up RFID Sensors", *RFID Journal June 2004*

[15] "MEMS Come to Oz Wine Industry", *Electronic News June 2004*

[16] "Accenture Prototype helps Pickberry Vineyard improve Crop Management", http://www.accenture.com/xdoc/en/services/technology/case/pickberry.pdf

[17] Managing your Chill Chain--The Undiscovered Country, *Meat & Poultry, February 1999*

[18] Tolle, Gilman & Culler, David, Design of an Application-Cooperative Management System for Wireless Sensor Networks, *2ndEuropean Workshop on Wireless Sensor Networks (EWSN) Istanbul, Jan 31-Feb2, 2005.*

[19] Szewczyk, Robert et al., "Lessons from a Sensor Network Expedition", *1st European Workshop on Wireless Sensor Networks, Berlin, Jan 19-21, 2004.*