SFH80 A094004 – Åpen

RAPPORT

RF-based Sensor Technology for Data Capture – Standards, Architectures, Experiences and Challenges.

Carl-Fredrik Sørensen, Eskil Forås and Gunnar Senneset

SINTEF Fiskeri og havbruk AS

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SINTEF REPORT

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TITLE

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CLIENT(S)

KMB Lønnsom foredling

REPORT NO.	CLASSIFICATION	CLIENTS REF.	
SFH80 A094004	Open	Ingrid Camilla Claussen	
CLASS. THIS PAGE	**ISBN**	**PROJECT NO.**	**NO. OF PAGES/APPENDICES**
Open	978-82-14-04641-0	840145	45
ELECTRONIC FILE CODE		**PROJECT MANAGER (NAME, SIGN.)**	**CHECKED BY (NAME, SIGN.)**
RF-based sensor technology.doc		Eskil Forås	Finn Olav Bjørnson
FILE CODE	**DATE**	**APPROVED BY (NAME, POSITION, SIGN.)**	
	2010-01-15	Jostein Storøy, Research Director	

ABSTRACT

This document reports on state-of-the-art and partly state-of-the-practice in deployment and application of RF-based sensor technology for data capture with emphasis on standards, architectures, and experiences from research and actual industrial implementations. Further, challenges related to implementation, use, and deployment are briefly summarised. A special focus is made towards application in the Norwegian fish farming industry. The report will thus both have a retrospective viewpoint as well as look for future research directions and challenges.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	RF based sensor technology	RF-basert sensorteknologi
GROUP 2	Sensor networks	Sensornettverk
SELECTED BY AUTHOR	Software architecture	Programvarearkitektur
	Standards	Standarder

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1 Introduction

This document reports on state-of-the-art and partly state-of-the-practice in deployment and application of RF-based sensor technology for data capture with emphasis on standards, architectures, and experiences from research and actual industrial implementations. Further, challenges related to implementation, use, and deployment are briefly summarised. A special focus is made towards application in the Norwegian fish farming industry. The report will thus both have a retrospective viewpoint as well as look for future research directions and challenges.

This report will briefly present some application scenarios by the introduction of sensor networks in the food industry by giving examples. Information and exchange standards form glue between existing systems and the introduction of new systems. Thus, different standards are needed to both give a unified and agreed view on which information to be exchanged and which protocols that can be used to exchange this information.

Data is electronically captured from the environment and needs to be interpreted and used in specific contexts to give value for decision and process support in existing or new computer systems. Sensor networks give possibility to monitor a range of properties related to the working environment and to how specific food items have been exposed to these properties. Sensors can be either static or mobile. Static sensors will usually have a fixed position; while mobile sensors are applied to physical items that naturally flow in the physical and temporal space. The different modes of operation and thus also communication, will affect how and where to apply sensors and require different physical and communication setups that may change over time. Sensors are increasingly integrated with RFID to give a unique identification of the context where the sensor is applied. This integration is especially important when the sensor is mobile since RFID thus can be used to identify and relate samples to the temporal geographical properties as well as to where the RFID/sensor has been applied (typically on a mobile physical item).

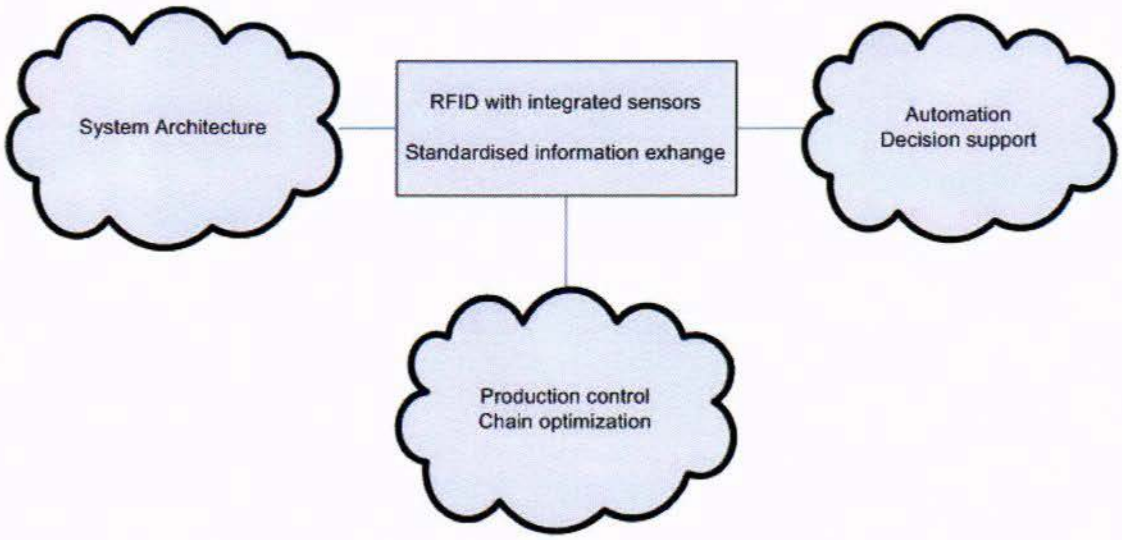

Figure 1 Exploitation of RFID sensors for different purposes

Figure 1 above shows how the introduction of sensors integrated with RFID as well as a standardised way of communicating sensor properties can be exploited for different purposes like increased automation, decision support, and optimisation of production and logistic processes in the supply chain. Increased food production monitoring, control and automation can possibly enable better means for decision support in both the short and long term related to improved food quality, better logistics, improved food production etc.

Standardised information exchange can be done by different means and several initiatives for standards will be presented in this report. The main challenge related to information exchange is to provide sufficient master data to enable temporal relationships between the sensor, the sensor environment, the sensor type and measurements and the objects that may use or exploit the information.

The potential enormous amount of information that can be collected and used is however still in its infancy related to application, documentation, and process improvement. The potential for fine-grained data acquisition and food management using wireless and mobile sensors may give openings for both new and improved methods and management. At the same time the ability to provide electronic real-time information about an increasingly amount of environmental properties is a challenge both with respect to data management and application. Higher-level context information can be aggregated using data from diverse sources and used to provide increased support in many aspects of the modern food industry. It is therefore necessary to build up decision and process support models and systems that can relate reason about and actuate based on the available information, either automatically or through human-computer interfaces.

2 Application of context

Information or properties of relevance in a food context is the *identification* and *position* of items (used in tracing of items) and sensor data related to these items [37]. Both the identification/trace information and sensor data are relevant for presentation to users as well as for applications adapting to the information. Trace information can be used passively by presenting the steps a product has taken from the manufacturer to the store to a user. It can also be used actively to detect if an item has passed a boundary and raise an alarm, e.g. for theft prevention. This is similar for sensor data. Sensor data can be presented to a user who then decides if he wants to act upon it, or it can be used more actively, e.g., by a cooling system which automatically turns down the temperature if a product inside is too warm. It is obvious that the easiest way to manage context information is to present it to a user and then let the user decide what to do. If, e.g., an item is located at several different positions, it is not difficult to plot these on a map to provide trace information. It requires a bit more logic for an application to take this information, process it, and then present the information to the user if the item has deviated from its planned route, in what state it is (e.g., if the last known location was the garbage), if it has been transported by air etc.

The most advanced way to handle context information is applications which automatically and autonomously act on this information. It can be possible for an application to predict when the item will arrive at a cross-docking site and automatically order further transportation to be ready at that time. Common for all these situations is that they have a tracking solution as a foundation, and build the application logic on this foundation. This means that when such a solution is in place, it is possible to start with the easiest type of context-awareness, just presenting the information to a user and then later expand the solution with more advanced functionality. In RFID-based systems, the identification of items is inherent. Additional context information can be captured by sensors and/or from other systems that then can be related to a particular identified item. Using various sensors, it is possible to get many different types of context information which then can help to define the state of the item, the situation it is in, how it has been treated, where it has been, and when it was there. If all this information is combined and stored for future use, a very detailed history of an item's lifetime can be obtained. Not only where the item was and when it was there, but also information about the state and situation the item was in at that time. Information about the item's state between the locations can also be obtained. RFID is based on locating tags at "checkpoints" where there are RFID readers, and it gives no information on what happened between these readings. This information can be added by using sensors storing context information between tag-reads.

2.1 Summary

This chapter has provided theory and issues related to how context can be applied using context-aware applications and systems. Real-time adaptation of processes and systems using sensors and other computing devices is an area of research that mixes different ICT disciplines with other disciplines like biology, chemistry, cybernetics, automation, etc.. Application of information and increased decision support is thus something that needs to be analysed and designed to give a higher value for the user.

3 Sensor Technology and Networks

The use of sensor technology is increasingly adopted in the production industry to support and control, e.g., manufacturing, production, and logistic processes, as well as more general environmental monitoring and control. It is vital in robotics, especially to sense and collect information used to regulate the behaviour of mobile robots and engines. The sensors are increasingly instrumented with wireless communication capability, thus are able to communicate with the surroundings, forming sensor networks [63].

The computing capacity of an individual computing device is steadily increasing while at the same time the device becomes smaller and cheaper. This enables construction of devices with exceptional small mechanical structures that are able to sense fields and forces in the physical world and are able to communicate the sensed information using extremely small radios. The cost of the devices is also following this trend by becoming increasingly cheaper thus enabling deployment of inexpensive, low-power communication devices in the physical space, providing dense sensing close to physical phenomena, processing and communicating this information, and coordinating actions with other computing devices [13].

Wireless sensor networks can be used in a lot of different areas and applications because of the shift to mass-produced intelligent sensors and thus an increase in the density of instrumentation in addition to the availability of pervasive networking technology. The areas can be roughly differentiated into [13]:

- Monitoring space,
- monitoring things,
- monitoring interactions of things with each other and the encompassing space

Space monitoring includes environmental and habitat monitoring, precision agriculture, indoor climate control, surveillance, treaty verification, and intelligent alarms. Monitoring things includes structural monitoring, ecophysiology, condition-based equipment maintenance, medical diagnostics, and urban terrain mapping. The last category involve the most dramatic applications monitoring complex interactions, including wildlife habitats, disaster management, emergency response, ubiquitous computing environments, asset tracking, healthcare, and manufacturing process flow [13].

A sensor has some basic functions [20]:

- sense physical parameters in the environment,
- eventually process the raw data locally to extract features of interest,
- store this information momentarily, and
- use a wireless link to transmit this information either to other sensors or to a base station/receiver system for further processing and action

Wireless networks are used in a spectrum of applications that lie between two extremes: the infrastructure mode and the ad hoc mode [20]. In the *infrastructure* mode, mobile nodes communicate through base stations, special nodes that link together through a conventional network. Typical examples of this infrastructure mode include mobile telephony, paging systems, and wireless LANs that use IEEE 802.11. In the *ad hoc* mode, there is no base station infrastructure [20]. If the destination is in range of the source node, that node sends the packet to the destination node. If the destination is not in range, the source node sends the packet to an intermediate node, which forwards the packet to other nodes until the packet reaches its destination or fulfils some other termination criterion. Both architectures assume that there is a way to find the route a packet must follow from its source to its destination. Defining this route is the subject of intensive research.

The infrastructure-based architecture is popular for several reasons, particularly its relative simplicity. Base stations do not have power restrictions and enjoy a better spectrum usage because they allow frequency planning. Advocates of ad hoc networks cite their higher versatility and potentially lower power consumption. Since no planning and no infrastructure are required, ad hoc networks can be deployed quickly and in remote areas [20].

Hybrid solutions may be designed that lie somewhere in between these two extreme architectures. An infrastructure-assisted architecture can mix both approaches. In this architecture, a mobile node beyond a base station's range could use other nodes in the range to relay the packets to the base station. A packet may or may not go through the infrastructure depending on the location of the source and destination nodes. Similarly, two or more separate infrastructure-based networks can exchange packets through a sequence of hops on mobile nodes, thus forming a single network [20].

To reduce power consumption, wireless sensor nodes will most often remain sleeping until they need to undertake a specific task, e.g., at specific times or frequencies. Thus, a sensor node will wake up at specific times and perform a measurement. External events may also trigger sensor wake-up. Sensors can then based on the configuration; decide either to store information in the internal memory or to communicate this information to other sensor nodes or to base stations. It is therefore important to create communication schemas that allow for low-power communication when appropriate. This is especially important in ad hoc sensor networks where receiving sensor nodes are also sleeping.

The Figure 2 below (inspired by [45]) shows a generic sensor network architecture where sensors gather data autonomously. The data from a sensor are either pushed or pulled from the sensor into a base station which can forward the data to a sensor network server for further processing and eventually storing of the sensor readings. The sensors can communicate with each other to set up/configure communication paths. Typically, some sensors will take the responsibility for pushing the data to defined "sinks" on behalf of other sensors and at the same time report their own data. This responsibility is shown in Figure 2where a few sensor nodes communicate with sensor readers/base stations in network architecture

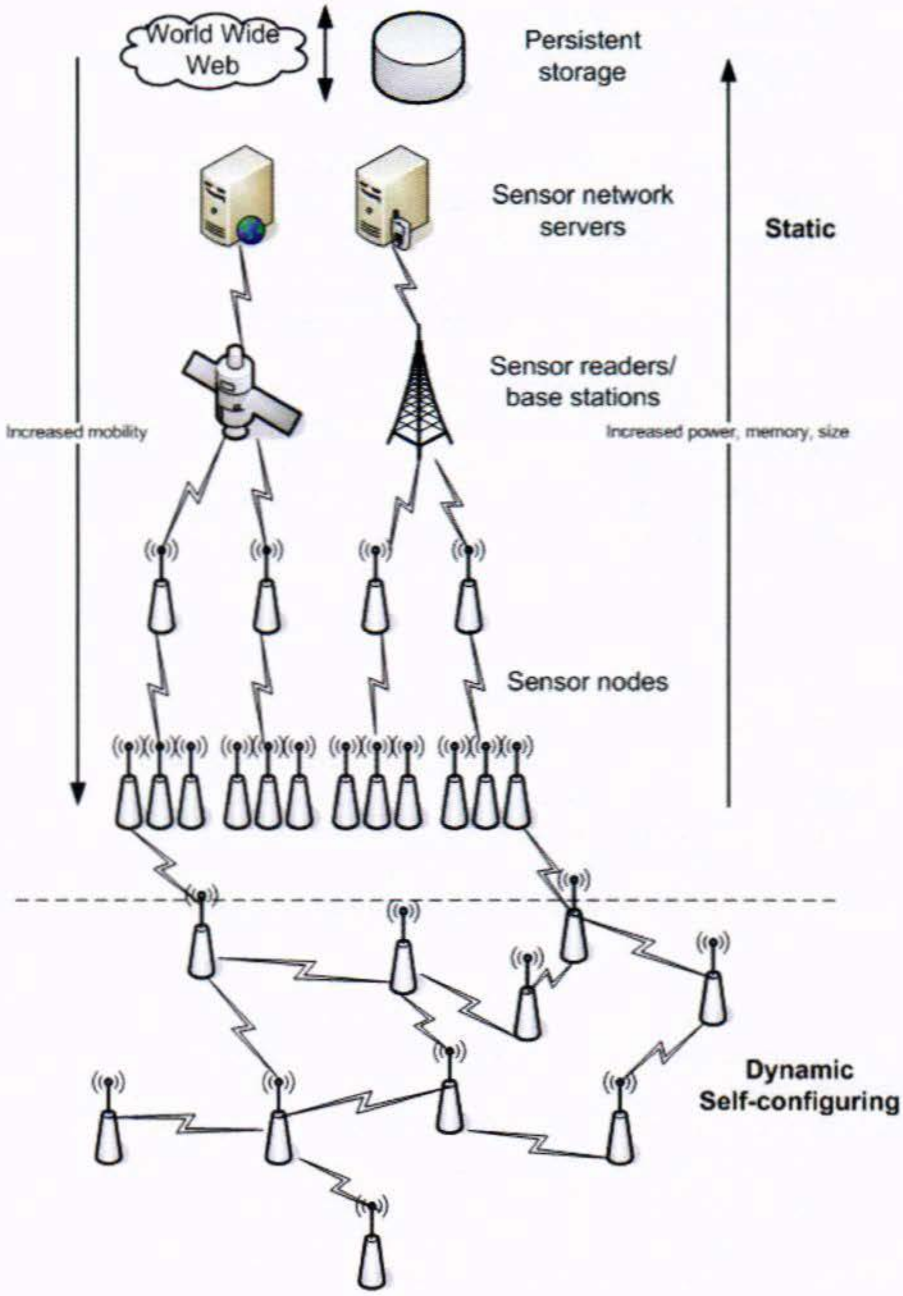

Figure 2 A generic sensor network architecture

3.1 Sensor Network Challenges

The deployment and application of information gathered from sensors and sensor networks involve some unique challenges compared to normal networked computing devices [45]. Some of the issues will be briefly discussed below.

Miniaturisation – Sensor networks are often deployed in confined spaces, thus miniaturisation ensures that they are unobtrusive. This can be done by reducing the antenna size, battery and radio power requirements. For some types of sensors, the lifetime requirements and the type of usage can imply different setups related to radio power, sample frequency, type of data sensed, unit of measurement, communication protocols (push vs. pull of data), data aggregation and computation, etc.

Power management – Long time operation of sensor networks requires economic power management. That means in practice that sampling and communication frequency needs to be

minimised to save power. Some kinds of sensors do not have a separate power source, but is activated by, e.g., induction fields, i.e., these sensors need an external triggering to operate. Thus, sensors are often characterised as either active or passive based on how and when they are sensing and returning sample information.
Different schemes of communication and sampling setup are typical methods to manage power. The type of usage, e.g., in temperature measurements, can imply how often and which kind of sampling and reporting regime to be used. The same applies to activation of deactivation of the sensors where sensors only are active to support certain processes or events and are inactive else.

Radio communications – The environmental conditions like humidity, temperature and wind, can hinder reliable radio communication. Thus, these may influence the need to alter transceiver power, or use other means of communication like lower frequency or acoustic communication instead of the normal mode of communication.

Scalability – The number of sensors or sensor groups will typically increase in some environments, or the sensors can be deployed in such a large number that point-to-point communication at certain time intervals is bigger than the available bandwidth. The sampling and communication frequency can also lead to congestion and bad throughput. Different techniques can be applied to reduce such conditions, e.g., by assigning super-nodes responsible to collect information from sub-nodes, by adding more base stations/sensor sinks (gateways), to increase the time a sensor is awake and able to communicate, or to invoke sensors/sensor groups in a sequence thus activating fewer sensors at a time, and to have a longer communication windows for either the base station or the sensors.

Remote management – As the number of sensors increasing, the sensors are mobile, or are deployed in remote areas, remote access may be necessary to monitor the sensors, fix defects, shut down subsystems, change schedules, etc. Sensors should be possible to be configured in groups since one-to-one configuration will not scale up as the number of sensors increases.

Usability – The components used in sensor networks should as much as possible consist of standard components that are more easily available, deployable, maintainable, and easier to understand. Plug-and-play techniques are preferable to proprietary set up and configuration. The data access should also be similar across the different sensors or sensors network to ease monitoring and management.

Standardisation – Sensors from different providers or vendors may often be instrumented with different software and radio frequency, thus making it necessary to develop separate middleware and communication systems to be able to integrate them into the sensor network. Standardised interfaces and radio frequencies may enable interoperability among the different products and the monitoring software and applications using the samples.

Security and safety – Sensor networks should normally blend into the surroundings and only when appropriate, carry messages, alarms and other information. The sensor networks and the software need to cope with the loss of sensor nodes, either to failure or damage, thus preventing erroneous sensing and communication from starting or stopping events or activities that can make physical damage. In addition, it is vital that the data are protected against deliberate or accidental alternation. The security mechanisms should however not hamper authorised access to the information.

3.2 Wireless Identification and Sensing Platform (WISPs)

The use of RFID has increased the interest to also apply RFID-like technology for wireless sensor networks where RFID technology can be exploited to also develop and apply sensors that operate like RFID tags. I.e., sensors are gathering their operating energy from RFID reader transmission in the same manner as RFID tags (RFID PHY and MAC layer). A WISP [62] is a device that operates as passive a RFID tag (battery-free), but includes a very small-scale computing platform for sensing, computation and communication. The Intel WISP features a wireless power supply, bidirectional UHF communication, and a fully programmable ultra-low-power 16-bit flash microcontroller with analog-to-digital converter [7]. Storage capacitors can store RF energy when in range of RFID readers thus allowing unpowered functionality for a period. A challenge to such a combination of technology is partly similar to any integration of RFID and sensors (semi-active or active RFID with sensors) because the RFID protocols need to be modified to manage sensor queries. Another issue is of course that the power is intermittent and the working time of a sensor thus can be non-deterministic.

The literature shows examples of both active and passive RFID tags with sensors that sense acceleration [62], temperature [7], location by use of photo-sensing [56], etc. It can be expected that the combination of RFID and sensors will increase in the future, giving abilities for more context-aware applications and decision support, as well as providing support for smart work processes in a range of industrial areas including the food sector. In combination with traditional wired sensor networks, data can be captured in real-time providing real-time decision and work support.

3.3 Wireless Sensor Networks

WiseNET [20] provides a platform that uses a co-design approach that combines a dedicated duty-cycled radio with WiseMAC, a low-power media access control protocol, and a complex system-on-chip sensor node to exploit the intimate relationship between MAC-layer performance and radio transceiver parameters. This optimizes overall power consumption by exploiting the intimate relationship between MAC layer performance and the radio transceiver parameters.
A sensor node must also operate as a relay for implementing multihop communication by receiving the data coming from one or several of its neighbours and then processing it before routing it to the next neighbour toward the destination. To perform these functions, a sensor node — which includes many subsystems — can be integrated into a single system on chip to minimize power consumption and reduce the cost.

3.4 Summary

This chapter has provided an overview of how a collection of different hardware like sensors can be integrated in networks to provide a more fine-grained monitoring of different properties in an environment. Some application areas have been described that apply sensor networks, but a full-fledge deployment of especially wireless sensors are still in an early stage related to the maturity of hardware and protocols. Sensor networks as a field still faces many challenges that need to be solved to give an immediate value. Different challenges in this area have been presented and partly discussed. The development suggests, however, that the vision of ubiquitous computing presented by Weiser [71] is close to a reality, also in an industrial setting. Distributed and mobile data acquisition using RFID and sensors enables a new level of granularity for improved process and decision improvement and support.

4 Standards, Protocols and Solution Architectures

This section will present different standard initiatives related to RFID, sensors and other applicable standards. There exists many different standards that can be employed, but the domain of sensors is still a quite unsettled are with respect to standardisation [10]. Covered below are some of the seemingly most important standards like EPCGlobal, IEEE1451 and SensorML.

4.1 EPC – Electronic Product Code

EPCglobal leads the development of industry-driven standards for the Electronic Product Code (EPC) to support the use of Radio Frequency Identification (RFID). RFID (Radio Frequency Identification) is used in all areas of automatic data capture allowing contactless identification of objects using RF [26]. RFID technology solutions are receiving much attention in research and development departments of large corporations.

EPCglobal has proposed several standards related to different levels in a reference architecture framework. The current version of the EPCglobal Architecure Framework is Final Version 1.3 from March 2009 [23].

The most interesting standards covered by EPCGlobal related to sensor network applications are EPCIS [22], ONS [24] and ALE [21]. These standards define an architecture (EPCIS) with supporting services (EPC, ALE and ONS) that provides well-defined interfaces between EPC tags and sensors using EPC for unique identification.

RFID data can be formatted in different standards where the Physical Markup Language[1] is an example and send to different targets as messages, streams, or through other formats via Web services, HTTP responses, etc.

4.2 Radio frequency (RF) based sensor networks

This section will describe sensor networks which communicate wirelessly with each other and with sensor readers/base stations.

4.2.1 IEEE 802.x Standards and Wireless Communication

Several standards for wireless communication are in use to provide communication channels for sensors and more generally between computing devices. The most known standards are Wireless Local Area Network – *WLAN* (IEEE 802.11)[2], Wide Area Network – *WAN* (IEEE 802.16), and *BlueTooth*[3]. In addition to these standards, some proprietary protocols and standards are used, especially within radio frequencies that are not restricted. The different wireless standards are directed to different use and can thus not be used for all purposes. The IEEE 802.x standards are, e.g., mostly using TCP/IP (ISO-OSI protocol stack) and thus all nodes need to have an IP and MAC-address to exploit these networks.

In sensor networks with many sensors, it may not be practically to assign IP-addresses to every node, thus other means for identification is necessary.

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[1] http://web.mit.edu/mecheng/pml

[2] http://www.ieee802.org/11/

[3] http://www.bluetooth.com/

BlueTooth is a short-range network where the nodes are assigned names which can be broadcasted for peer-to-peer communication. Near Field Communication – NFC[4], and RFID (ISO/IEC 18000[5], EPCGlobal[6], ISO 14443) is mostly based on semi-active or passive tags and communication is thus only initiated when within reach of a sensor reader that actively initiates communication. The distance between the communicating devices and the specific usage area are thus of importance for which network standard to select and use.

Sensors (like other mobile computing devices) may have built-in support for more than one communication protocol. With IPv6 (MobileIP), the possible address room for IP addresses has increased substantially to enable all kind of computing devices to have a unique IP address. This is especially important since Internet in many cases will be the most prominent and available network architecture to communicate through.

In addition to Internet, the mobile phone networks (GSM, UTMS, CDMA, etc.) and satellite networks are interesting to exploit when not directly in reach of direct Internet connections.

Sensor networks have normally either had a specific purpose for which kind of properties to monitor, and different schemas of operation or sampling methods (including sampling frequency) have decided the communication patterns. In event-based sensor networks, only deviations from a normal situation may initiate communication between peers or to base stations. Such sensor networks may thus be regarded as "sleeping" until an event occurs. Other sensor networks may provide samples at certain intervals that are transmitted to a receiving node for processing.

4.2.2 IEEE 802.15.4 and Zigbee

ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4-2006 standard for wireless personal area networks (WPANs [7]), such as wireless headphones connecting with cell phones via short-range radio. The technology is intended to be simpler and less expensive than other WPANs, such as Bluetooth. ZigBee is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking (source: Wikipedia[8]).

The ZigBee Alliance[9] is an association of companies that maintain and publish the ZigBee standard. The goal of the ZigBee Alliance is to provide the consumer with ultimate flexibility, mobility, and ease of use by building wireless intelligence and capabilities into everyday devices. ZigBee technology will according to their objectives, be embedded in a wide range of products and applications across consumer, commercial, industrial and government markets worldwide. Zigbee is thus envisioned as a standards-based wireless platform optimized for the unique needs of remote monitoring and control applications, including simplicity, reliability, low-cost and low-power.

The current list of application profiles either published or in the works are:

- Home Automation
- ZigBee Smart Energy
- Telecommunication Applications

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[4] http://www.nfc-forum.org/specs/
[5] http://www.hightechaid.com/standards/18000.htm
[6] http://www.epcglobalinc.org/
[7] http://www.ieee802.org/15/pub/TG4.html
[8] http://en.wikipedia.org/wiki/ZigBee
[9] http://www.zigbee.org

- Personal Home
- Hospital Care

ZigBee builds upon the physical layer and medium access control defined in IEEE standard 802.15.4 for low-rate WPAN's. To complete the standard, the Zigbee specification adds four main components: network layer, application layer, ZigBee device objects (ZDO's) and manufacturer-defined application objects which allow for customization and favour total integration[10].
ZDOs are responsible for a number of tasks, which include keeping of device roles, management of requests to join a network, device discovery and security.

At its core, ZigBee is a mesh network architecture. Its network layer natively supports three types of topologies: both star and tree typical networks and generic mesh networks. Every network must have one coordinator device, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and meshes allow the use of ZigBee routers to extend communication at the network level (they are not ZigBee coordinators, but may act as 802.15.4 coordinators within their personal operating space), but they differ in a few important details: communication within trees is hierarchical and optionally utilizes frame beacons, whereas meshes allow generic communication structures but no router beaconing (source: Wikipedia[10]).

IEEE 802.15.4 is also basis for the WirelessHART[11] and MiWi[12] specifications which as ZigBee, attempt to offer a complete network solution by developing the upper layers which are not covered by the IEEE standard.

WirelessHART is according to Hart Communication Foundation[11], the first open wireless communication standard specifically designed to address the needs of the process industry for simple, reliable and secure wireless communication in real world industrial plant applications.

Miwi and MiWi P2P are proprietary wireless protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs) that are designed for low data transmission rates, short distance, cost constrained networks[13].

4.3 Standards on combinations of RFID and sensors

The combination of RFID and sensors (e.g., temperature, pressure, humidity etc.) has given rise to new ways to capture data where the sensed data can be directly related to specific identified items through the use of RFID. Basically, the environment is monitored by an extension of a classical RFID tag with a sensing hardware. The normal mode of operation is to use the RFID reader to also collect information from the embedded sensors using the standard RFID reader protocol. Thus, a sequence of operations to read stored information on a tag is to first activate the RFID tag using a normal RFID read operation. This operation will return an ID along with some schema/protocol telling that the RFID tag has additional information stored on it. Thus, the reader can initiate a data transfer from the RFID user memory.
The combination of EPC and sensor networks is not covered by any single standard, even though some suggestions for how to do this have been presented [42, 69]. Basically, the EPCglobal Network has been proposed as the basic framework to extend or integrate with Wireless Sensor Networks.

[10] http://en.wikipedia.org/wiki/ZigBee_specification
[11] http://www.hartcomm2.org/hart_protocol/wireless_hart/wireless_hart_main.html
[12] http://www.microchip.com/
[13] http://en.wikipedia.org/wiki/MiWi

A separation of concerns model does, however, split between how to represent and how to communicate information related to both EPC and eventual sensor information. The hardware vendors are thus at the present able to use proprietary models in the hardware integrating sensors with an RFID tag. The communication protocol will similarly need to be adapted by how information is to be communicated between an RFID reader and the tag. A goal for most vendors will be to have enough generalisations to also enable generic RFID readers to read sensor information through the standard low-level RFID protocols.
In the higher levels of an architecture including sensor-enabled RFIDs, other means of communication and representation will be necessary. Several initiatives have been established to standardise how to describe sensors and how to enable transportation of data from these sensors to subscribing systems. Below, the Open Geospatial Consortium describes such an initiative.

4.4 Open Geospatial Consortium

A sensor network consists of many different sensors at different locations that are connected to and accessible by computers. A *sensor web* refers to sensor networks that are accessible over the web using standard protocols and APIs. The idea is to have a multitude of sensors available online that monitors different conditions, and to provide metadata describing the live and stored data to discover, access, and use them through a web browser. The sensor web is also to be used to control these sensors remotely for configuration and maintenance [57] [5].

Open Geospatial Consortium (OGC) [14] is an international organization that develops standards for geospatial and location-based architectures and services. OGC is behind an initiative called "Sensor Web Enablement" to build a framework of open standards to support the sensor web.

The OGC reference architecture for sensor web enablement (SWE) provides different models and interfaces to represent and manage any physical sensors situated in any environment. The standards from Open Geospatial Consortium are labelled as OpenGIS standards. Parts of or the whole architecture is thus very interesting as a platform for modelling and integrating sensors and sensor applications into other applications, e.g., decision support systems. One of the main problems with other standards presented in this report related to management of observations and measurements is the lack of a proper meta-model to take care of how to interpret and understand readings from sensors. The inclusion of sensor readings like temperatures into, e.g., TraceCoreXML, does not give an accurate picture of important properties related to the measurements like where the temperature sensor was placed, which configuration it had related to sampling (frequency, accuracy, sampling method, etc.) and how to interpret the actual readings.

There are six main areas of functionality that are targeted by OpenGIS sensor web [5]:

- Discovery of sensor systems, observations, and observation processes that meet an application or user immediate needs
- Determination of a sensor's capabilities and quality of measurements
- Access to sensor parameters that automatically allow software to process and geo-locate observations
- Retrieval of real-time or time-series observations and coverage in standard encoding
- Tasking of sensors to acquire observations of interest
- Subscription to and publishing of alerts issued by sensors or sensor services based upon certain criteria

Support for this functionality is enabled by a set of specifications for encoding sensors and sensor observations, and several service interfaces using web services. Every standard is based on XML.

[14] http://www.opengeospatial.org/

There are currently seven different standards that are created by the SWE working group, which are all pending OpenGIS specifications [5] [38]:

- **Observations & Measurements Schema (O&M)** – Standard models and XML Schema for encoding observations and measurements from a sensor, both archived and real-time.
- **Sensor Model Language (SensorML)** – Standard models and XML Schema for describing sensors systems and processes; provides information needed for discovery of sensors, location of sensor observations, processing of low-level sensor observations, and listing of taskable properties.
- **Transducer Markup Language (TransducerML or TML)** – The conceptual model and XML Schema for describing transducers and supporting real-time streaming of data to and from sensor systems.
- **Sensor Observations Service (SOS)** - Standard web service interface for requesting, filtering, and retrieving observations and sensor system information. This is the intermediary between a client and an observation repository or near real-time sensor channel.
- **Sensor Planning Service (SPS)** – Standard web service interface for requesting user-driven acquisitions and observations. This is the intermediary between a client and a sensor collection management environment.
- **Sensor Alert Service (SAS)** – Standard web service interface for publishing and subscribing to alerts from sensors.
- **Web Notification Services (WNS)** – Standard web service interface for asynchronous delivery of messages or alerts from SAS and SPS web services and other elements of service workflows.

The first three standards are XML Schemas for encoding of sensors, sensor observations, and real-time streaming to and from sensor systems. These three are required to have a common understanding of the functionality of a sensor, and what the data coming from the sensor means. The last four standards are web service interfaces that enable communication with the sensors. Many of the standards rely on other standards, e.g., various ISO standards. Details about these will not be given but they will be referred to where appropriate to understand how the SWE standards are created.

4.5 SensorML

SensorML provides standard models and an XML encoding for describing any process, including the process of measurement by sensors and instructions for deriving higher-level information from observations. Processes described in SensorML are discoverable and executable. All processes define their inputs, outputs, parameters, and method, as well as provide relevant metadata. SensorML models detectors and sensors as processes that convert real phenomena to data.

Another important part directly related to OpenGIS and SensorML is *Observations and Measurements*; a conceptual model and encoding for observations and measurements. This is formalized as an Application Schema, but is applicable across a wide variety of application domains. An Observation is an action with a result which has a value describing some phenomenon. The observation is modelled as a Feature within the context of the General Feature Model [ISO 19101, ISO 19109]. An observation feature binds a result to a feature of interest, upon which the observation was made.

4.5.1 SensorML Capabilities

Electronic Specification Sheet - In its simplest application, SensorML can be used to provide a standard digital means of providing specification sheets for sensor components and systems.

Discovery of sensor, sensor systems, and processes - SensorML is a means by which sensor systems or processes can make themselves known and discoverable. SensorML provides a rich collection of metadata that can be mined and used for discovery of sensor systems and observation processes. This metadata includes identifiers, classifiers, constraints (time, legal, and security), capabilities, characteristics, contacts, and references, in addition to inputs, outputs, parameters, and system location.

Lineage of Observations - SensorML can provide a complete and unambiguous description of the lineage of an observation. In other words, it can describe in detail the process by which an observation came to be from acquisition by one or more detectors to processing and perhaps even interpretation by an analyst. Not only can this provide a confidence level with regard to an observation, in most cases, parts or all of the process could be repeated, perhaps with some modifications to the process or by simulating the observation with a known signature source.

On-demand processing of Observations - Process chains for geolocation or higher-level processing of observations can be described in SensorML, discovered and distributed over the web, and executed on-demand without a priori knowledge of the sensor or processor characteristics. This was the original driver for SensorML, as a means of countering the proliferation of disparate, stovepipe systems for processing sensor data within various sensor communities. SensorML also enables the distribution of processing to any point within the sensor chain, from sensor to data center to the individual user's PDA. SensorML enables this processing without the need for sensor-specific software.

Support for tasking, observation, and alert services - SensorML descriptions of sensor systems or simulations can be mined in support of establishing OGC Sensor Observation Services (SOS), Sensor Planning Services (SPS), and Sensor Alert Services (SAS). SensorML defines and builds on common data definitions that are used throughout the OGC Sensor Web Enablement (SWE) framework.

Plug-N-Play, auto-configuring, and autonomous sensor networks - SensorML enables the development of plug-n-play sensors, simulations, and processes, which seamlessly be added to Decision Support systems. The self-describing characteristic of SensorML-enabled sensors and processes also supports the development of auto-configuring sensor networks, as well as the development of autonomous sensor networks in which sensors can publish alerts and tasks to which other sensors can subscribe and react.

Archiving of Sensor Parameters - Finally, SensorML provides a mechanism for archiving fundamental parameters and assumptions regarding sensors and processes, so that observations from these systems can still be reprocessed and improved long after the origin mission has ended. This is proving to be critical for long-range applications such as global change monitoring and modeling.

4.6 Observations & Measurements

Observations and Measurements is a standard focusing on representation and exchange of observation results. By having a common standard for this it will not be necessary to implement support for a long range of vendor-specific data formats for each sensor in the sensor network. Below is a brief introduction to O&M.

Observations and Measurements have at its core a basic observation type.

This type has four key properties:

- The featureOfInterest is a representation of the object regarding which the observation is made.
- The observedProperty is the property associated with the feature of interest, and describes the phenomenon observed.
- The procedure is a description of the process used to get the result.
- The result is the value received. The type of the result must be consistent with the property observed.

Table 1 shows an example on these four properties related to earth observations.

Table 1 O&M Example

O&M	Earth Observation
Observation->Result	Observation value, measurement value
Observation->Procedure	Method, sensor
Observation->ObservedProperty	Parameter, variable
Observation->FeatureOfInterest	Media(air, water…)

The standard describes the observation as a "property-value-provider" for the feature of interest. This means that the result contains the observed value of a given property of the feature. The other detailed information in the observation type is of more interest for applications that evaluate errors in the estimated value.
Domain specialization will be needed in any actual implementation. This will primarily be done by the associated classes, and not by the observation class itself. These classes are referred to as the "second layer" in the standard. For example where the model says <<FeatureType>>, this will be determined by actual feature instances for that application. Detailed schemas for these second-layer classes are generally domain-specific schemas utilizing O&M.

4.7 IEEE 1451

IEEE 1451 is a planned set of standards for smart sensors that will make it easier and cheaper to deploy a wide variety of sensors[15].

1. IEEE 1451.0 – This portion of the standard defines the structure of the TEDS (Transducer Electronic Data Sheets) the interface between .1 and .X, message exchange protocols and the command set for the transducers.

2. IEEE 1451.1 – Specifies collecting and distributing information over a conventional IP network.

3. IEEE 1451.2 – Wired transducer interface – 12 wire bus working on a revision which will put IEEE 1451 on RS-232, RS-485 and USB.

4. IEEE 1451.3 – This is the information to make multi-drop IEEE 1451 sensors work within a network.

5. IEEE 1451.4 – This portion of the standard specifies the requirements for TEDS (Transducer Electronic Data Sheets). This is software only.

6. IEEE 1451.5 – This section of the standard specifies information that will enable 1451 compliant sensors and devices to communicate wirelessly, eliminating the monetary and

[15] http://www.smartsensorsystems.com/What_does_IEEE_1451_do.htm

time costs of installing cables to acquisition points. The IEEE is currently working on three different standards, 802.11, Bluetooth and Zigbee.

7. IEEE 1451.6 – This is the information required for the CAN (consolidated auto network) bus.

8. IEEE P1451.7[16]proposed standard for a Smart Transducer Interface for Sensors and Actuators - Transducers to Radio Frequency Identification (RFID) Systems Communication Protocols and Transducer Electronic Data Sheet Formats, describes communication methods, data formats and provides a Transducer Electronic Data Sheet (TEDS) for sensors working in cooperation with Radio Frequency Identification (RFID) systems. This document does not outline, recommend, or prescribe to any specific air-interface protocol. This document is intended to be air-interface agnostic.

Currently, IEEE 1451.1, IEEE 1451.2 and IEEE 1451.4 have become published standards. IEEE 1451.3 has been approved and is awaiting publication. IEEE 1451.2 is awaiting revision. IEEE 1451.4 has commercially available products, largely because National Instruments has enthusiastically backed this standard and is encouraging its clients and alliance members to take advantage of the synergies it provides.

4.8 ANSI N42.42

The purpose of the ANSI N42.42 standard is to facilitate manufacturer-independent transfer of information from radiation measurement instruments for use in Homeland Security. This standard specifies the XML data format that shall be used for both required and optional data to be made available by radiation instruments. The structure of the data is described by an XML Schema (.xsd) file. The schema file allows XML parsers to validate the format of instrument data files: it defines the standard names for data elements and attributes, whether or not they are optional or required for each class of instrument, and the hierarchical relationships between them. A graphical version of the schema is also available. (Source: NIST[17]).

4.9 OPC

Object Linking and Embedding (OLE) for Process Control (OPC) is a standard defined by the OPC Foundation[18]. OPC defines a set of standard COM objects, methods, and properties that specifically address requirements for real-time factory automation and process control applications [40]. Thus, vendors of such applications can develop a reusable and highly optimised OPC server to communicate with different data sources like distributed control systems (DCS), SCADA systems, PLC systems, and corporate information management systems. The basic OPC runs on Windows operating systems and uses the built-in COM/DCOM support for communication. OPC client applications can then connect to different OPC servers to both read and write data to these servers. This enables both monitoring and control of different types of automation systems. The basic OPC DA specification is however mostly usable for desktop applications running on Windows operating systems reducing the interoperability between systems since these must run on Windows. Therefore work has been ongoing to specify and implement Web-enabled communication using XML, HTTP and SOAP to communicate with OPC servers. This has lead to the OPC XML-DA specification providing interfaces to OPC using Web services [65].

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[16] http://ieee1451.nist.gov/
[17] http://physics.nist.gov/Divisions/Div846/Gp4/ANSIN4242/xml.html
[18] http://opcfoundation.org

Another problem with the basic OPC is the missing support for complex data types often encountered in increasingly instrumented automation systems. This problem has been approached by specifying an OPC Complex Data standard enhancing which OPC application to manage all kind of data.

Together, these two OPC standards can be used to provide an XML-based protocol for all types of automation systems which of course also can be extended to also include mobile and wireless sensor systems that contain RFID.

4.10 SODA and other initiatives

Also other standards may be interesting in this context, e.g., ECHONET which specifies an open system architecture that enables the integration of various home appliances and sensors from multiple vendors[19]; DeviceKit[20] which is an OSGi enabled technology that provides support for interfacing with hardware devices from Java™ code; DDL (Device Description Language) which is supposed to support automatic device integration, including sensors and actuators with intelligent environments.

The Device Kit can be used to split the serialized dependency that software development has on hardware platform development. Application code and business logic interface with the Device Kit to get information from the hardware device. It provides a layer of abstraction against which applications can be developed for devices even when hardware-specific information is unknown.

The Device Kit environment consists of the following components: an application, a runtime, and a hardware device. The runtime is divided into the adapter and profile layer, device layer, transport layer, and the connection layer.

DeviceKit and DDL are two independent proposals to the Service Oriented Device Architecture (SODA) Alliance[21].

4.11 ISA 100.11

The ISA-100.11a standard is intended to provide reliable and secure wireless operation for non-critical monitoring, alerting, supervisory control, open loop control, and closed loop control applications. The standard defines the protocol suite, system management, gateway, and security specifications for low-data-rate wireless connectivity with fixed, portable, and moving devices supporting very limited power consumption requirements. The application focus addresses the performance needs of applications such as monitoring and process control where latencies on the order of 100 ms can be tolerated, with optional behavior for shorter latency.
"To meet the needs of industrial wireless users and operators, the ISA-100.11a standard provides robustness in the presence of interference found in harsh industrial environments and with legacy non-ISA-100 compliant wireless systems," said ISA100 co-chair Pat Schweitzer of ExxonMobil. The standard addresses coexistence with other wireless devices anticipated in the industrial workspace, such as cell phones and devices based on IEEE 802.11x, IEEE 802.15x, IEEE

[19] http://www.echonet.gr.jp/
[20] http://www.eclipse.org/ohf/components/soda/
[21] http://www.sensorplatform.org/soda

802.16x, and other relevant standards. Further, the standard allows for interoperability of ISA-100 devices 22.

4.12 Discussion and summary

Several relevant standards for representation of sensors and RFIDs, and exchange of information between systems have been presented above. None of the standards actually rule out any of the others with respect to communication of information from the many heterogeneous systems that typically are deployed in modern food production and management.

The main issue is not whether it is possible to communicate information between systems but more which standard that will become the most prevalent for communication of information within and among actors in the food chain. As long as the information is related to proper meta-information describing the context of the information like measurement method, quality of measurement, measurement unit, measurement frequency, exception management etc., the data provided can be used in other systems as long as the data can be interpreted correctly by these systems.

The use of Internet protocols both enables a text-based exchange of information and an interface for reading and writing this information. Many tools have been developed that is able to build up parser programs in run-time based on the meta-information provided in the XML-messages (e.g., XSDs and XML Schema). Middleware with defined interfaces can be used to intercept and translate from one type of schema to another, thus providing another representation and view of the same information.

Application owners and developers should therefore not focus only whether they are able to manage all the different formats, but much more how to employ the information in process and decision support. Separation of concerns thinking may also be a key for selecting standards for implementation within companies. Strong OPC focused architectures would normally mean that some of the interfaces already are well-defined, and OPC could thus form a communication standard for non-OPC objects like wireless sensor networks. Similarly, a focus on EPCIS-like architectures can give a strong indication about how information should be provided. The differences between these two are in theory (and possible practice as well) not very big since both architecture types are based on measurement events either initiated by the sensors, the readers or by a subscribing application.

The main problem with the EPCglobal as well as the OPC standards is the scope of these solutions since these are built with a specific usage in mind. OpenGIS is much more open with respect to both application and openness, but may at the same time be hard to use since few limitations have been specified. This can cause problems when communicating information between different actors.

The low level protocol standards specifying radio frequencies and signals are of importance related to applicability, scalability and usability in different industrial scenarios. This report has emphasis on the application of sensors in value-added services using sensors and sensor technology to improve, change, and monitor different qualities related to business processes with respect to decision and process support. RFID and sensor networks are thus enabling technology to both increase data capture and give the data capture a specific context on a rather fine granularity. The new possibilities that such technology can give industrially are either described

[22] www.isa.org/ISA100-11a.

on a too coarse level for being directly applied (in the form: "It is believed that…", or on a too fine level to be of real value because of implementation costs and deployment (in the form: "If every actor implements this…"). It is therefore necessary to analyse and specify a level that is applicable for specific business processes and thereby provide information in a granularity that suits the eventual decision and business support.

5 Research challenges and requirements for sensor networks

5.1 Challenges in Context-Aware Systems

Implementing a context-aware system requires addressing many issues [58]:

- **How does the system represent context internally?** How do we combine this information with the system and application state? Where should the system store context -- locally, on the network, or both? What are the relevant data structures and algorithms?
- **How frequently does the system need to consult contextual information?** What is the overhead of considering context? What techniques can we use to keep this overhead low?
- **What are the minimal services that an environment must provide to make context awareness feasible?** What are reasonable fallback positions if an environment does not provide such services?
- **What are the relative merits of different location-sensing technologies?** Under what circumstances should we use one and not another? Should we treat location information just like any other contextual information, or should we handle it differently? Is historical context useful?

Dey and Abowd [15] describe the difficulties of developing context-aware applications. First, designers lack conceptual tools and methods to account for context awareness. The available context acquisition mechanisms drive the choice of context information to be used in applications. The selected sensors might not be the most appropriate, and the details and shortcomings of the sensors may be carried up to the application level. Second, distribution, modifiability, and reusability are problems to be faced. Mobile devices are heterogeneous with different computing, communication, and user interface capabilities, thus context-aware applications require lightweight, portable, and interoperable mechanisms across a wide range of platforms.

To support a mobile worker, it is important to identify both what context is vital for the worker, how to collect this context, as well as how to use it when creating supporting systems for the mobile worker. The context in a mobile and dynamic environment might have a much higher influence on work processes than in a distributed, but static environment. As can be seen above, context-awareness has in a small degree been included in workflow, process, and cooperative work (CSCW) systems. CSCW has, however, to a much larger degree included context since CSCW deals with interactive cooperative work.

[16] states that the goal of context-aware computing is to make interacting with computers easier. The management of context should be automated to let the supporting applications deal with it, instead of the users. This perspective means that the application developer should both decide what information is of interest, as well as how to deal with it. A context-aware, mobile work support application has to deal with context related to all the categories of context described above.

When building architectures to support non-stationary work, a number of issues arise. Many of the existing components are often network specific and fail to provide adequate performance over a range of infrastructures [18]. The interfaces to such components are also often application specific, making use of different kinds of, e.g., sensor components difficult. The information passed from sensors might often be too fine-grained for upper-level components. It is therefore a need to specify generic application architectures for part of the sensor application domain to utilise different kinds of sensor components. Infrastructures modified from a fixed to a wireless setting are in danger of missing important utilities because of missing support for the dynamic situation when in a mobile environment. Context-aware applications have to take into account contextual issues across the whole system design, from the infrastructure and system layer, to the domain and physical layer. For mobile devices including sensors and sensor networks to handle and reflect on many possible context sources, a lot of resources has to be spent. It is therefore important to find a balance between the utilisation of context and the consumption of resources.

Context information will have different importance based on which kind of context both the user and wireless devices themselves are situated within. It is therefore a matter of utility, reliability and safety for how context information should be included into mobile and/or static work support applications. Important context information should pass to the user where non-influential context information is either filtered by the context source based on user/device preferences and capability, or through coordination services especially tailored for the user/device.

5.2 Technical and organisational challenges

The evolution of sensor technology is going rapidly, but there are still some partly inherent technical challenges to overcome. Some are pure technical while others are partly technical and partly organisational. Below are some of these challenges listed.

- Integration of sensor networks into the physical management of
  - food production, refinement, transport and sale
  - decision support systems in the value chains
- Relationships to existing systems, production and logistic processes

Many ICT and production systems are already in place in many companies, meaning large investments in infrastructure and industrial processes. The main focus has been on optimising performance and physical throughput of individual systems rather than taking an integrated view of larger areas of the production process including all machinery and environment monitoring. In many respects the individual machines are autonomous of other machines with respect to data acquisition and use of these data. Sensor measurements are thus captured and used locally in the individual system. Interfacing information from other sensors in the vicinity or at other systems is seldom used locally in the individual system. A better integration of sensor information from the total production environment into a networked system with integrated monitoring and decision support can be envisioned related to improved use of individual machinery and improved business processes.

- Knowledge of how to:
  - instrument, adapt and configure in both small scale (micromanagement, process adaptation) and large scale (process improvement and optimisation, etc.)
  - design, manage, improve, adapt, etc. decision/business processes
- Scalability related to information overflow
- Management of and adaptation to fuzzy conditions
- A key challenge of a context-aware system is obtaining the information needed to function in a context-aware manner.
- In some cases, the desired information may already be part of a user's personal computing space, like schedules, personal calendars, address books, contact lists, and to-do lists.
- Dynamic information must be sensed by systems in real time from the user's environment – such as position, orientation, people's identities, locally observable objects and actions, and emotional and physiological states [58].

5.3 Requirements to application of sensor networks

This section will outline some generic requirements related to the use and integration of RF-based technology into both new and existing software architectures and infrastructures [50]:

- RF-based sensor networks need to support heterogeneous hardware configurations. Devices from virtually any manufacturer can, temporarily or permanently, become a part of the sensor network.
- Infrastructure solutions need to be able to integrate future, non-RF devices as well without requiring large refactoring efforts of existing software, architectures, and infrastructures.
- Smart sensors are increasingly becoming an important part of RF-based solutions, thus enabling a need for managing heterogeneous data sources sampling a range of different properties of the environment or events related to the environment.
- The ability to automatically detect which devices are currently in a network is another very important requirement. RF infrastructures need the functionality to scan networks to discover devices. This is relevant equally when devices are installed and when the networks are changing configuration, i.e., when they are extended or reduced.
- RF-Infrastructure solutions need the capability for health monitoring and automation of standard maintenance tasks to be able to handle scalability. The infrastructure should be able to tell when something breaks, and send appropriate alerts with respect to what are the problems.
- RF infrastructures need to have the ability to centrally configure device settings across multiple sensor networks in distributed locations. Configuration settings should present in common profiles to enable aggregate update on a multitude of devices at the same time.

5.4 Summary

This chapter has outlined a few challenges and requirements for implementing systems based on the use of sensor networks and context-aware computation systems. Application of collected information can be solved through models of work processes, logistic processes, biological and chemistry processes, but implementation of these still faces many challenges that need to addressed. Some of the challenges may be contradictive and considerations must thus be taken about which properties and functionality that are most important to manage and support. Deployment and uptake of technology depend on trust which must be built into the systems from the beginning. The change from centralised systems to highly distributed and decentralised systems is a separate challenge with respect to information management and exchange, timeliness and scalability as well as properties like security, privacy and usability. It is nearly impossible for a human to envisage and employ information provided by a large number of individual computing devices that are spread in space and that provide information at different periods or moments in time. Software and hardware need to be cheap, easy to manage and use, and work without human intervention most of the time. This calls for systems that can provide the necessary services to make such systems non-intrusive and trustworthy.

6 Sensor networks and RFID solutions

Several sensor network applications have been developed the last recent years, especially in research context, to investigate and develop solution architectures taking into account a diverse range of technical and practical challenges. This section will present some application areas outside the normal supply-chain management processes RFID typically has been used to. Below some articles detailing different application areas of sensor networks and RFID solutions are presented.

6.1 RFID applications

RFID tagged objects are not in a strict sense part of a sensor network since such objects do not actively communicate with their surroundings. It is however possible to use RFID as part of sensor networks by providing readers at specific locations, times and in business processes.

RFID can be used to enhance the experience and learning of visitors and eventually workers in physical locations by letting an RF tag be carried by visitors and be read at designated places of special interest. Specific information can then be adapted for later retrieval at dynamically generated Web pages based on a coupling between the RFID, a specific user and the reading spot. Thus, the physical environment can be coupled to a virtual environment either on the spot at a screen or later when accessing the Web pages from another computer. An example of interactive RF and RFID applications are at museums [27, 33] and at historic sites [68]. Central to these applications are location-aware information and services.

Many different integrated applications are using RFID to display information about physical objects or spaces. Elope [55] are, e.g., supporting interactive spaces using mobile devices, RFID readers, and nearby equipment like projectors and active screens. E-tag [70] is using tagged objects to present information on a wireless handheld device equipped with a tag reader. Relevant Web pages can be brought up about tagged objects. In CoolTown [35], multiple kind of tags are allowed and users can browse Web pages associated with objects and rooms using their mobile devices. Raskar et al. [56] shows radio frequency identity and geometry using active RFID with photo sensors. WISPs are used to instrument everyday objects with sensing capabilities by use of RF based powering [7, 62].

6.2 Success factors for RFID and sensor networks

A white paper in RFID Journal [52], describes seven critical success factors for RFID in manufacturing. Many of these also apply for generic industry and for generic sensor types since most of these are related to the uptake of new technology and change of business processes [52]:

- Deploy Proven Use Cases that Solve Real Problems. RFID information has been proven to address many of the pressing challenges today's manufacturers face. You can benefit from others' experience and avoid reinventing the wheel.
- Adopt a Flexible Deployment Architecture. One size does not fit all. Organizations of different types and implementations of different sizes require different deployment architectures. Make sure the systems you choose offer the flexibility you need.
- Take Advantage of Real-Time Data. Don't just capture RFID information in a data warehouse. Take full advantage of real-time alerts and insights to reduce error rates and improve productivity.

- Integrate RFID Data and Events with Production Systems. Leverage RFID data where it can add the most value: real-time intelligence for your existing ERP, MES, WMS and MRO systems.
- Use a Standards-Based Approach. Adopting solutions that adhere to EPCglobal standards will ensure that your RFID-based systems can evolve and scale with minimal risk.
- Require Broad Device Support from the Beginning. Regardless of your initial requirements, most organizations find they need a mix of tags and readers from multiple manufacturers. Make sure you have the flexibility to expand your implementation without being locked into a single vendor's products.
- Plan for Continuous Improvement. As you gain experience with RFID, you will find new ways to tune your processes and take advantage of the information it can provide. Make sure your solution can easily adapt as your needs evolve.

Especially important for context-aware applications are the ability to use and take action in real-time based on information about the movement or location of physical assets, equipment or customer orders, as well as based on the environmental properties the asset. With real-time data, you can correct errors before they become costly problems, reducing the time and cost associated with routine verification. Real-time alerts can be sent directly to a handheld device, web browser or stack light, providing key personnel with immediate notification when:

- A process step is missed
- An order is mis-shipped
- An asset is moved to the wrong facility
- Asset contents are due to expire

RFID/sensor readers should be placed at critical distribution/production checkpoints. A rule-based system that understands the meaning of these locations should then be able to identify when an item is in the wrong place or have been exposed to wrong environmental or production conditions and subsequently correct the problem. When automated verification and error correction becomes routine, it is easier to focus on the exceptions that require special attention.

6.3 Case studies of RFID and sensor networks

RFID has primarily been used in the industry to tag objects with unique identifiers to provide and optimise supply chain management. The price of RFID tags and equipment has for quite a long time been so high that mainly high-value products have been tagged with RFID. The prices are now so low that RFID has become "mainstream" in many different industrial segments. Few EPCIS implementations have been reported so far, but several case studies have been performed that investigate the use of RFID in different industrial uses. Especially the area of supply chain management has been early adopters of RFID and RFID applications [48, 49]. Downstream actors in the value chain have been dominant in the application of RFID as can be illustrated by when RFID technology has been introduced on a large scale (e.g., Walmart, Metro, U.S. Department of Defence).

Some other examples of application of RFID and/or sensor networks:

- Case study in cloth retail supply chain [41]
- RFID for internal location tracking [53]
- Food industry: agriculture [3] [8] [31], fish [28] [30], cheese [54]
- Temperature sensors in chicken [73]
- Sensor network for water quality [51]

- Sensor network in aquatic environment [66]
- Environment sensor network [17] [45]
- Wine cellar sensor network [12]
- Shooter localisation in urban terrain [44]
- Radiation detection with distributed sensor networks [6]
- Others: Pervasive deployment [72], case study [25]

6.4 Risks and benefits of using RFID

There are some overview articles which try to sum up risks and benefits of using RFID, primarily in the retail industry. Bhattacharya et al. [4] conducted a literature study of 362 articles, on the status, drivers, benefits, challenges and strategy to adopt RFID in retail industry. Their major conclusion was that four major drivers contribute to the adoption of RFID in retail industry: Benefits, mandate compliance, technology drivers and anti-counterfeiting. The major benefits in the study are: operational efficiency, improved visibility, reduced cost, improved security, improved customer service level, better information accuracy, and increased sales. The major challenges was: impeding diffusion of the technology by business are privacy issues, lack of standards, data integration issues, high cost, employee reluctance to change, business process redesign, and reliability issues. They also identified the places in the retail supply chain where most of the expected benefits are concentrated on the later end of the chain such as replenishment, warehouse management, distribution, in-store operations, sales, and return handling.

Castro et al. [9] show an overview of RFID applications and presents a roadmap for RFID adoption. They state that the retail industry is considered a primary driver of RFID adoption. RFID technology is claimed to have the potential to optimize supply chain processes in the retail industry as well as improving warehouse activities. RFID is also claimed to offer key benefits to enhance the quality and reliability of operations in the healthcare industry, manufacturing, transport and logistics, and the defence sector.

Taking a more sober approach to RFID, Khan and Kurnia [34] conclude in their literature study, that despite the many potential benefits of RFID, the RFID infrastructure is ill-equipped. At the moment, technology prices act as the greatest inhibitor for large scale deployment coupled with premature technology standards. They also point out that there have been issues regarding privacy concerns around the deployment of RFID. Further they suggest that apart from overcoming some challenges in RFID adoption, all benefits of RFID can only be realized with greater collaboration between all concerned partners. RFID has the potential in improving manufacturing and retail business processes, yet at the same time supply chain partners run the risk of sinking it under their own weight by not cooperating. Their final conclusion is that how the companies respond over the next two to three years will determine eventual success or failure of RFID.

6.5 Electronic sensor types with RFID

This section gives an overview of some sensors produced by a few manufacturers today. The section will not go into details about how these sensors work; only what they are able to observe to give an idea about what is available. The section will focus on sensors relevant for this report, e.g. sensors which can be used to provide context information related to item tracking in general and fresh food specific.

6.5.1 Manufacturers

The sensors described in this section come from the manufacturers CAEN, KSW, and Montalbano. CAEN is an Italian company producing, e.g., RFID readers and tags. They also produce an RFID tag which includes a temperature sensor, called a Temperature Logger UHF Semi-Passive tag (CAEN 2008). KSW focuses on RFID, and delivers both active and passive RFID equipment. They have also included a temperature sensor on their active tag, called VarioSens (KSW 2008). Montalbano produces mainly semi-passive RFID tags which can include many different types of sensors (Montalbano 2008). Montalbano has developed a platform which is modular and makes it possible to include a wide range of sensor types on the RFID tags. Two of them are shown in this section, but they have many other possibilities as well, e.g. pressure and shock sensors. These manufacturers are selected as examples, and there are many others. It is obvious that the market for RFID tags including environment sensors is growing, as many companies are developing such products.

6.5.2 Product types

This section presents different types of sensors, with examples from the manufacturers presented above. A set of characteristics is given for each sensor to give a brief description of the performance and qualities of such sensors. It can be expected that the combination of RFID with different sensor types will increase in the future to also include more complex sensor types on different types of RFID. The products described are mainly semi-passive in the sense that they have a built-in battery for the sensor while communication is based on the use of standard RFID readers activating the communication of also sensor values. The need for power supply will probably be the main drawback of sensors of this type because the price of combined sensors is much higher than standard passive RFID. Passive RFID is most often not reused after initial application and can be discarded when ending up at e.g. the retail part of the value chain. For higher priced items, the reuse option will become very important and thus the expected lifetime should defend the primary investments.

Combined RFID and sensors will thus probably be used in a different scale than passive RFID where carefully consideration of placement, replacement and reuse needs to be considered and planned before deployment. A longer lifetime also increases the requirements for sustainable materials able to manage different environments over time without degrading in performance and use.

TEMPERATURE

The most used and discussed sensor type is the temperature sensor. This is very relevant for the fresh food industry and in many other situations where temperature is relevant. Each of the three manufacturers produces temperature sensors, and one example from each is included. Each example below in Figure 3 is a semi-passive RFID tag including a temperature sensor.

	**CAEN RFID Mod. A927 from CAEN** • Time interval for readings is 6 seconds, can be configured on request • Semi passive tag read/write • 3 year lifetime • Supporting ISO 18000, but extended to support sensor data. • Configurable after production • Unix time, internal clock • Two sensors. One of them a probe, enabling internal and external sensing of a box for example.
	**VarioSens from KSW** • 0 up to 720 values (10Bits per value) • Time interval: 2s up to 9h • Monitoring delay: 0 up to 720 days • Read distance: 0 up to 25cm • 0,6 s for reading the whole data (720 values) • Battery MnO2Zn - printed battery (1,5V ... 1,1V)
	**MTsens from Montalbano** MTsens measures time and acquires data of exposure to heat with programmable frequency and performs a very accurate data logging.

Figure 3 Examples of semi passive RFID – temperature sensors

ACCELERATION

The second example is an acceleration sensor a s shown in Figure 4. This type of sensor is able to detect the acceleration of an item, typically by attaching an RFID tag with the sensor to the item. This can be used to detect rough treatment of items, e.g., if it has been tossed or fallen down from a height.

MTshock from Montalbano

- Full scale +-2g/6g
- -20/+60 degree Celsius
- Reusable and low cost
- Programmable rate for data acquisition and storage

Figure 4 An example of a RFID –Acceleration sensor

HUMIDITY

The last example is a humidity sensor sensing the humidity, which is very important to preserve the quality of certain products. The example shown in Figure 5 below is from Montalbano, as was the acceleration sensor.

MThumidity from Montalbano

- Combined temperature and RH% sensing.
- 0-100 RH%
- Programmable rate for data acquisition and storage
- Reporting over 1000 temperature and RH pairs

Figure 5 An example of RFID – humidity sensor

6.6 Smart sensors

A "*smart sensor*" is a transducer (or actuator) that provides functions beyond what is necessary to generate a correct representation of a sensed or controlled quantity (e.g., temperature, pressure, strain, flow, pH, etc.)[23]. The "smart sensor" functionality will typically simplify the integration of the transducer into applications in a networked environment. For example, a measurement from a temperature transducer requires the network controller to make a voltage-to-temperature conversion to represent the data in either degrees fahrenheit or degrees celcius. An intelligent temperature transducer (smart sensor) has a built-in transducer electronic data sheet (TEDS) to make the measurement conversion and provide the data in units of temperature to the network controller. To do this, the smart sensor module also contains the digital interface to provide a communication channel between the network control and the smart sensor.

[23] http://www.smartsensorsystems.com/What_are_Smart_Sensor_Systems.htm

Smart sensors technology enables a broad range of ubiquitous computing applications. The low cost, small size and un-tethered nature let them sense information at previously unobtainable resolution [32].

There are two main components of a functional smart sensor: 1) a transducer interface module (TIM) and 2) a network capable application processor (NCAP)

6.6.1 TIM

TIM is a module that contains the interface, signal conditioning, Analog-to-Digital and/or Digital-to-Analog conversion and in many cases, it also contains the transducer. A TIM can range in complexity from a single sensor or actuator to a module containing many transducers including both sensors and actuators.

6.6.2 NCAP

An NCAP is the hardware and software that provides the gateway function between the TIMs and the user network or host processor (the transducer channel). The IEEE 1451 standard (see Section 4.7) defines the communications interface between an NCAP or host processor and one or more TIMs. Three types of transducers are recognized by the IEEE 1451 standard; sensors, event sensors and actuators.

A transducer channel is considered 'smart' because of three features:

- It is described by a machine-readable, Transducer Electronic Data Sheet (TEDS).
- The control and data associated with the transducer channel are digital.
- Triggering, status, and control are provided to support the proper functioning of the transducer channel.

An NCAP or a host processor controls a TIM by means of a dedicated digital interface medium. The NCAP mediates between the TIM and a higher-level digital network. The NCAP may also provide local intelligence.

6.6.3 Smart Sensor Plug and Play

The IEEE 1451 standard provides for TIMs that can be plugged into a system and be used without having to add special drivers, profiles or make any other changes to the system. This is referred to as "plug and play" operation. The primary features that enable plug and play operation are the TEDS and the basic command set. A TIM may be added to or removed from an active transducer interface media with no more than a momentary impact on the data being transferred over the bus. "Hot Swap" is the term used to refer to this feature.

6.7 Summary

This chapter has presented some of the sensor technology that is available in the market today. The list is not extensive, but gives an indication that RFID tags with sensory capability are starting to become more common in the marketplace for electronics. There is still some work with respect to real-time management and data acquisition using the GEN-2 standard for data communication. Other issues that need to be considered when applying this kind of technology, is to provide mechanisms and functionality that is robust with respect to semantic coupling between the sensors and the objects they are to be applied to. This is partly covered by, e.g., EPCIS that provides business events to the different stages that an RFID is written to or read from. The information provided by the sensor must further be presented and integrated into a context of decision support and business process usage. Such integration is more often than not about changing granularity models for monitoring and providing supporting applications that can use the data for something meaningful.

7 Software solution architectures

This chapter will briefly go through different solutions and architectures related to the implementation of systems that both include and exploit sensor networks for different purposes. In this chapter, RFID infrastructures will also be presented despite RFIDs not being sensors since they do not sample or measure their surroundings. The use and application of RFID do, however, have some important properties related to the temporal and spatial dimensions since the discovery of these can provide physical evidence that items tagged are at a certain place at a certain time. Thus, the RFID readers can be defined as sensors since these are able to identify changes in the environment by the introduction or absence of tagged objects in the vicinity of the reader when the reader is active. The properties or structure of data read by an RFID reader are similar to how samples normally are measured and sent from different sensor types: <RFIDReaderID, ReadTime, RFID> compared to the more general <SensorID, SampleTime, SampleValue>. The proposed RFID infrastructures and common sensor data storages and systems thus show content and management synergy both related to data management and to scaleability.

7.1 EPCIS

The most suitable architecture for support of RFID services seems to be EPCIS from EPCglobal. An extension of EPCIS to also address sensor measurements has been addressed without any immediate results so far in the EPCIS standard. EPCIS is however very well suited to provide simple interfaces to access information about tagged objects which may serve as a platform for accessing other information that are relevant for the tagged item. Sensors to be used in applications need to be uniquely identified and have a context of location and time to be used in other applications. RFID is a technology that provides a wireless protocol for generating events on identifiable objects, including RFID sensors. EPCIS is designed with RFID in mind, but supports all kind of tagged objects

noFilis has developed a infrastructure called CrossTalk to support RFID across heterogeneous hardware platforms [50]. CrossTalk is a SOA-based infrastructure and agent-based architecture developed using Java technology. Also other vendors are developing basic RFID infrastructures and solutions to enable EPC event management and discovery (e.g, IBM, Oracle, SAP etc.).On top of these basic solutions, other solution providers can develop generic or specific services for different business domains (e.g., Telenor IRIS, Matiq, etc.).

7.2 OPC Unified Architecture

OPC as described in Section 4.9 is used as a platform for communicating information in a client-server manner using Microsoft OLE/COM technology. OPC servers have traditionally been hard to configure and set up for solution providers because of the heterogeneous nature of systems and communication carriers. In the recent years, Internet protocols have become prevalent in most communication enabling better interoperability and more light-weight clients. OPC is being released in a new version that incorporates Internet protocols and the different sub-standards developed by OPC Foundation. The OPC Unified Architecture (OPC UA) [43] is the new standard for data communication in process automation. OPC UA is expected to replace the Microsoft-based specifications by unifying the functions provided by these specifications.

OPC UA addresses in addition to data communication, also information modelling thus allowing meta-data exposure and richer information models. OPC UA consists of 37 services where three services deal with discovery and six with connection handling. The services are designed in a service-oriented manner allowing bulk operations to avoid roundtrips.

7.3 Sensor network architectures

Infrastructure sensor networks have become quite common especially in production environments using robotics and automated product lines. These sensor networks are mostly using standard TCP/IP protocols for communication and have dedicated software services and database management systems for aggregation and persistence.

Several experimental sensor networks have been tested the recent years, providing sensed information from many different kinds of sensor types, including audio and video as well as more normal environmental properties like temperature, pressure, humidity, motion, etc. coupled to location and time. The information captured is used for different kinds of functionality as described in Section 3.

Wireless sensor networks have mostly been applied similarly as the infrastructure sensor networks with the only difference that the sensors are communicating wirelessly. I.e., they are infrastructure sensor networks with fixed locations and sufficient available resources to enable a steady flow of information from the sensor to servers and to subscribing clients.

Ad hoc wireless sensor networks are heavily researched with respect to many issues as described in Section 3.1. Scalability, communication modes and energy issues are considered as the most challenging. Lifton et al. [39] describe the Pushpin Computing system which is a hardware and software platform for modelling, testing, and deploying distributed peer-to-peer sensor networks consisting of many identical sensor nodes. Self assembly and configuration are among the issues addressed by Pushpin.

Service-oriented sensor platforms have also an increasing interest since service-orientated applications (SOA) have been hot as a new way to organise and build applications using Web services technology like HTTP, SOAP and XML. The SODA Alliance[24] works with standards for service-oriented device architectures. The service-oriented approach is described in, e.g., [36].

7.4 Standardised Information Exchange

The main issue with respect to all kind of information exchange is the ability to provide a semantic interpretation of the data, either for computation or for presentation purposes. Internet protocol standards like XML provide means for expressing semantics through designated schemas. Several information exchange standards are used today for providing semantic descriptions of data to be exchanged between different systems and eventually across enterprises. The standards are often described through interfaces in service-oriented/web-based architectures or by the use of exchange protocols like XML. Some discussions have been made how to best make traceability and property information as sensor data available between enterprises. Forås et al. [29] argue that business-to-business standards will provide interfaces for business information exchange between enterprises and can thus also include other kind of information that is related to the business processes.

The "push" kind of protocol is however not always appropriate for information exchange because inability to use or interpret the data. Another approach is to provide links to interfaces or web-pages to access this information. This might save space in the normal B2B messages and be

[24] http://www.sensorplatform.org/soda/

downloaded as separate processes when applicable. It also makes sense to provide interfaces from the originator of the information since semantic content can be better expressed or communicated when the original information is provided instead of information that has flowed between many different partners. It such a setup, it will always be danger of creating errors and changes that contradict or change the original information. Thus, standardised system interfaces may replace push of information by providing a pull instead where applicable. The semantic content will then be known by the provider and integration can then a matter of integration of services and transformation of information where applicable.

7.5 Summary

Actors implementing sensor networks into an ongoing processing plant are facing many challenges related to integration of such systems into the operation of systems and existing technology. The apparent change in granularity and scale of information that can be captured may require changes in infrastructure and existing computer systems related to system architecture with belonging functionality and qualities. In addition to local changes in software and networks, new functionality and interfaces have to be integrated into the existing systems. Integration costs are often overlooked when new technology is to co-exist with the current. Separation of concerns models help to provide principles for this integration, both with respect to information logistics and changes in the infrastructure. The value of investments has thus more than acquisition costs to consider.

Heterogeneous systems and technology call for standardised way to communicate and exchange information. Here, middleware and protocols are used to mask differences and to provide semantic value for the diversity of applications and systems. Information logistics thus become as important as the physical logistics to provide added value in the deployment and operation of the new technology. Similarly, middleware and protocols are used as a platform for communication between different actors where different kind of operation modes needs to be considered based on the nature of information sharing. EPCIS provides an event-based platform for RFID/EPC tagged items that can be shared both within and across enterprises. OPC is mostly used within enterprises together with similar technology like different bus technologies. The extension of OPC towards Web protocols enables a better semantic connectivity between clients and servers. Web service protocols can thus be expected to be the main communication platform to integrate the heterogeneity of systems that will continue to exist despite all standardisation initiatives. High cohesion and loose coupling give improved separation of concerns while middleware and standardised protocols form the basis for integration between systems.

8 Status of using RF-based sensor technolology in the farmed fish industry

This chapter will present use of RF-based sensors technology in the Norwegian farmed fish industry.

8.1 Farming

The industry is currently using sensors that monitor environmental parameters. These parameters are mostly temperature and oxygen levels. The most advanced systems today may be connected to the feed machines and be able to override feeding if oxygen levels drop too low, ie. smart systems, however the sensors themselves do not have this authority and as such only provides input to systems higher up.
Sensors in water may be cabled to a transducer (sender) that communicates with receivers by RF-technology. This is an example of RF as it is used today. Mostly the communication is through wires directly to the feed barge and no RF technology is used.

RF technology as it is on the market today is using wavelengths that functions well in air. The same wavelengths are not as good in water. Most development on wireless water communication is therefor based on acoustic systems. These systems are not yet widely used, but the need for them is expected to increase as the need for measuring and control increases in the fish farming industry.

8.2 Live fish carriers

The situation is similar to the fish farm. Sensors monitor environmental parameters like temperature, oxygen, and waterchemical parameters, however, the problem of distance is not the same as in fish farms. Wires are used to connect the measuring equipment, and the need for RF based technology is not the same, the future may bring more RF based technology to this area. The sensors are feeding data into smart systems that increases oxygenation if the oxygen drops too low, and otherwise adjusts the chemical balance of the water tanks based on the sensor feedback.

Intercommunication in the fish farm supply chain

To ensure information for decision making support throughout the supply chain, information has to be exchanged or made available between the food business actors.

The first critcal information exchange happens between the farm and the live fish carrier. Counting results is often affected by poor communication between the involved actors. The fish farm should give the live fish carrier information about loading activity to improve counting accuracy. The live fish carrier should at the same time provide the counting results for the fish farm employees. RF based sensors could help alleviate this problem.

8.3 Processing

The fish processing industry is similar to other food processing industry and measure mostly weight, length and some quality parameters. This data capture is becoming more and more important, as processing moves toward more individual handling of raw goods instead of bulk processing. The few sensors in use today is wire based. This allows for a coarse division of the goods, which is then packed into pre labeled packages.
With an increase in sensor technology, measuring more quality parameters, a finer granularity of

goods can be achieved. This increases the need for RF based ID's and RF based sensors, as premium quality goods can be packed into RF marked crates with internal temperature loggers.

8.4 Transport

There is little measurements taken during transportation today, the temperature problem is solved using ice in packaging. With new types of packaging and super chilled products, the need for ice in transportation can be reduced, this then reduces the need for packaging volume, however, this presupposes that the temperature can be monitored and documented to ensure product quality.
To ensure good enough quality on the temperature data in this future scenario, we need temperature loggers inside the packaging. This makes wired sensors an infeasible solution, and the need for RF based sensors are expected to increase.
With the increased demand on temperature logging, due to new packaging, the truck needs to enable real time communication from the sensor loggers inside the truck to either the sender or the receiver of the goods.

9 Discussion

We have presented different technologies and approaches related to the electronic instrumentation of different work environment. The introduction of communicating sensors and actuators gives new opportunities for application of ICT for automation and better monitoring and control of the production and work processes.
The use of context to help plan and adapt work activities has been the norm in almost all manual labour and is thus important when manual processes either are to be automated or given more electronic support to optimise the performance and quality of the current work processes.
Some environmental properties are more important than others related to food production and therefore have a higher priority for industrial implementation. Combined identification of physical items and sensing opportunities of these properties gives local information that can be used for supply-chain management and to more advanced and possibly automated decision support related to treatment history and the further use of these items.
From a computerised view, relations are formed between physical items, the environment, and the processes the physical items have been exposed to during the lifetime of that item. Which properties that can be monitored is a matter of technological development, price and capability to use the captured information in the decision support. In addition, it is possible to also add the human aspect and presence as important aspects for better supporting their work processes and influence on the environment.

Smart work processes try to embrace these relationships as a way to build up a view of how work can be performed when the environment is collaborating with the performing actors to reach local or global process goals (like making high quality food with longer durability).

The use of sensors can thus have both a local influence on the production processes as well as provide relevant information on quality in a historic perspective. The local influence will require a context-aware computing environment that is able to adapt the work processes in such a way that process or environmental goals are fulfilled. This can either be done by communicating with electronic actuators that similarly to the sensors also are part of the instrumentation of the local area of interest. The actuators may have specific roles like adjusting the local property to be within an acceptable threshold or to be more complex systems involving both reasoning and decision support that may or may not involve human interaction. An example of the first may be cooling or heating systems with local or distributed thermostats, the latter may involve a number of systems that together collaboratively work towards a goal of equilibrium of several environmental properties like humidity, temperature, pressure, air quality, light conditions, etc.
In areas where process goals can be in conflict, special conflict reasoning systems need to be established that may help in providing a sub-optimal state by the use of stated process rules and priorities based on the knowledge both about the ongoing and planned activities, and the current and optimal environmental properties.

Ther might be some problems introducing computing and interaction devices in a possible hostile environment such as the farming, transport and harvesting of farmed fish. The environment is harsh with respect to temperature, light, pollution, pressure, air quality, etc. and human operation may become cumbersome or in the worst case impossible. Decision and work support must then be provided automatically or semi-automatically using modes of operations that are as much as possible non-intrusive. Thus, the computing services will fade into the background instead of being a primary concern.

10 Conclusion and future work

This report has presented several different topics related to the introduction and use of sensor and sensor networks in the food industry. Integral to all topics is the use of computerised systems to exploit and enhance the possibilities which a better understanding and temporal view of the surroundings can give with respect to automation and decision support. The fish farming industry has limited information about environment and production factors today. Granularity of the existing information is coars giving limited possibilities for production surveilence and optimization. Local context acquisition and environment monitoring can be related to specific logistic units such as cages, boats, trucks, etc. through the use of RFID-tagged sensors applied on the logistic unit. This gives the possibility to collect fine-grained information that can be used to optimise production or logistics. Context-aware applications and systems enable automatic reasoning and decision support that can automate logistic and production processes in much more details than before. Work can be better automated, optimised and performed safer by supporting smart work processes in the production and logistic areas.

Sensors with different capabilities and a more mature RFID technology give possibilities to establish (temporal) sensor networks that are self-configurable and able to perform more fine-grained measurements. Coupled with actuators (and robots), work tasks may be automated by enabling human-like decision support where environmental properties are of importance.

With an increase in sensor technology and increased demand on exchange of data between different actors in the supply chain, the need for standardisation on information exchange is also increasing. One promising solution is the EPCIS architecture framework, which we are currently testing in several projects. Temperature sensors used in the project KMB competitive processing are based on EPC.

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