Internet of Things and Food: ITaaU/FSA programme	
Project title:	FOOD SAFETY ASSURANCE: COMBINING PROVENANCE & THE INTERNET OF THINGS
Principal investigator (institution):	Professor Peter Edwards (University of Aberdeen)
Co-investigators/partners	Co-investigators: Dr Milan Markovic, University of Aberdeen Dr Martin Kollingbaum, University of Aberdeen Dr Alan Rowe, University of Aberdeen Partners: RYE & SODA (RESTAURANT) ABERDEEN TRACEALL GLOBAL LTD.
Description	The project deployed low-cost sensors into a commercial restaurant kitchen and developed a semantic software infrastructure able to monitor HACCP (food safety) compliance.
Keywords	Internet of things, provenance, sensors, Semantic Web, linked data, workflow
Project timeframe	Project duration: 3.35 MONTHS 1/12/2015 - 11/3/2016
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Report date	1/4/2016

Executive Summary

This three month pilot-study explored the potential of low-cost commercial wireless sensors as a means to monitor food safety compliance within a restaurant kitchen. A software infrastructure was developed (built upon existing standards including the Semantic Sensor Network and PROV ontologies) able to manage sensor data streams. Inference rules were designed to represent HACCP (Hazard Analysis and Critical Control Point) food safety protocols and these were used to generate a record of compliance/non-compliance events directly from the raw sensor data.

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Aims, Objectives & Methods

Aims:

- To develop an initial ontological model for food safety management based on the HACCP (Hazard Analysis and Critical Control Point) approach, through analysis of the Food Standards Scotland (FSS) *CookSafe* manual and sessions with professional catering staff.
- To develop a simple working prototype able to assemble the history of a food item from Delivery/Collection through to Service – testing this against a restaurant's food safety house rules to identify discrepancies. This will initially focus on temperature control house rules, but may be expanded to others if time permits.
- To deploy low-cost sensors into a commercial kitchen to monitor food storage and preparation activities – logging this data into an existing semantic infrastructure.
- To conduct a small-scale evaluation study with restaurant staff to assess attitudes to the sensor technology deployment and the utility of the provenance traces.

Objectives & Methods:
Project objectives were as follows:

- Build a lightweight ontological model to represent HACCP based food safety management. Output: An initial OWL ontology representing hazards, control measures, limits [D1].

- Conduct knowledge elicitation from users to capture existing restaurant working methods and food-safety house rules. Output: An *internal* project document describing the set of existing house rules from Rye & Soda.

- Construct a wireless meat probe sensor to measure temperature of meat during the cooking process.

- Represent temperature control house rules using a combination of the *D1* vocabulary, and a workflow plan language.

- Build an API wrapper to integrate data from CAO Gadgets wireless sensor tags and the wireless meat probe; used to monitor food before and during the cooking stage.

- Extend an existing sensor/provenance software platform to facilitate storage and integration of food safety data. Output: Initial software platform capable of describing sensors, sensor data and house rules [D2].

- Deploy the *D2* platform with Rye and Soda restaurant. The deployment will involve collection of real data within a restaurant setting during normal business activity. Output: datasets from restaurant kitchen deployment [D3].

- Create basic anomaly identification engine [D4] – comparing expected (house rules) with actual (provenance) – to identify discrepancies.

- Test the anomaly identification engine using real food histories generated in the kitchen.

- Evaluate the platform and wider issues around IoT deployment via a user feedback session with kitchen staff.

- Disseminate project outcomes via a series of presentations and publications. Outputs: ITaaU/FSA workshop presentation [D5], final report [D6], conference paper discussing outcomes [D7].

The Role of Provenance
A provenance representation can be used to document the history of a physical (or digital) object. Given the description of a workflow plan (i.e. prospective provenance documenting expected behaviour) and records of actual events (i.e. retrospective provenance documenting what really happened), provenance can help support compliance analysis - by determining whether expected protocols have been followed. For example, in the food safety context - whether chilled food has been stored within the correct temperature limits (typically 1-5◦C).

While the W3C recommendation for provenance capture (PROV) is suitable for modelling the retrospective part of a provenance record (i.e. workflow execution) it does not support descriptions of workflow plans. Approaches such as D-PROV [MM13], ProvOne [CVLM+14], and P-PLAN [GG12] have all proposed extensions to the PROV model, to enable more detailed descriptions of such plans. These extensions typically introduced new concepts to describe workflow structures in terms of expected workflow steps and corresponding inputs and outputs. As part of our earlier work on the SC-PROV model [ME13, ME14] we expanded on these efforts, by providing a means to document constraints (e.g. preconditions) that might be associated with individual steps of a workflow plan. The ability to represent such constraints is especially relevant within the food safety domain, where frameworks such as HACCP (Hazard Analysis and Critical Control Point) define process workflows in terms of critical limits associated

with the various workflow steps. Currently, design and monitoring of HACCP based workflows in commercial kitchens is predominantly a manual exercise and relevant records (e.g. temperature readings) are stored off-line.
We argue that by enhancing IoT technology with a means to record the provenance of food preparation activities we can automate HACCP compliance monitoring, and facilitate other activities such as data exchange. Semantic technologies (OWL, RDF) are critical to the realisation of our approach, with the Semantic Sensor Network [COM12] and PROV ontologies acting as key enablers.

Key Findings

All project objectives were met, and all the planned deliverables were realised (see items under *Additional Outputs* and *Appendix C* below). In this section we present the achievements of the project in terms of the original objectives.

Objective	**Progress & Deliverable(s)**
Build a lightweight ontological model to represent HACCP based food safety management. Output: An initial OWL ontology representing hazards, control measures, limits [D1].	We conducted a desk exercise to study the Food Standards Scotland *Cooksafe* manual; based on this we developed an OWL ontology describing concepts required to model prospective and retrospective provenance of a HACCP based workflow. Deliverable(s): FS-PROV ontology, FS-PROV Extension for project use cases. See "Additional Outputs".
Conduct knowledge elicitation from users to capture existing restaurant working methods and food-safety house rules. Output: An *internal* project document describing the set of existing house rules from Rye & Soda.	Interviews were conducted with the Head Chef of Rye & Soda restaurant to understand their local house rules. The restaurant also provided us with a copy of their house rules document. Deliverables(s): Internal project document containing discussion of Rye & Soda house rules (not included in the project data release).
Construct a wireless meat probe sensor to measure temperature of meat during the cooking process.	We were able to identify a commercial wireless meat probe that was able to meet the requirements of the project and so it was not necessary for us to build our own. Details of the probe can be found in Appendix A.

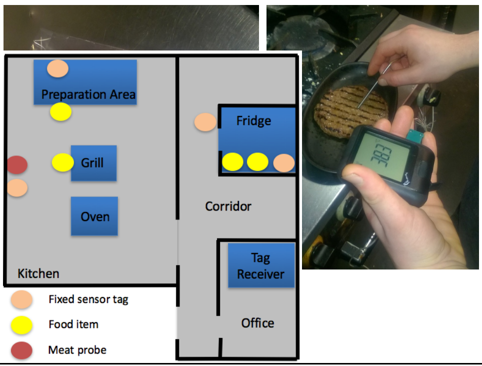
Represent temperature control house rules using a combination of the *D1* vocabulary, and a workflow plan language.	A workflow planning language was not required, as the ontology model was designed to include relevant concepts such as Plan, Step, etc.
Build an API wrapper to integrate data from CAO Gadgets wireless sensor tags and the wireless meat probe; used to monitor food before and during the cooking stage.	We developed software able to work with the CAO Gadgets wireless tag API to extract sensor readings for a given sensor and date range. We also developed software to parse meat probe readings from the text file written by the probe to a paired PC device. Deliverable(s): Code forms part of the Food Safety Framework. See "Additional Outputs".
Extend an existing sensor/provenance software platform to facilitate storage and integration of food safety data. Output: Initial software platform capable of describing sensors, sensor data and house rules [D2].	Using an existing semantic platform (JENA), we developed software to transform raw sensor data into their semantic representations (in accordance with the SSN ontology). Deliverable(s): Code forms part of the Food Safety Framework. See "Additional Outputs".
Deploy the *D2* platform with Rye and Soda restaurant. The deployment will involve collection of real data within a restaurant setting during normal business activity. Output: datasets from restaurant kitchen deployment [D3].	A total of 11 sensors were deployed into the Rye & Soda kitchen. These comprised: 4 wireless tags attached to fixed locations; 1 wireless meat probe; and 6 wireless tags attached to individual raw burgers. During the deployment the emphasis was on the storage, preparation and cooking stages – we did not consider delivery. Fig 1 shows some of these sensors in situ, while Fig 2 shows the kitchen floorplan and sensor locations. Note however that the burger sensors did of course move around the kitchen.  Figure 1 – Left: Wireless sensor tag attached to bag containing raw burger. Right: Wireless meat probe testing core temperature.

	Figure 2 – *Rye & Soda* kitchen floorplan showing sensor locations To capture sensor data during kitchen operations, it was necessary for us to design a series of food storage and preparation scenarios that reflected examples of HACCP compliance and non-compliance. This also overcame any ethical concerns over the project team being responsible for identifying issues in restaurant working practices during the pilot study. The scenarios are outlined in Appendix C. Deliverable(s): Datasets for various scenarios (see Appendix C).
Create basic anomaly identification engine [D4] – comparing expected (house rules) with actual (provenance) – to identify discrepancies.	We extended the C-SPARQL Engine with new features for querying linked-data streams, and to support inference rules. Deliverable(s): IoT Stream Inspector software. See "Additional Outputs".
Test the anomaly identification engine using real food histories generated in the kitchen.	Example inference rules were designed and these were used to generate provenance abstractions from the raw sensor data using the Food Safety Framework. Sample queries were then executed to check the validity of the results.
Evaluate the platform and wider issues around IoT deployment via a user feedback session with kitchen staff.	A structured interview was designed to explore, with kitchen staff, a range of issues including attitudes to sensor devices, impact of the technology on daily activities, potential impacts of data sharing, and the relationship between IoT devices and future inspection/regulatory processes. Due to the availability of personnel, only two interviews have been conducted to date, with more planned in the coming week.

Disseminate project outcomes via a series of presentations and publications. Outputs: ITaaU/FSA workshop presentation [D5], final report [D6], conference paper discussing outcomes [D7].	Dissemination activities have been ongoing and are described more fully under "Dissemination Activities" below.

Key Issues

Key Conclusions:

1. It is possible to identify HACCP compliance/non-compliance through analysis of linked sensor data.

2. Provenance abstractions are a potentially useful form of representation of compliance/non-compliance within a scalable food safety management system.

3. IoT solutions for use in a food safety setting would need to address many issues around sensor configuration, reliability, practicality, etc. (see remarks under Challenges below).

4. Based upon a very small sample (to date), kitchen staff did not oppose the deployment of sensors as they clearly understood the value of food safety, and felt that automated systems would be more convenient than manual record keeping. They also noted that the presence of sensors would be likely to have a greater impact on compliance than traditional labels. However, they believed that such sensor data would not replace the need for human inspections, as much of the valuable feedback from the inspector is based on aspects which are difficult to sense (e.g. kitchen structure, cleanliness, etc.).

Challenges:

1. *Quality and accuracy of the sensor data*
   Wireless sensor devices required careful testing/calibration before use and regularly thereafter. Another issue relates to the exact nature of the measurements. For example, a wireless temperature tag attached to a Ziploc bag containing a single chilled burger is actually measuring the air temperature close to the outside of the packaging. How good a proxy is this for the surface temperature of the food item?

2. *Traceability of a single food item*
   Tracking a single food item from the point it enters the kitchen to the point it is served to a customer is a hard problem. While we can successfully track at the macro-scale, such as a box of chilled burgers, monitoring an individual food item throughout the process of delivery, storage, preparation/handling and cooking was beyond us. In the pilot project it was necessary for us to manually make

connections between the various data streams, in order to link them to create the food item 'history'.

3. *Detection of real-life events*
   Detecting certain infrequent events (such as a fridge deep clean) is difficult to detect based on observations of raw sensor data (movement, temperature and humidity readings). Such events have the potential to trigger false positives in terms of HACCP (non)compliance.

4. *Durability of sensors*
   Sensors deployed in a kitchen environment have to be able to withstand harsh environments (e.g. high/low temperatures, high humidity, etc.). They also have to be easy to clean to avoid them becoming a source of contamination. The wireless sensor tags used in the pilot-project do not appear to have been designed with this in mind.

5. *Physical infrastructure constraints*
   To deploy IoT devices within a commercial kitchen it will be important to consider issues such as: availability of wireless connectivity, metal obstacles, thick walls, unusual building layouts and locations (e.g. basement level).

Next Steps

At the moment our focus is on the dissemination of project achievements (see discussion elsewhere in this report).

Engagement & Impact

Throughout the project we have engaged with restaurant management and staff, as this was very much a research in the wild effort. At this stage it is too early to assess the impacts of the work, given the short duration and scope of the project. Significant turn-over of staff in Rye & Soda restaurant during the project period makes it difficult to assess direct impacts on the restaurant and its personnel, although some preliminary findings have emerged from post pilot-study interviews with kitchen staff (see under *Key Issues*).

Throughout the project we have engaged with an industry partner (Traceall Global Ltd) and have plans to continue this; we anticipate some benefits to them through knowledge transfer. Engagement with food safety regulators (Food Standards Agency, Food Standards Scotland) has been another characteristic of the project, and we would expect their thinking to be influenced by our findings.

Additional Outputs

FS-PROV Ontology:
A generic core ontology for modelling prospective and retrospective provenance of HACCP-based workflows.

URL: https://w3id.org/abdn/foodsafety/fs-prov

FS-PROV Extension:
For the purposes of the experiments conducted on the data collected from Rye & Soda, we have extended the FS-PROV Ontology with details of planned steps, HACCP constraints and relevant parameters.

URL: https://raw.githubusercontent.com/m-markovic/FoodSafety-Data/master/fso_extended.ttl

IoT Stream Inspector:
A general-purpose framework for processing linked data streams based on the C-SPARQL engine (https://github.com/streamreasoning/CSPARQL-engine). The framework is capable of running simple inference rules defined as SPARQL INSERT queries.

URL: https://github.com/m-markovic/IoT-Stream-Inspector

Food Safety Framework:
An implementation of the IoT Stream Inspector for the purposes of the Food Safety deployment.

URL: https://github.com/m-markovic/FoodSafety

Dissemination Activities

Presentations to Date:
March 7-8th 2016
Presentation at ITaaU/FSA Event, Church House, London.
"Food Safety Assurance: Combining Provenance & The Internet of Things", M Markovic

March 24th 2016
Presentation to Scotland Food & Drink (Trade Body) at Scotch Whisky Research Institute, Edinburgh
"Food Provenance: Is it What it Claims to Be & Is it Safe?", P Edwards

March 30th 2016
Presentation to Food Standards Scotland (FSS) at FSS Offices, Aberdeen
"Food Safety Assurance: Combining Provenance & The Internet of Things", P Edwards

We are discussing with our industry partner (Traceall Global Ltd) a visit to their offices in Glasgow to disseminate project outcomes.

Publications:
M. Markovic, P. Edwards, M. Kollingbaum & A. Rowe, "Modelling Provenance of Sensor Data for Food Safety Compliance Checking", Sixth International Provenance & Annotation Workshop (IPAW 2016), McLean, Virginia, USA, June 6-9, 2016.
Accepted and will appear in Springer-Verlag Lecture Notes in Computer Science Series.

M. Markovic & P. Edwards, "Semantic Stream Processing for IoT Devices in the Food Safety Domain", Semantics 2016, Leipzig, Germany. *In preparation*.

We are considering if there are any other opportunities for publication, for example in relevant Food or Food Safety venues.

Funding Strategy for Future Activity

We recently secured a significant award from EPSRC to explore issues of trust and privacy in the Internet of Things. *Trusted Things & Communities: Understanding & Enabling A Trusted IoT Ecosystem* (EP/N028074/1, £1.1M, 2016-2019) will investigate issues around use of IoT devices in a domestic setting. We have yet to finalise specific deployment scenarios, but options could include food storage (in addition to energy monitoring, air quality, etc).

We plan to continue our discussions with industry contacts through Scotland Food & Drink to explore opportunities for developing the role of IoT devices in the food sector.

Key References

COM12 M. Compton, P. Barnaghi, L. Bermudez, R. Garca-Castro, O. Corcho, S Cox, J. Graybeal, M. Hauswirth, C. Henson, A. Herzog, V. Huang, K. Janowicz, W. D. Kelsey, D. Le Phuoc, L. Lefort, M. Leggieri, H. Neuhaus, A. Nikolov, K. Page, A. Passant, A. Sheth, & K. Taylor. *The SSN ontology of the W3C semantic sensor network incubator group*. Web Semantics: Science, Services and Agents on the World Wide Web, 17:25-32, 2012.

ME13 M. Markovic, P. Edwards & D. Corsar, *Utilising Provenance to Enhance Social Computation*, In The Semantic Web (ISWC 2013) - Proceedings of the 12th International Semantic Web Conference (Sydney, Australia, October 21-25, 2013), Springer-Verlag, LNCS 8219: 440-447, 2013.

ME14 M. Markovic, P. Edwards & D. Corsar, *SC-PROV: A Provenance Vocabulary for Social Computation*, In Proceedings of the 5th International Provenance & Annotation Workshop - IPAW 2014 (Cologne, Germany, June 2014), Springer-Verlag, LNCS 8628:285-287, 2015,

GG12 D. Garijo & Y. Gil, *Augmenting PROV with Plans in P-Plan: Scientific Processes as Linked Data*, In Proceedings of the Second International Workshop on Linked Science 2012 - Tackling Big Data, CEUR 2012.

MM13 P. Missier, S. Dey, K. Belhajjame, V. Cuevas-Vicenttin & B. Ludaescher, *D-PROV: Extending the PROV Provenance Model with Workflow Structure*. In Proceedings of TaPP '13 - the 5th USENIX Workshop on the Theory and Practice of Provenance (USENIX Association), Berkeley, CA, USA, April 2013), ACM, 2013.

CVLM+14 V. Cuevas-Vicenttín, B. Ludäscher, P. Missier, K. Belhajjame, F. Chirigati, Y. Wei, S. Dey, P. Kianmajd, D. Koop, S. Bowers & I. Altintas, *Provone: A PROV Extension Data Model for Scientific Workflow Provenance*. URL: http://vcvcomputing.com/provone/provone.html. , 2014

Appendix A: Technology Review

Technology	Description	Evaluation	Used in project ?	Verdict
Wireless meat probe	A wireless meat probe capable of measuring the temperature of a probed item. For real time custom access to the log files, the meat probe has to be synchronised with an application running on the same network that the meat probe is connected to. Description from the manufacturer: Thermocouple probe temperature measurement range -270 to +1300°C (probe dependent). Supplied with K type thermocouple probe. Temperature accuracy +/- 1.5°C More information about the device is available from: http://www.filesthrutheair.com/product/EL-WiFi-TC-Thermocouple-Sensor	The meat probe was used in a real kitchen environment to measure temperature of cooked burgers. The sampling rate was set to 10 seconds and the transmission period was set to 1 minute. The device was also left running for several days prior to the experiments. Battery life was not tested. The meat probe's accuracy was tested against another calibrated meat probe. Cloud-based storage via http://www.filesthrutheair.com/ not tested.	Yes	The device is prone to losing Wi-Fi signal even if the strength of the signal is satisfactory. The device can only connect to networks that are open or restricted by a WEP password. Issues with syncing files from the meat probe after long periods without Wi-Fi signal. The reading error is within the limits advertised by the manufacturer. The device would benefit from the ability to record the identity of the product that is being probed (e.g. via attaching to an RFID scanner). Some important readings might be missed by a monitoring

				system due to the high (10 seconds) minimal sampling rate.
Ethernet Tag Manager	This device is required in order to store readings from CAO Gadgets wireless tags into the cloud. The device is also responsible for informing the wireless tags about any changes to settings made by the user via an online interface. A brief description from the manufacturer: Can be controlled from iPhone, iPad, Android devices through apps, PC and Mac through https://www.mytaglist.com/eth/. Links up to 40 Wireless Sensor Tags and Kumo-Sensors. No subscription/service fee of any kind for life. More information about the device is available from: http://store.wirelesstag.net/products/ethernet-tag-manager	Tested at several locations including home, university office, and Rye & Soda. Maximum number of sensors connected at the same time: 10.	Yes	The device needs a specific network port to be open in order to enable comms with the cloud. As the device is designed entirely as a plug & play device, there is no option to specify this port manually which results in difficulties on networks with a firewall in place (e.g. a typical university network). On one occasion, it was observed that a device lost connectivity for several hours for no apparent reason. The issue was resolved by restarting the device. A downside of the device is that it has to be connected directly to a switch/router via a lan cable and it cannot be connected wirelessly.

Wireless Tag (13-bit Temperature and Humidity)	A small plastic battery-powered long-range wireless tag, which contains sensors able to detect temperature, moisture and movement. A brief description from the manufacturer (CAO Gadgets): Temperature logging and notification with 0.02°C resolution temperature sensor (+/-0.4°C error) Air humidity logging and notification with 0.12% resolution RH sensor (+/-1% error) Unlimited storage of logged temperature and motion event data on cloud (can be deleted any time) Minimum sampling rate: 30 seconds. More information about the device is available from: http://store.wirelesstag.net/products/wireless-tag-13-bit-temperature-and-humidity Requires Ethernet Tag Manager	Tested at several locations including home, university office, and Rye & Soda. Tested in a range of settings including, cold, warm, dry and humid environments The tag's temperature accuracy was tested against calibrated meat probe. Tested with 30 sec sampling rate and various transmission periods ranging from 30 sec to 2 mins. Online API tested by making requests to retrieve raw sensor data.	Yes	During our project several devices stopped operating for no apparent reason. Devices not capable of withstanding high temperatures in the hot hold area (tested at Rye & Soda). Devices are not calibrated after purchase and manual calibration has to be performed. The temperature reading accuracy advertised by the manufacturer does not seem to be a reliable indicator. Wireless tags are prone to losing connectivity with the Ethernet Tag Manager. Movement detection is unreliable for all available options. The minimum time between two detectable movement events is very high - 20

				seconds. An automatic service requested a battery replacement for one of the tags after only 4 months of operation. The cloud storage changes the timestamps of the recorded readings when logged in from different time zone even if the tags have not been moved to that time zone. The wireless tag API ignores the end date parameter with requests for raw sensor data.
Wireless Tag Pro 2.0	Same as for the Wireless Tag (13-bit Temperature and Humidity), however, this device also supports on-device storage during periods when the tag Is not connected to the Ethernet Tag Manager. More information about the device is available from: http://store.wirelesstag.net/products/wireless-tag-pro Requires Ethernet Tag Manager	Same as for the Wireless tag (13-bit Temperature and Humidity)	Yes	Syncing of data stored on the device seems to be unreliable and can jam the device for several minutes when it comes back into the range of the Ethernet Tag Manager.

Appendix B: Literature Review

Stream Processing Semantic Platforms

1. A Knowledge-Based Approach for Real-Time IoT Data Stream Annotation and Processing

A description of an approach for abstracting sensor data using the Symbolic Aggregate Approximation (SAX) technique. Abstracted data is published as linked data using a suite of ontologies including Stream Annotation Ontology (SAO), PROV-O, and the Quality of Service and Quality of Information (QoS|QoI) ontology.

S. Kolozali, M. Bermudez-Edo, D. Puschmann, F. Ganz and P. Barnaghi, "A Knowledge-Based Approach for Real-Time IoT Data Stream Annotation and Processing", In Proceedings of 2014 IEEE International Conference on Internet of Things (iThings), and Green Computing and Communications (GreenCom), IEEE and Cyber, Physical and Social Computing (CPSCom), 215-222, IEEE, Taipei, 2014. DOI: 10.1109/iThings.2014.39.

Available from:
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7059664

2. OpenIoT Middleware Platform

The paper describes an open source project for managing the deployment of large IoT infrastructures. The middleware platform also supports continuous semantic queries over sensor data using the OpenIoT ontology which extends the Semantic Sensor Network ontology.

Project website: https://github.com/OpenIotOrg/openiot

J. Soldatos, N. Kefalakis, M. Hauswirth, M. Serrano, J.P. Calbimonte, M. Riahi, K. Aberer, P.P. Jayaraman, A. Zaslavsky, I.P. Žarko and L. Skorin-Kapov, "Openiot: Open source internet-of-things in the cloud". In Proceedings of the OpenIoT Project Workshop 2014, LNCS 9001, 13–25, Springer, 2015.
DOI: 10.1007/978-3-319-16546-2_3.

Available from:
http://link.springer.com/chapter/10.1007%2F978-3-319-16546-2_3

3. A Semantic Processing Framework for IoT-Enabled Communication Systems

A semantic application of the OpenIoT middleware platform extended to continuously query and process stream data using CQELS (Continuous Query Evaluation over Linked Streams) query engine and event-condition-action (ECA) rules in AnsProlog. The example application links sensor data annotated using

SSN to geographic data, user-generated data and implicit information (e.g. user profiles).

M.I. Ali, N. Ono, M. Kaysar, K. Griffin and A. Mileo, "A Semantic Processing Framework for IoT-Enabled Communication Systems", In The Semantic Web-ISWC 2015, 241-258, Springer International Publishing, 2015.

Available from:
http://iswc2015.semanticweb.org/sites/iswc2015.semanticweb.org/files/93670207.pdf

Food & Smart Product Ontologies

4. **The Linked Open Vocabularies for Internet of Things (LOV4IoT) project**

   LOV4IoT is a repository containing collections of links to a number of IoT related ontologies. A separate section entitled Food, Beverage, Recipe & Restaurant ontologies contains 30 ontologies:

   http://www.sensormeasurement.appspot.com/?p=ontologies#food

5. **Realizing Networks of Proactive Smart Products**

   The paper includes descriptions of smart product ontologies, which are implemented in a framework for realizing networks of smart products with agent-based technologies.

   Smart product ontologies:
   http://projects.kmi.open.ac.uk/smartproducts/ontologies/

   M. d'Aquin, E. Motta, A. Nikolov and K. Thomas, "Realizing Networks of Proactive Smart Products", In Proceedings of the 18th International Conference, EKAW 2012, Springer LNCS, Volume 7603, 337-352, 2012.

   Available from:
   http://data.open.ac.uk/applications/ekaw2012.pdf

6. **Ontology Construction: Cooking Domain**

   A thorough description of designing a cooking ontology, which consists of five modules including Food, Kitchen Utensils, Actions, Recipes and Auxiliary modules (dish types, units of measurement, etc.).

   F. Batista, J.P. Pardal, P. Vaz, N. Mamede, and R. Ribeiro, "Ontology Construction: Cooking Domain", Technical Report, INESC-ID. Lisbon, 2006.

   Available from:
   http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.132.4197&rep=rep1&type=pdf

7. **FOODS: A Food-Oriented Ontology-Driven System**

   This paper includes a description of a food ontology describing various food items based on their kind, origin of the ingredients (e.g. animal based), nutrition values, etc.

   C. Snae and M. Brückner, "FOODS: A Food-Oriented Ontology-Driven System", In Proceedings of the 2nd IEEE International Conference on Digital Ecosystems and Technologies, 168 – 176, IEEE, 2008. DOI: 10.1109/DEST.2008.4635195

   Available from:
   http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4635195&tag=1

8. **Food Track & Trace Ontology for Helping the Food Traceability Control**

   The paper describes the Food Track&Trace Ontology (FTTO) - a part of a general framework devoted to managing food traceability. The main goal of the proposed FTTO Ontology is to include the most representative food concepts involved in a supply chain in a single ordered hierarchy. The paper contains a table summarising a number of existing food-related ontologies.

   T. Pizzuti, G. Mirabelli, M.A. Sanz-Bobi and F. Goméz-Gonzaléz, "Food Track & Trace Ontology for Helping the Food Traceability Control". Journal of Food Engineering, 120, 17-30, 2014. DOI: 10.1016/j.jfoodeng.2013.07.017

   Available from:
   http://www.sciencedirect.com/science/article/pii/S0260877413003749

Food Monitoring & Traceability

9. **Sensor Network for HACCP Food Safety Management**

   The paper describes a platform for managing and recording continuous readings from wireless sensors. Alarms are triggered if readings cross some HACCP threshold and users can also inspect daily reports of sensor readings.

   Hanyu, Hiroshi, Toshihiro Shimura, and Takuya Fukui. "Sensor Network for HACCP Food Safety Management." IET International Conference on Communication Technology and Application (ICCTA 2011), 662-666, IET, 14-16 October 2011, Beijing, China.

   Available from:
   http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6192949&tag=1

10. **A Case Study of Sensor Data Collection and Analysis in Smart City: Provenance in Smart Food Supply Chain**

Authors use machine learning techniques to calculate the probability of contamination of non-sampled food items based on provenance of food movements throughout the food supply chain.

Qiannan Zhang, Tian Huang, Yongxin Zhu, and Meikang Qiu, "A Case Study of Sensor Data Collection and Analysis in Smart City: Provenance in Smart Food Supply Chain," International Journal of Distributed Sensor Networks, vol. 2013, Article ID 382132, 12 pages, 2013. DOI:10.1155/2013/382132

Available from:
http://www.hindawi.com/journals/ijdsn/2013/382132/cta/

11. A Low Cost Internet of Things Solution for Traceability and Monitoring Food Safety During Transportation

The paper describes a GS1 compliant infrastructure based on instrumenting individual transport vehicles involved in the transportation of food with low cost (Raspberry Pi) sensor processing units. Such units are then connected to RFID readers, which provide information about the current inventory loaded onto the vehicle. The Raspberry Pi then hosts a RESTful web service that provides access to the inventory in real-time. Additional data such as temperature and humidity readings inside the vehicle are also provided.

M. Maksimović, V. Vujović, and E. Omanović-Mikličanin, "A Low Cost Internet of Things Solution for Traceability and Monitoring Food Safety During Transportation", In Proceedings of the 7th International Conference on Information and Communication Technologies in Agriculture, Food and Environment, Kavala, Greece, September 17-20, 583-593, 2015.

Available from:
http://ceur-ws.org/Vol-1498/HAICTA_2015_paper66.pdf

12. Food Traceability using RFID and Wireless Sensor Networks in an Aquaculture Enterprise

Master's thesis testing feasibility of an automated traceability platform based on the use of RFID tags in the fishing industry. The report also includes a detailed overview and custom test results of some existing hardware (e.g. RFID printers, readers, temperature loggers, etc.) and third party management platforms.

A. Parreño Marchante, "Food Traceability using RFID and Wireless Sensor Networks in an Aquaculture Enterprise", Technical University of Cartagena, 2011.

Available from:
http://repositorio.upct.es/bitstream/handle/10317/1861/tfm9.pdf?sequence=1

13. The Design of an Electronic Pedigree System for Food Safety

Authors describe an extension to the GS1 standard for food monitoring with an ability to record additional data about the production and transport environment (e.g. temperature) and data collected during food inspections. The data storage is handled by an independent third party in a secure master repository.

W. Han, Y. Gu, W. Wang, Y. Zhang, Y. Yin, J. Wang, and L.R. Zheng, "The Design of an Electronic Pedigree System for Food Safety", Information Systems Frontiers, 17(2), 275-287, 2015.

Available from: http://link.springer.com/article/10.1007/s10796-012-9372-y

14. Traceability in the Meat Industry – The Farm to Plate Continuum

The paper discusses various motivations and requirements for meat traceability at different stages of the food chain. In addition, the paper discusses the roles of various stakeholders (e.g. producers and customers) in relation to meat traceability.

G. H. Shackell, "Traceability in the Meat Industry – The Farm to Plate Continuum", International Journal of Food Science & Technology
Volume 43, Issue 12, 2134–2142, December 2008.
DOI: 10.1111/j.1365-2621.2008.01812.x.

Available from:
http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2621.2008.01812.x/full

15. Food Traceability Chain Supported by the Ebbits IoT Middleware

This paper describes an XML-based, event-driven, service-orientated middleware platform for monitoring meat (from farm to fork) using RFID tags and other relevant sensor readings such as temperatures observed in cold storage or transport stages. More detailed deliverables of this EU project can be found at http://www.ebbits-project.eu/news.php

K. Furdik, F. Pramudianto, M. Ahlsén, P. Rosengren, P. Kool, S. Zhenyu, P. Brizzi, M. Paralic, and A. Schneider, "Food Traceability Chain Supported by the Ebbits IoT Middleware". Dynamic in Logistics, Springer Lecture Notes in Logistics Series, 343-353, 2015. DOI: 10.1007/978-3-319-23512-7_33

Available from:
http://link.springer.com/chapter/10.1007/978-3-319-23512-7_33/fulltext.html

16. Value-Centric Design of the Internet-of-Things Solution for Food Supply Chain: Value Creation, Sensor Portfolio and Information Fusion

This paper proposes a design framework for IoT infrastructures in the Food Supply Chain that opposes the traditional traceability-centric approaches. It is argued that in order to increase the adoption of IoT technologies in the Food Supply Chain both business and technological challenges have to be addressed. A comprehensive report on real field trials exploring the added values including shelf life prediction, sales premium, precision agriculture, and reduction of assurance cost.

Z. Pang, Q. Chen, W. Han and L. Zheng, "Value-centric design of the internet-of-things solution for food supply chain: value creation, sensor portfolio and information fusion". Information Systems Frontiers, 17(2), 289-319, 2015. DOI: 10.1007/s10796-012-9374-9

Available from:
http://link.springer.com/article/10.1007%2Fs10796-012-9374-9

17. A Field Test Study on a Dynamic Shelf Life Service for Perishables

The paper reports on a series of interviews and field tests in relation to the deployment of IoT sensors for dynamic prediction of product shelf life with a view to reduce food wastage. The results highlight the importance of temperature sensor accuracy in shelf life prediction.

Å. Jevinger, M. Göransson and K. Båth, "A Field Test Study on a Dynamic Shelf Life Service for Perishables". In Proceedings of the Nordic Logistics Research Network (NOFOMA) 2014 conference, 78-92, Copenhagen, Denmark, 11-13 June, 2014. [ISBN: 978-87-997433-0-8]

Available from:
https://dspace.mah.se/handle/2043/18320

18. iFridge: An Intelligent Fridge for Food Management Based on RFID Technology

This paper describes an application that tests the feasibility of using RFID tags to determine the position of food items inside a fridge.

Lei Xie, Yafeng Yin, Xiang Lu, Bo Sheng, and Sanglu Lu. "iFridge: An intelligent fridge for food management based on RFID technology." In Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication, 291-294. ACM, 2013. DOI: 10.1145/2494091.2494181

Available from:
http://www.ubicomp.org/ubicomp2013/adjunct/adjunct/p291.pdf

19. A Case Study of CPNS Intelligence: Provenance Reasoning over Tracing Cross Contamination in Food Supply Chain

This paper describes a heuristic tracing algorithm for detection of cross-contamination in the food supply chain. The approach assumes the existence of food provenance delivered via an IoT network.

Shunqing Yan, Yongxin Zhu, Qiannan Zhang, Qin Wang, Ming Ni, and Guangwei Xie, "A Case Study of CPNS Intelligence: Provenance Reasoning over Tracing Cross Contamination in Food Supply Chain," In Proceedings of 32nd International Conference on Distributed Computing Systems Workshops, IEE, 330-335, 2012. DOI: 10.1109/ICDCSW.2012.67

Available from:
http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6258176&tag=1

20. Virtualization of Food Supply Chains with the Internet of Things

Virtualization enables supply chain actors to monitor, control, plan and optimize business processes remotely and in real-time through the Internet, based on virtual objects instead of observation on-site. This paper analyses the concept of virtual food supply chains from an Internet of Things perspective and proposes an architecture to implement enabling information systems. As a proof of concept, the architecture is applied to a case study of a fish supply chain.

C.N. Verdouw, J. Wolfert, A.J.M. Beulens, and A. Rialland, "20. Virtualization of Food Supply Chains with the Internet of Things", Journal of Food Engineering, 176, 128-136, 2016. DOI: 10.1016/j.jfoodeng.2015.11.009

Available from:
http://www.sciencedirect.com/science/article/pii/S026087741530056X

21. IOT Based Provenance Platform for Vegetables Supplied to Hong Kong

The authors describe a traditional web-based application built on collections of provenance data documenting the lifecycle of vegetable products from farm to supermarket. Information about the movement of the vegetable products is obtained via an IoT network utilising RFID technology.

Jie Yin , Xu Zhang, Qing Lu, Chen Xin, Chunfang Liu, and Zhinan Chen, "IOT Based Provenance Platform for Vegetables Supplied to Hong Kong", Recent Advances in Computer Science and Information Engineering, Lecture Notes in Electrical Engineering Series, 127, 591-596, 2012.

Available from:
http://link.springer.com/chapter/10.1007%2F978-3-642-25769-8_83

22. Provenance System for Livestock Supplied to Hong Kong Based on RFID Technology

The paper describes the use of RFID technology to monitor livestock supplied to Hong Kong; RFID ear tags and vehicle cards are both employed to create a provenance record.

Jie Yin, Zhi Nan Chen, Qing Lu & Jun Li, "Provenance System for Livestock Supplied to Hong Kong Based on RFID Technology", In Proceedings of 2011 International Conference on Computational and Information Sciences (IICIS), IEEE, 707-709, 2011. DOI: 10.1109/ICCIS.2011.204

Available from:
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6086296

Trust & The Food Industry

23. Data Driven Quantitative Trust Model for the Internet of Agricultural Things

This paper describes a data-driven trust model based on Bayesian networks. The model utilises historical data received from the AIoT network (Internet of Agricultural Things) and eliminates the need for expert experience.

W. Han, Y. Gu, Y. Zhang and L. Zheng, "Data Driven Quantitative Trust Model for the Internet of Agricultural Things", In Proceedings of International Conference on the Internet of Things (IOT), 31-36, 2014.

Available from:
http://ieeexplore.ieee.org/xpls/icp.jsp?arnumber=7030111&tag=1

Sensors Relevant to The Food Domain

This section provides just a few examples of relevant sensing technologies.

24. Food Contamination Monitoring via Internet of Things, Exemplified by using Pocket-Sized Immunosensor as Terminal Unit

The authors describe a sensing solution designed to monitor food contamination, and use the pathogen *V. parahaemolyticus* for testing purposes. The sensor is based on a CMOS image sensor and is designed to interoperate with a smartphone.

Sung-Min Seoa, Seung-Wan Kima, Jin-Woo Jeona, Jee-Hyun Kima, Hee-Soo Kimb, Jung-Hwan Chob, Won-Ho Leec, and Se-Hwan Paeka, "Food Contamination Monitoring via Internet of Things, Exemplified by using Pocket-Sized Immunosensor as Terminal Unit", Sensors and Actuators B: Chemical, 233, 148-156, 2016. DOI: doi:10.1016/j.snb.2016.04.061

Available from:
http://www.sciencedirect.com/science/article/pii/S0925400516305330

25. Battery-Free Radio Frequency Identification (RFID) Sensors for Food Quality and Safety

The paper describes an unobtrusive battery-free RFID sensor that enables freshness monitoring of various food products. Examples discussed in the paper include monitoring freshness of milk and fish, as well as direct monitoring of bacteria growth.

R. A. Potyrailo, N. Nagraj, Z. Tang, F. J. Mondello, C. Surman, and W. Morris, "Battery-Free Radio Frequency Identification (RFID) Sensors for Food Quality and Safety", Journal of Agricultural and Food Chemistry 60 (35), 8535-8543, 2012. DOI: 10.1021/jf302416y

Available from:
http://pubs.acs.org/doi/ipdf/10.1021/jf302416y

26. Silk-Based Conformal, Adhesive, Edible Food Sensors

RFID-like edible sensors based on silk antennas that can be attached directly onto a food item to detect spoilage based on changing chemical properties, which affect the signal broadcast by the antenna.

H. Tao, M. A Brenckle, M. Yang, J. Zhang, M. Liu, S. .M Siebert, R. D. Averitt, M. S. Mannoor, M. C. McAlpine, J. A. Rogers, D. L. Kaplan, and F. G. Omenetto, "Silk-Based Conformal, Adhesive, Edible Food Sensors," Advanced Materials, 24. 1067–1072, 2012. DOI: 10.1002/adma.201103814

Available from:
http://onlinelibrary.wiley.com/doi/10.1002/adma.201103814/abstract

27. Monitoring of Bacteria Growth Using a Wireless, Remote Query Resonant-Circuit Sensor: Application to Environmental Sensing

A short–range (14 cm) wireless method for determining changes in the environment based on observing changes in the impendence spectrum recorded by a printed inductor-capacitor circuit.

K.G. Ong, J. Wang, R.S. Singh, L.G. Bachas, and C.A. Grimes, "Monitoring of Bacteria Growth using a Wireless, Remote Query Resonant-Circuit Sensor: Application to Environmental Sensing", Biosensors and Bioelectronics, Volume 16, Issues 4–5, 305-312, 2001.

Available from:
http://www.sciencedirect.com/science/article/pii/S0956566301001312

28. Wireless Sensors in Agriculture and Food Industry - Recent Development and Future Perspective

A survey of wireless communication standards, sensors and actuators for agriculture and the food industry. The paper identifies a number of sensor application areas including traceability, M2M communication, food safety inspections, precision farming, weather monitoring, etc.

N. Wang, N. Zhang, and M. Wang, "Wireless sensors in agriculture and food industry—Recent development and future perspective", Computers and Electronics in Agriculture, Volume 50, Issue 1, 1-14, January 2006.

Available from:
http://www.sciencedirect.com/science/article/pii/S0168169905001572

29. Radiofrequency Identification and Surface Acoustic Wave Technologies for Developing the Food Intelligent Packaging Concept

This paper provides a comprehensive overview of the state of the art in RFID and SAW technologies in the context of smart food packaging. Amongst other things, the paper mentions the potential of active RFID tags, which can include various sensors (e.g. temperature and humidity sensors). It also describes the advanced properties of SAW-based tags, which can operate with lower energy levels and can withstand a wide range of temperatures.

Antonio López-Gómez, F. Cerdán-Cartagena, J. Suardíaz-Muro, M. Boluda-Aguilar, M.E. Hernández-Hernández, M.A. López-Serrano and J. López-Coronado, "Radiofrequency Identification and Surface Acoustic Wave Technologies for Developing the Food Intelligent Packaging Concept", Food Engineering Reviews, 7(1), 11-32, 2015. DOI: 10.1007/s12393-014-9102-y

Available from:
http://link.springer.com/article/10.1007%2Fs12393-014-9102-y

30. Applications of Wireless Temperature Measurement using Saw Resonators

This paper discusses various potential applications of Surface Acoustic Wave (SAW) resonators. One of the applications discussed is a wireless meat probe that removes the need for any type of wires or additional user units attached to a probe.

D.S. Stevens et al. "Applications of wireless temperature measurement using saw resonators". In Proceedings of Fourth International symposium on acoustic wave devices for future mobile communication systems, Chiba University, Japan, 2010.

Available from:
http://www.sengenuity.com/tech_ref/WIRELESS_TEMP_Applications.pdf

31. Smart Cookware

This patent describes a smart cooking appliance where the heating is achieved by a wireless power supply. A secondary device (e.g. a cooking pan) that is placed within the wireless power supply can then perform various "smart" activities such as temperature control.

D.W. Baarman, J.B. Taylor, S.A. Mollema and W.T. Stoner, “Smart cookware”. Access Business Group International Llc.. U.S. Patent Application 13/143,517, 2010.

Available from:
https://www.google.com/patents/US20120000903

32. RFID-Controlled Smart Range and Method of Cooking and Heating

This patent describes an invention where a vessel containing a read/write RFID tag is heated based on the recipe stored in the tag. Communication between a vessel and a heating source (e.g. a hob) is achieved via series of antennas.

B.L. Clothier, “RFID-controlled smart range and method of cooking and heating”, Thermal Solutions, Inc., U.S. Patent 6,953,919, 2005.

Available from:
https://www.google.com/patents/US6953919

Appendix C: Data Sets (Project Output)

As discussed above, a number of food storage and preparation scenarios were designed to allow sensor data to be captured and evaluated. The scenarios which reflected HACCP compliance (so-called *good day scenarios*) and non-compliance (*bad day scenarios*) were as follows:

Good	1-4	Remove a single burger from the fridge and cook it until it reaches 75°C (repeat x4)
Good	5	Remove two burgers from the fridge and cook them until they reach 75°C
Bad	1	Leave a single burger out of the fridge for 1 hour. Put it back in the fridge for 40 min and then cook it until it reaches 75°C
Bad	2-3	Remove a single burger from the fridge and cook it below 75°C (repeat x2)
Bad	4	Remove two burgers from the fridge and cook one until it reaches 75 °C and keep the second one below 75°C
Bad	5	Remove a single burger from the fridge for approx. 5 min then return to fridge for approx. 5 min and repeat 5 times; then cook until it reaches 75°C

Raw temperature readings from the wireless tags and the wireless meat probe recorded during the simulated experiments at Rye & Soda on 10 February 2016 and 11 February 2016 are available. The repository also includes example provenance abstractions, inference rules and provenance queries used in the project.

URL: https://github.com/m-markovic/FoodSafety-Data

Our project partner (Rye & Soda restaurant) is happy for this data to be used provided that the business is always named and that the basis on which the data was collected is made clear (see comments about scenarios above) and use of the data reflects the brand in a positive manner.