Building **R**adio frequency **ID**entification for the **G**lobal **E**nvironment

Sensor-enabled RFID tag handbook

Authors: Antti Ruhanen (Confidex), Marko Hanhikorpi (Confidex), Fabrizio Bertuccelli (CAEN), Annamaria Colonna (CAEN), Westy Malik (UPC), Damith Ranasinghe (Cambridge), Tomas Sánchez López (Cambridge), Na Yan (Fudan), Matti Tavilampi (UPM Raflatac)

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About the BRIDGE Project:

BRIDGE (**B**uilding **R**adio frequency **ID**entification for the **G**lobal **E**nvironment) is a 13 million Euro RFID project running over 3 years and partly funded (€7,5 million) by the European Union. The objective of the BRIDGE project is to research, develop and implement tools to enable the deployment of EPCglobal applications in Europe. Thirty interdisciplinary partners from 12 countries (Europe and Asia) are working together on : Hardware development, Serial Look-up Service, Serial-Level Supply Chain Control, Security; Anti-counterfeiting, Drug Pedigree, Supply Chain Management, Manufacturing Process, Reusable Asset Management, Products in Service, Item Level Tagging for non-food items as well as Dissemination tools, Education material and Policy recommendations.

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This document:

This handbook is aimed at a wide range of users, namely students, end customers, researchers, system integrators, hardware software suppliers and IC suppliers planning to incorporate sensors with RFID. This handbook will give a good overview on the technical capabilities and limitations of this technology.

Disclaimer:

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1 Introduction

In recent years RFID enabled automatic identification has generated a lot of interest. Various industries have realized the importance of asset tracking in real time or increasing asset visibility. Any asset, be it a person, automotive part, objects in distribution chain, book in a library, good in transit etc. increases in value by providing location visibility. If apart from being tracked, we can record their surrounding environmental conditions or condition of the object itself like temperature, pressure, humidity, inclination, acceleration, and light exposure etc. for any deviation from the normal or just plain recording. Then we have all the data necessary to make informed decisions about the object.
The omnipresent barcode labels that triggered a revolution in identification systems are being found to be inadequate in an increasing number of cases [1].
The integration of sensors (especially the silicon based ones) into semi-passive RFID tags has recently generated a lot of interest among the RFID community. Only the silicon can meet the aggressive cost performance requirements of most new applications. Silicon based sensors are also benefiting from vast resources developed for the mainstream electronics: microprocessors, memories, and advanced linear microcircuits. The advantage of using silicon sensor technology is not only in increased price/performance ratio, but also in an incredible volume manufacturing capability that IC manufacturing brings [2].

1.1 Purpose of the document

This handbook is aimed at a wide range of users, namely students, end customers, researchers, system integrators, hardware software suppliers and IC suppliers planning to incorporate sensors with RFID. This handbook will give a good overview on the technical capabilities and limitations of this technology.

1.2 Theory and background

The technology that creates a foundation for silicon sensors and microstructures is called micromachining. It is more precisely defined as a three dimensional sculpting of silicon, using standard or modified semiconductor batch processing technology. Silicon micromachining has gradually transformed the way today's engineers think about the physical sensing devices. The field of mechanical structures in silicon – specifically sensors – has received much attention in recent years [2].
The silicon sensor market is moving in a direction similar to other electronic components: higher integration level. In the case of silicon sensors, there are two options for a possible on chip integration: electronic integration and mechanical integration [2].
Silicon is widely used in the manufacturing of purely electronic integrated circuits where only its electrical properties are exploited. The electronic integration uses the electrical properties of the silicon. Its integration relies on developed technology form on monolithic and hybrid integrated circuits. The basic sensing element includes only four resistors. These resistors require additional signal conditioning in order to provide a useful signal for the final user application. Traditionally, all signal conditioning was performed outside the sensor chip using discrete components. Different levels of on chip signal conditioning offers both advantages and disadvantages. The higher the electronic integration content of the chip, the higher is the engineering and the tooling cost required. However a higher integration level offers a lower cost in high volumes.
The mechanical integration uses the mechanical properties of the silicon. The existing mechanical designs are manufactured using traditional one at a time technology. The potential of scaling down mechanical components on a single chip offers access to a high volume, low cost, batch mode manufacturing technology.
In the last few decades, significant research, development and money have been invested in microelectromechanical systems (MEMS). MEMS refers to devices fabricated using bulk, surface or LIGA microfabrication technology [2].

Another visible technology trend is the incorporation of microcontroller power for performing different functions at the sensor level.

1.3 Sensor enabled RFID tag taxonomy

This section introduces the terminology used throughout the whole document. It is important to know basic concepts related to RFID tags to be able to understand the problems and the solutions that we are dealing with in this document. The terminology used in this document is commonly accepted among RFID community.

RFID system is a wireless identification system containing RFID reader, tags, local software/infrastructure and back-end system (e.g., Enterprise Resource Planning system (ERP)). RFID tag is the identification device in the system and contains at least a microchip attached to an antenna that sends data to an RFID reader. The RFID tag contains a unique serial number, and can also contain additional data. RFID tags can be active, passive, or semi-passive tags. An RFID tag contains always the identity feature, despite it is active, passive or semi-passive.

1.3.1 Distinction between tag types

Passive tag: An RFID tag that does not contain a power source. The reader is transmitting RF signals. This electro-magnetic field - generated by the reader - powers the tag and enables it to send back information stored on the chip.

Semi-passive tag: A class of RFID tags that contain a power source, such as a battery, to power the microchip's circuitry. Unlike active tags, semi-passive tags do not use the battery to communicate with the reader. Communication is done in a totally same manner than passive tags do. Semi-passive tags might be dormant until activated by a signal from a reader. This conserves battery power and can lengthen the life of the tag.

Active tag: A class of RFID tag that contains a power source, such as a battery, to power the microchip's circuitry. Active tags transmit a signal to a reader and can be read from 100 feet (35 meters) or more.

Sensor: An electronic device that produces an electronic signal in response to a physical stimulus. Sensors are more frequently being integrated into RFID tags to allow for the detection of a stimulus at an identifiable location. Example: temperature monitoring of a chilled item. Sensor can be integrated to any of the above classes.

1.3.2 EPCglobal tag classes

EPCglobal advances also higher-functionality tag classes in parallel with class 1, which addresses fully passive backscatter tags.

Class 2 tags remain passive, but go beyond Class 1 by adding capabilities such as authenticated access.

Class 3 tags are defined as battery-assisted passive, which communicate using the backscatter techniques of passive tags, but derive power from the battery instead of using RF energy from the reader. This enables a significant range extension, while maintaining the class 1 advantage of minimum tag complexity.

Class 4 tags are also battery enabled, but are fully active, and can receive and transmit independently, allowing still greater range and also greater interference immunity.

1.3.3 Sensor enabled RFID tags

A Sensor enabled RFID tag (later also: "sensor tag") is an RFID tag which contains a sensor to monitor some physical parameter (e.g., Temperature) but also contains the same identification function than a 'normal' RFID tag does. This kind of sensor tag may fall into class2, class3 or class4 in EPCglobal's tag classification. As fully passive, a class 2 sensor tag can measure physical parameters (use sensors) only when powered up by an interrogator. Since class 3 tags are battery assisted, they can work independently. Therefore it may contain logging features to keep track of measurement results as a function of time or it can record predefined events. The advantage of class 4 is the increased reading reliability and distance.

1.4 Usefulness of sensor enabled RFID tags

Adoption of RFID has boosted during recent years. A major enabling factor has been the ratification of globally accepted standards (mainly ISO18000-6C) and thus the availability of mutually compatible hardware. Nowadays these RFID tags are used for many applications like supply chain management, returnable asset management and work-in-progress applications in manufacturing. Putting up and maintaining the needed RFID and IT infrastructure is always an investment that should be utilized efficiently. Sensor enabled tags can use the same infrastructure.

Sensor enabled tags have a superior advantage over many other competing technologies: Automated data collection with standardized (and even potentially existing) infrastructures. There are various value adding functions that sensor tags could enable: Temperature sensor tags to provide a temperature profile of the whole cold chain of perishable items (like presented in chapter 6); acceleration sensor tags to provide evidence of shocks during transportation of valuable fragile items; electronic seal tags to provide tamper evidence of any transported item or product package even without visual inspection. But these are only few examples of the potential use cases.

While thinking of sensor enabled RFID tags, we must not forget the basic RFID functionality: The unique identification of the object. This function is still essential part of sensor enabled RFID tags and it also facilitates the connection of the sensor data with the specific object.

2 State of the art

In this chapter the state of the art is covered by means of existing products, patent research and short descriptions about level of technology in key components and manufacturing processes.
Existing products are good benchmarks for anyone regardless the position in value chain. Patent research is traditional way to get an idea about level of technology. Sensor enabled tags would not be possible without IC-integrated sensors. It is beneficial to know the capabilities of these sensors. The functionality of sensor enabled tags is supported by battery. In this chapter we give a quick overview to the most relevant power sources. Also some considerations from manufacturing point of view are covered.

2.1 Products on the market

This section introduces the “state-of-the-art” -products available on the market. Browsing is done in Q1/2007. Main focus is on similar RFID based sensor integrated products, but also some products which could be substituted with a sensor tag, are also presented. Both functional (e.g., purpose of use, communication protocol, data logging capability) and non-functional (e.g., size, lifetime, durability) are presented.

2.1.1 RFID based technologies

Current markets for sensor enabled RFID tags are still quite immature. There are not many manufactures who offers tags with sensor functionality. Those who already offer solutions or products can be easily stated as pioneers in this field of RFID. Most important findings (closest to scope of this document) are presented in the following paragraphs.
“***CAEN – A927 Temperature Logger UHF Semi-Passive Tag***” is a UHF semi-passive UHF RFID tag, which monitors the temperature as a function of time. In typical use, the battery lifetime is around 3 years. The tag can be used for an example to monitor temperature over the whole supply chain of medical products or perishable food items. The tag is ISO 18000-6B compliant. [3]
“***Infratab – Freshtime Tag***” is a semi-passive RFID tag compatible with ISO UHF 18000-6B. According to manufacturer's website, ISO 18000-6C (gen2) and ISO HF 15693/18000-3 are under development. Freshtime's tags are used for monitoring the temperature of perishable items. Lifetime is from 1 day up to 3+ years depending upon the battery and setup. After programming the information from the perishable item, the tag can work independently and alert user when needed. These alerts can include temperature threshold violating, elapsed time or they can be based on shelf life calculations. Also more detailed data and history can be obtained via RFID queries. [4]
“***KSW – VarioSens Basic***” is a credit card sized semi-passive RFID HF label. Tag is ISO 15693-3 compliant. Tag enables user to measure temperatures, to compare temperatures with standard values and to store related information. This information can be collected by an RFID reader. Depending on the application and measurement interval, the label can be reused. [5]
“***ALIEN – Battery Assisted Passive Tag***” is long range backscatter tag working in 2.45GHz ISM band. The tag includes 220mAh lithium battery, which will provide many years of operation. The tag can be interfaced with any sensor via I2C bus (custom application is needed). Standard product family offers a version with an onboard temperature sensor. In this sensor enabled version, the size of memory is 4kB. Read/write range is reliable up to 30m. [6]
“***American Thermal – Log IC***” is an active HF RFID tag, which can be used as a watchdog in temperature-sensitive or temperature-regulated environments. The tag allows monitoring the temperature as a Mean Kinetic Temperature and as function of time. The tag can be programmed to display a warning light if the temperature has dropped below the specified value. 64000 readings promised. The tag is licensed to be used as a reusable or disposable tag. [7]

"Montalbanotechnology – MTSens" is HF RFID smart label with the shape and size of a credit card. It can be placed on flat or rounded surfaces. The tag acquires data of temperature as a function of time. The data can be read any time during the life cycle of the device and also after the battery has run out. The battery will last at least four months. The tag is compatible with the standard RF-ID ISO 15693. [8]

"***Savi – Sensor Tag***" is an active RFID sensor tag for metal containers. The tag works in 433MHz operating frequency. The tag enables user to monitor both temperature and humidity of metal containers during transportation and in storage. More advanced sensors, which include door, light and shock sensors, are also available. It can be used to monitor the security and integrity of shipments. The tag gives a real-time alarm to reader if the collected data should rise above or fall below the set range that a user has defined. Battery life is promised to be around 4 years in typical use. Working range reaches approximately 100m with Savi Fixed Reader. [9]

"***Microstrain – EmbedSense***" is a passive RFID tag using frequency of 125kHz. The tag is designed for rotating machines, smart structures and medical devices. It is suited for use in harsh environments. The tag can measure temperatures up to 150℃ and centrifugal forces up to 60,000 g. Reading distances are typically in the range of 25 to 50mm. [10]

"***Axcess Inc – Active sensor family***" includes many different types of active RFID tags using 315MHz frequency. Depending on the model, they can be used to identify persons or vehicles. Operating life is around 1-3 years and the range is around 10m in normal use. Depending on the model the tag can store data either on temperature, humidity or radiation. [11]

"Bioett – Biosensor" is a combination of bar code and passive RFID tag. The Biosensor will react to temperature and time, and increase the strength of the electric signal. This signal is collected by a hand-held scanner as well as the ID of sensor. [12]

"Evigia – EV524" platform includes a family of products, which all operate at the frequency of 2.4GHz. Tags can be used to measure temperature, humidity and vibration. The standard package includes a battery capable of up to 2.5 years. With bigger long-life package, the operating period can reach up to 4 years. Reading range is over 60m with a hand-held reader. The tag can be set to alarm when measurements exceed the permitted range. [13]

"Bisa - ActiveTag" includes family of three active tags working in 2.45GHz ISM band. The temperature sensor tag allows user to monitor temperature of tagged item. The tag with vibration sensor can detect either continuous or impulsive vibration or impacts. It can be used to measure for an example acceleration. Reading range is between 30 to 50 meters. [14]

"Cypac - SecurePak" is a post package which includes data storage and tamper and damage detection. Package includes integrated temperature sensor. SecurePak has 5mm read range. It uses Frequency of 13.56MHz and is compatible with ISO 15693. [15]

"G2 Microsystems – G2C501" is an active UHF tag which can be combined with motion, temperature, security, shock, humidity, radiation or pressure sensor. The sensor can wake the tag when predetermined conditions are met. Measurements can be stored in on-chip non-volatile memory or in an external flash memory if an access point or reader is unavailable. Data can be reported back through the 801.11 access point, ISO 24730-2 readers or with EPC readers. [16]

"Identec Solutions – i-Q32T" is an active UHF tag with a temperature sensor. It can receive data at distances of up to 30m from a hand-held device and up to 100m from a fixed interrogator. The tag has a battery life of over 6 years. The tag is available with an internal or external temperature sensor, which can measure temperature of the tagged item in definable intervals. [17]

"Scanpak's - TTB-434-01" is a class IV active tag. There are four different models, which contain light, pressure, temperature or weight sensor. All of these models include tamper, battery level and shock sensors. Shock sensor wakes up the tag when it is moved. The tag operates at 434MHz frequencies and can communicate with a reader at distance of 100m or more. [18]

2.1.2 Competitive technologies

There are few different technologies on the markets that compete with RFID sensor tags. Despite that these other sensors are made almost without exception only for sensing, they are quite big and expensive. The most significant competitors are data loggers, indicators and WSNs (Wireless Sensor Network). Normal RFID tag is probably attached on the package anyway, so adding the sensor tag is not a big change. As earlier has been told, sensor tag can store the data just like data loggers. Advantages of data loggers are their better features. Depending on the model, data logger can measure voltage, current and some other units that aren't available with sensor tag. But because of their size and price, there are no arguments for using data logger as a part of logistic chain.

Another competing technology is the family of indicators. They are usually disposable, cheap and simple adhesive stamp that can be placed on a dry surface. One of the best advantages of indicators is their visibility. They act as visual deterrent to careless handling. Unlike the sensor tags, indicators cannot store the data of measurement and time. Indicator has normally only one measurement which can be for an example temperature, shock, humidity or pressure. At the situations where more than one measurement is needed, several indicators are needed instead of using only one sensor tag. A sensor tag can reach wider measurement range and it is more accurate than indicator. If you are already using normal RFID tag on your system, there are no good arguments for using indicator instead of changing normal tag to sensor tag.

Wireless sensor network (WSN) is a common noun for autonomous sensor nodes that can communicate to each other in order to create an Ad-Hoc network. This means that each sensor supports a multi-hop routing algorithm (i.e., several nodes may forward data packets to the base station). Network needs one gateway node to give access to the sensor data. This technology might fulfil the requirement of applications where sensor tags could be used as well. Each node should have a unique ID. However, this approach is quite heavy. Nodes communicating each other and forming Ad-Hoc network needs to have sophisticated algorithms and energy to run those algorithms. More power efficient method is to use single reader as a “master”, like done with RFID. Therefore, the WSN and RFID technologies are getting closer to each other. Convergence of RFID and WSNs is discussed in chapter 5.

2.2 Patent research

Patent research is one method for evaluating the state-of-the-art in RFID general. The patent search survey was started by searching patents that contained RFID and sensor. Quite soon it came obvious that two different areas were more popular than others. Those two areas where; tire pressure sensors and cold chain management. The survey was then continued by focusing the search for these two areas. Both search queries were made by using PatBase database. Search was made in the title and in the abstract sections of patents.

2.2.1 Tire pressure monitoring

The search was started by evaluating different search areas. Quite soon it came obvious that tire pressure sensors have a lot of patents involving it. The reason for it is that in the end of 1990s more than 100 deaths were caused in USA by roll-over accidents, which were caused by tire tread-separation in Firestones tires. This caused President Bill Clinton administration to publish TREAD act, which mandates the use of suitable tire pressure monitoring system to alert driver to of a severe under-inflation in tires. A total of 26 patents involving RFID in tire pressure sensing were found. They are listed in table 1.

The patents were searched by using two different search queries regarding RFID sensor tags in tire pressure sensing. The queries had slight differences on their approach to the subject. Time period for the search was not limited, although the Clinton act was made in the 90s. Therefore the oldest patent listed here that deals with tire pressure sensing and radio technology was dated January 13th 1971. Also the geographical area was not limited because the patents that are valid in EU and USA are often being applied in other areas and vice versa.

Query for tire pressure monitoring # 1: (RFID or radio frequency identification or tag or transponder or inlay or label) and sensor and (temperature or pressure or accelerat*)
Query for tire pressure monitoring # 2: (RFID or radio frequency identification or tag or transponder or inlay or label) and sensor and passive.

Table 1: Patents regarding tire pressure sensing

Patent	Patent Title
US 7061380 B1	Monitoring and recording tag with RF interface and indicator for fault
WO 06059822 A1	Power-free/wireless sensor based on surface acoustic wave with energy collecting type
US 6255940 B1	Apparatus for monitoring a condition of a tire
US 6970100 B2	Temperature tag and system for monitoring, recording and reporting
US 20050242939 A1	Tire pressure monitoring system
US 6720866 B1	Radio frequency identification tag device with sensor input
US 6854324	Tire monitoring apparatus
US 20030080862 A1	Tire pressure monitoring system
US 6788192 B2	Transponder for tire, tire with transponder and manufacturing method
US 6712276 B1 Application	Method and apparatus for automated measurement of properties of perishable consumer products
US 6544614 B1	Packaging with incorporated temperature sensitive label
US 5483827 A	active integrated circuit transponder and sensor apparatus for sensing
US 6087930	active integrated circuit transponder and sensor apparatus for sensing
WO 9929524 A1 Application	Pressure sensor for a tire and method therefore
GB 2327755 A1 Application	label with temperature sensor
US 5540092 A	system and method for monitoring a pneumatic tire
WO 9736758 Application	system and method for monitoring a pneumatic tire

2.2.2 Cold chain management

Another part of this study was to examine RFID use in cold chain management. This was also something that was popular during the preliminary search, although at the moment there is no direct mandate from governments to use RFID in cold chain management. But naturally vendors are obligated to quarantine the freshness and the safety of the transferred goods. Also the time period was not limited in this search. Also the geographical area was not limited.
Query for cold chain management: (rfid or radio frequency identification or transponder or inlay) and tag and ((transport* or logistic* or food or perishable) and temperature and monitor*)

Table 2: Patents regarding cold chain management

Patent	Patent Title
US 20060214788 A1	RFID System for monitoring food hygiene
US 20060213904 A1	System and method for monitoring food
US 20060145844 A1	Temperature tracking and monitoring system used for commodities transportation
US 20060145863 A1	RFID tag with visual environmental condition monitor
WO 2006043834 A2	Apparatus and methods for processing and distribution of perishable products
WO 2006016343 A1	Monitoring expiration dates of perishable products
US 20060006987 A1	Radio IC tag reader writer, radio IC tag system, and radio IC tag data writing method
EP 1583015 A2	Method and arrangement for managing logistic flows
US 20050052284 A1	Automatic conditioning of data accumulated by sensors monitoring supply

Patent	Patent Title
	chain process
US 20040211507 A1	Electronic time-temperature indicator
US 20040227630 A1	Continuous security state tracking for intermodal containers transported through a global supply chain
US 20040145472 A1	RF identification tag for communicating condition information associate with an item.
US 5406263 A1	Anti-theft method for detecting the unauthorized opening of containers and baggage.

2.3 Applicable sensors

Over the past several decades, sensors have become essential components of the communication devices. Sensors, defined as [19] "devices that transform (or transduce) physical quantities such as pressure or acceleration (called measures) into output signals (usually electrical) that serve as inputs for control systems", are the bridges connecting the outside analogue world with the digital world which could be analyzed and processed easily. On the other hand, the rapid development of the RFID technology presents a brand new opportunity to evolve sensor application.
RFID sensor enabled tags, which can be used in such fields as project tracking, environmental monitoring, automotive electronic system, telemedicine and manufacturing processes controlling, etc., are bred as the result. Without doubts, they will play important roles in more and more areas as the technology is progressively growing.
Roughly, the primary sensors in use today can be classified according to their functions as follows.

- Temperature
- Pressure
- Acceleration
- Inclination
- Humidity
- Light
- Gas sensor
- Chemical sensors

2.3.1 Temperature Sensor

From the second half of the 20th century, adding intelligence to temperature sensor has become the trend with the development of automated industry. Generally speaking, the intelligent temperature sensor is roughly comprised of two parts, which are the sensor interface and the Analog-to-Digital (A/D) converter as shown in Illustration 1.

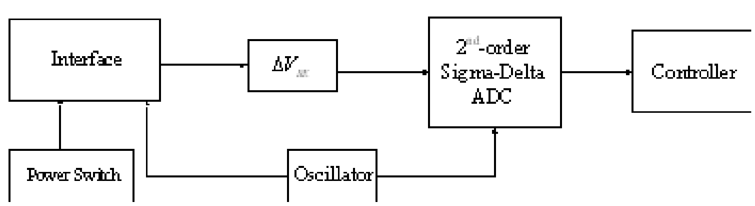


Illustration 1: Temperature sensor system architecture

The smart temperature sensor is usually compatible with standard CMOS technology, which means that two parts are fabricated on the same chip. The one advantage of this approach is that it is easy to be integrated to other RF modules, which helps to realize the wireless communication, and the other is obviously the cost. As informed by the published papers, the cost is between $0.25 and $1.00.

However, every coin has two sides. Since the sensing principle is based on the temperature character of bipolar transistors, as showed in illustration 2, the smart sensor is designed at the expense of less accuracy and limited temperature range. The offset of the opamp and mismatch of the bipolar transistors contribute most to the inaccuracy and the measured temperature range is limited to that of standard IC technology, which is usually from -50°C to +150°C.

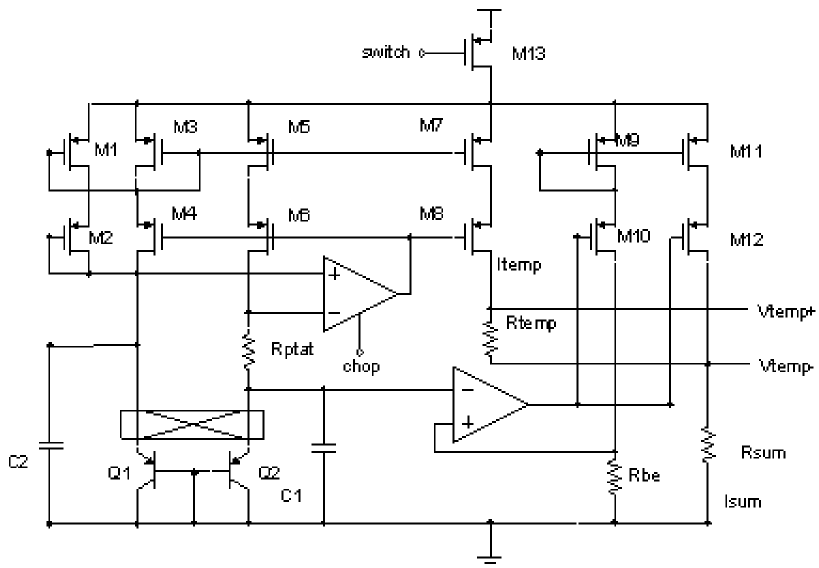


Illustration 2: Schematic of temperature sensor interface

The main application area of the smart temperature sensor includes thermal management in large digital systems, environmental monitoring, project tracking, telemedicine and habitat monitoring of tagged animals.

Cost, power consumption and accuracy are the most important specifications of the smart sensor. Some important results and products are listed in Table 3.

Table 3: Temperature sensor products

reference	**Inaccuracy**	**Range**	**Power Consumption (operating)**
Bakker,1996[20]	±1.0°	-40° to +120°	55 µW
Tuthill,1998[21]	±1.5°	-50° to +125°	3 mW
LM92[22]	±0.33° ±1.5°	30° -25° to +150°	1.8 mW
DS600[23]	±0.5° ±0.75°	-20° to +100° -40° to +125°	420 µW
MAX6607[24]	±0.6° ±0.7° ±1.0° ±1.5°	+20° to +50° 0° to +70° -10° to +85° -20° to -10°	19.2 µW
ADT7301[25]	±0.5° ±2.0°	0° to 70° -55° to +125°	5.2 mW
SMT160-30[26]	±0.7° ±1.2°	-30° to 100° -45° to +130°	900 µW
Pertijs,2005[27]	±0.3° ±0.5°	25° -50° to +125°	400 µW

2.3.2 Pressure sensor

Associated with increasingly matured technology, microelectromechanical systems (MEMS) have experienced a rapid development in recent years. As to the sensors, an accustomed method is to produce the miniaturized versions of their macroscopic antetypes. However, they exhibit better and better value over the conventional ones. As one of the primary representatives, the MEMS pressure sensor, as shown in illustration 3, has dominated the market nowadays.

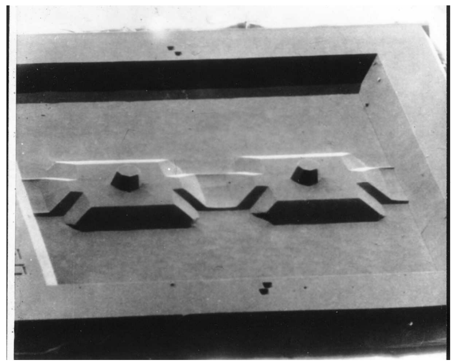


Illustration 3: The MEMS pressure sensor

There are mainly three approaches [28] to the MEMS pressure sensors.

(1) Piezoresistive sensors

The piezoresistive effect of silicon means that the resistance changes with applied stress on it [29]. Piezoresistive pressure sensor is realized by mounting on them the piezoresistors, the resistance change of which is linear with applied pressure. As reported, silicon strain-gauge, metal-diaphragm sensors were first introduced commercially in 1958 [30]. The micro-sensor companies began to move toward higher-volume, lower-cost applications in the 1970s [31–35]. In the present, biomedical and automotive applications are some of the most important application areas. These new types of sensor have some good merits originated from the high-quality silicon. For examples, the tensile strength of silicon can be three times higher than that of stainless steel wire, hysteresis associated with metal is eliminated and maybe most important, silicon has great gauge factors that are over an order of magnitude higher than those of metal alloys.

(2) Capacitive sensors

A capacitive sensor is invented based on the principle of parallel plate capacitors. After proper design, the capacitance of a capacitive sensor is nearly proportional to applied pressure [36], while the price for it is the decreased sensitivity. Compared with the piezoresistive pressure sensors, the capacitive sensor has more complex circuit requirements and a relatively simple transducer. As the result, the capacitive sensor benefits more from the increasing level of circuit design.

(3) Resonance sensors

The resonance pressure sensor measures the pressure by monitoring the resonant frequency of the embedded bridge [37–39]. The resonant beam acts as a sensitive strain gauge [40], the resonant frequency changes with the tension in the embedded structures, which is determined by the stress state of the diaphragm. There are many mechanisms to sense the resonant frequency. The structure could be excited by AC voltages while the resonant frequency being detected by monitoring piezoresistor [37, 38], optically excited and optically measured, or electrostatically excited and capacitively sensed [41]. One key point exists that the resonant pressure sensor could usually achieve better pressure sensitivity, lower temperature sensitivity and exhibits more immune to noise compared with the traditional piezoresistive and capacitive sensors, which brought the resonant pressure sensor a splendid future.

2.3.3 Acceleration Sensor

Previously, the researches about acceleration sensors have been usually focused on the gyroscopes of composite beam structure [42]. However, people found that the rectangular beam gyroscope had many advantages over composite one. For example, the test circuit could be simple due to the piezoresistive sensing, the sensitivity could increase significantly when applied with the ideal shape of the beam.
The acceleration sensor also benefits from process evolving. Such fabrication processes as anisotropic etching and deep reactive ion etching are usually used. Illustration 4 shows an acceleration sensor configuration. The rectangular beam transfers the acceleration signal to vertical and lateral vibration, thus the acceleration could be measured by sensing the resonant frequency in the desired direction, which is usually realized by the help of piezoresistive effect.

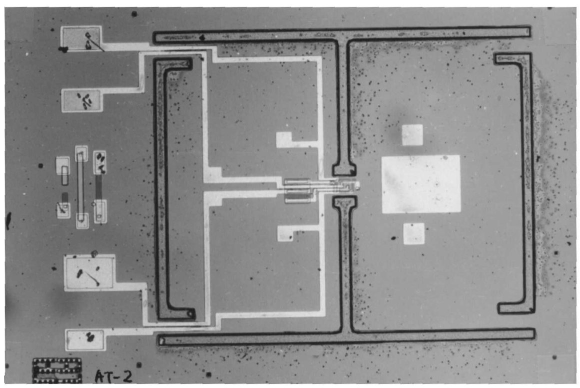


Illustration 4: The acceleration sensor

The market of acceleration sensors mainly lies in the automotive and related industries. Some interesting products are listed in Table 4 [25].

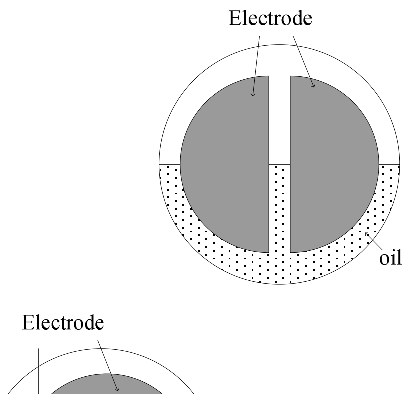
Table 4: The acceleration sensor products

Reference	Band Width	Range	Axes	Accuracy	Pakage	Power Consu
ADXL323	1.6K	$\pm 3g$	2	$\pm 10\%$	$4mm \times 4mm$	$180\mu A$@1
ADXL330	1.6K	$\pm 3g$	3	$\pm 10\%$	$4mm \times 4mm$	$180\mu A$@1
ADIS16006	2.25K	$\pm 5g$	2	$\pm 6\%$	$7mm \times 7mm$	$1.4mA$@

2.3.4 Inclination Sensor

The acceleration sensors being utilized as inclination sensors have been reported recently [43-45]. However, these are two obvious shortcomings. These sensors are impossible to obtain linear outputs in relation to inclination and their structure is somewhat too complex.

The capacitive inclination sensor is another option, which makes use of the dielectric oil [46]. This kind of sensor could get precisely linear output with response to the inclination angle. On the other hand, it emerges at the expense of the relatively small size.
As an example, Illustration 5 (a) and (b) show that the capacitors in the sensor are half filled with oil [47]. The oil surface is always kept horizontal even when the inclination sensor is tilted. As a result, the capacitance alters along with the change of the quantity of oil in both sides.



2.3.5 Humidity Sensor

The development of the humidity sensor is along with the requirement to make the automatic control of humidity a reality. Among different types of them, the capacitive one is preferred for its linear sensitivity in a wide range of relative humidity. The moisture absorption results in the change of the dielectric permittivity, whereby the relative humidity could be measured [48].
Polyimide is particularly selected as the layer for its many advantages. For example, it is easy to be integrated to circuit process and most important, polyimide has great chemical stability and high permeability to water.

2.3.6 Light Sensor

In the areas such as medical, industrial and environmental applications, the development of optical sensors is attracting great interest. Most optical sensors measure either the changes in luminescence intensity or lifetime [49, 50], based on the principle that the photocurrent being proportional to the light intensity.

2.3.7 Gas Sensor

Gas monitors, as shown in Illustration 6, are broadly used in environmental, automotive and medical application areas. For this reason, the mobility and portability should be emphasized and thus bring the requirement of low power consumption. On the other hand, the integration of the signal read-out circuit is performance/cost driven, which brings the development of smart CMOS gas sensors [51].

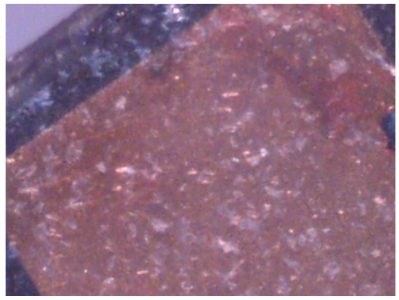


Illustration 6: The gas sensor

There are roughly five approaches [52] of designing CMOS gas sensors.

(1) The change originated from the conductivity of the metal oxide layer or polymer when exposed to the certain kind of gas gives birth to the chemoresistive sensor. The metal-oxide sensors are more stable at the expense of the high operating temperature. On the other hand, the polymer layer could work under lower temperature such as 200^{o}C.

(2) In the similar way, the chemocapacitive sensor works according to the change of the capacitance when exposed to gas. Specially, the chemocapacitive sensor is often designed differentially by adding a second reference capacitor.

(3) The resonant sensor is based on the change of the resonant frequency of a certain beam, on which is the layer absorbing the gas molecules [53]. Different gases can be distinguished when the molecules are absorbed. As mentioned in the acceleration sensor, the vibration of the beam could be measured through piezoresistive effect. After elaborate design, the output of the resonant frequency would be approximately inversely proportional to the mass of the beam. However, the signal-to-noise ratio is always the key point.

(4) The microcalorimeter senses the change of the operating temperature when the chemical reaction is taking place. For this reason, microcalorimeters usually work at very high temperatures. The thermal stability and long-term reliability should be carefully considered. On the other hand, the integration of CMOS technology is still a great challenge.

(5) Another interesting representation is chemFET, which senses the change in the threshold voltage of a certain gate. Usually, the catalytic gate [54], the polymer gate [55] or a suspended gate [56] are used. Among them, the polymer one attracts much interest since it is very easy to make film deposition. However, the polymers are usually temperature dependent and the sensitivity is still a problem.

2.3.8 Chemical Sensor

The smart chemical sensor is coated with different chemically selective materials (mental-oxide or polymer). Recently, the sensor arrays are often applied in CMOS-based chemical sensors [57] to realize the multi-function. By setting different working patterns, the sensors could work on the same chip and detect various kinds of analytes respectively.

There are three major types of smart chemical sensors as follows.

(1) Micro-capacitor: The principle of micro-capacitor is to monitor changes in the dielectric properties of the polymer. Usually, the sensor is made of an interdigital electrode structure and the read-out circuit is designed to work in differential mode.

(2)Micro-cantilevers: The micro-cantilever works according to the change of the resonant frequency of cantilever when analyte absorption occurs. The excitation could be made through electric pulse or Lorentz forces and the vibration is usually detected by piezoresistors.

(3)Micro-calorimeters: The micro-calorimeter senses the enthalpy changes when analyte absorption takes place. The signal could be detected by measuring the variation of the temperature caused by enthalpy changes, thus it is proportional to the analyte concentration.

2.4 Power sources

Class 3 and class 4 RFID tags are equipped with a power source. Nature of RFID tags is totally different from conventional battery powered devices due to the possible harsh operating environment and relatively long life time expectations. Options for power sources are represented and evaluated in this chapter.

2.4.1 Small batteries

Small batteries, like button-size batteries have been around for quite a long time. Therefore it can be said that the technology is mature and feasible. The smallest button-size batteries have the height of only 1.2 millimetres. If the button battery has been properly manufactured, its lifetime can be fife to ten years. Another upside is that they are very inexpensive; their price starts at 2 US cent/piece. On the other hand, button batteries aren't suitable for bending, because they need a hard package. Table 5 represents the characteristics of some commercially -available button-sized batteries.

Table 5: Small nominal batteries characteristics

Battery	Thickness (mm); Area (mm^2)	Nominal Voltage (V)	Nominal capacity (mAh)
Varta 1616 [58]	1.60; 201	3.0	55
Energizer 2012 [59]	1.2; 314	3.0	58

2.4.2 Flexible batteries

Flexible batteries have been a very promising candidate for being the future power source of RFID sensor tags. The reasons are quite obvious; they inherit low thickness and they are flexible.

There are two different approaches for constructing flexible batteries. One is by using lithium based chemistry and the other by using zinc based chemistry. The major difference between these approaches is the output voltage and capacity. Lithium based batteries usually offer an output voltage of 3 volts. Zinc based batteries can achieve 1.5 volts output voltage. The capacity of flexible batteries is bound to the battery area. Bigger area means bigger capacity.

In this chapter, nominal values of flexible batteries are used. The nominal values can be found in the battery manufactures websites. How the manufacturer measures the capacity is not often published. Usually the capacity of lithium batteries is measured during output voltage drop from 3 to 2.4 volts and in zinc batteries the drop from 1.5 to 0.9 volts. Normally the load in these measurements is in the scale of tens of kilo-ohms.

Usually the output voltage of zinc based batteries has drops from 1.5 volts to 1.1 volts when the capacity has dropped 10%. Approximately 90% of the capacity has been used when the output voltage has dropped to 0.9 volts. Lithium based batteries have more linear behaviour between the output voltage and the capacity. The capacity of normal 3-volt lithium battery is nearly drained when its output voltage reaches 2.4 volts.

Lithium based batteries can produce an output voltage of 3 volts. Lithium chemistry has high energy storing capacity. Lithium's high energy storing capacity comes from the fact that lithium is an alkaline metal. This means that the battery has to be tightly sealed, in order to keep the lithium under control. Sealing is naturally in high stress in flexible batteries. Therefore it is only natural that it plays a major role in the lifetime of flexible lithium batteries. Their nominal lifetime is around two to fife years. Lifetime is strongly affected by the amount of moisture that is able to condensate inside the battery. Table 6 represents the characteristics of three flexible lithium based batteries currently on the market.

Table 6: Lithium nominal characteristics

Battery	Thickness (mm); Area (mm^2)	Nominal Voltage (V)	Nominal capacity (mAh)
Solicore 24 [60]	0.38-0.45; 1104	3.0	24
Solicore 14 [61]	0.38-0.45; 729	3.0	14
Varta FLP25 [62]	0.36; 640	3.0	25

Zinc based structures have lower output voltage than lithium based structures. It is normally around 1.5 volts. Also their capacity is much lower than in lithium batteries. If we compare energy storing capacity of lithium and zinc batteries to their diameter, the zinc batteries energy density is approximately 2.3 times smaller than lithium based batteries. But never the least, their output voltage and energy storing capacity is enough for many applications. Table 7 represents the characteristics of two flexible zinc based batteries currently on the market.

Table 7: Zinc nominal values

Battery	Thickness (mm); Area (mm^2)	Nominal Voltage (V)	Nominal capacity (mAh)
Thinbattery technologies 25 [63]	0.76; 2590	1.5	25
Enfucell [64]	Thickness 0,3-1,0	1.5	3 mAh/cm^2

2.4.3 Power harvesting

Because RFID chips are designed to work with small power levels, they don't require huge amounts of power. For an example Impinj's Monza2 requires -11.5 dBm to perform a read operation. Naturally sensor tags require more energy, but this gives us good estimation where to start. The most important methods for harvesting power for RFID sensor tags are Seebeck-elements, piezoelectric elements and photocells.

The Seebeck phenomenon requires a temperature difference in order to function. This is hard in RFID tags because they are small in size and the temperature difference in small area is hard to achieve. But in some applications it might be enough.

Another method for producing electricity is by converting it from mechanical movement. This can be done by using a piezoelectric element, which transforms mechanical movement into electricity. Piezoelectric elements can be used to power-up RF-transmitters. For example a German manufacturer produces light switches, which take their operating power from a piezoelectric element. A piezoelectric element has one major drawback in RFID systems and that is the fact that piezoelectric elements require vibration of physical movement in order to produce electricity.

Photocells may also be used to produce power for the RFID sensor tag. They require electromagnetic radiation to produce electricity for the sensor tag. Photocells normally have limited bandwidth in which they can produce output power. In order to achieve larger bandwidths, special hybrid and 3-D structures are needed. This brings cost and complexity into the design. One approach is to use some kind of organic materials in the photocell. The problem with organic material is the same as with every organic material. Namely they decay and lose their abilities during time. There is at least one producer, Konarka, which produces flexible wideband photocells. Also infrared light can be used to produce electricity. It can be done by using photocells that are designed for those frequencies or by using an extra wideband photocell.

One of the most promising combinations for producing and storing power for the RFID sensor tag is photocell-supercapacitor combination. Supercapacitor is an element, whose power-handling capacity is far better than normal batteries power-handling capacity. It is able to produce high peak currents and at the same time it can store huge amounts of energy. At the moment the biggest problems with supercapacitors are their low tolerances for high voltages and that they are not flexible. Today's supercapacitors can handle operating voltages up to 1 volt. On the other hand, supercapacitors can be manufactured by using printing techniques, which enables low-priced large-scale production.

2.4.4 Rechargeable power sources

Rechargeable power sources include rechargeable batteries (secondary batteries) and structures that store energy inside magnetic or electric field. Rechargeable batteries basically utilize the same kind of chemistries as primary batteries do, but their energy density is lower than in primary batteries. Most promising structure for storing power inside the electric field is a supercapacitor. Its capacity and peak power performance is unmatched by any modern primary or secondary battery. Table 8 represents the characteristics of one flexible rechargeable battery currently on the market.

Table 8: rechargeable power sources nominal values

Rechargeable battery	Thickness (mm)	Nominal Voltage (V)	Nominal capacity (Wh/kg)
Varta PoLiFlex [65]	down to 2	3.7	170-200

Fuel cells are also one potential power source in future. Currently really small fuel cells are in the level of prototype and data from their actual performance is hard to come by.

2.5 Tag manufacturing today and tomorrow

Standard PCB (printed circuit board) processes can be used for manufacturing sensor enabled RFID tags. However, if tags are needed in high volume with low costs, more efficient manufacturing methods have to be used. These issues are discussed in this chapter.

2.5.1 Key components

Every RFID sensor tag includes the following components; antenna, RFID chip and sensor. The sensor can be included into the chip itself. In some occasions the sensor tag can include battery or another source of power. Manufacturing sensor tags can be a challenging task.

The difficulty level of the manufacturing process depends on the structure of the sensor tag. In the simplest possible solution the tag is passive and the sensor is integrated in the same chip with RF functionality. On the other hand the sensor tag can include an RFID chip, individual sensor(s) and a power source.
Some basic components that may be included in the sensor tag:

Battery:

Depending on the application an RFID sensor tag can have a battery included in it. The delivery format of the sensor tag limits the type of batteries that can be used. There are two main types of batteries that can be used; flexible or rigid. Both types can be found as primary and secondary batteries. The type of battery limits the available manufacturing method a little.

The most cost efficient method for flexible battery assembly is to print them into the substrate material. The substrate material can then be converted over the tag inlay. Conventional rigid batteries require rigid connectors which have to be connected to the battery separately. It can be said that rigid batteries require rigid substrate to connect. Therefore they are practical in systems, where flexibility is not the defining characteristic.

IC:

There are many different methods available for RFID IC attachment. The most common method at the moment is flip-chip technology, which will be the common method for low-cost RFID tags in the future. Wire bonding used to be a popular method for chip-on-board constructions. At the moment it's not very popular method in RFID tag manufacturing.

Another method is to connect the chip into flex or board, which is then connected to the antenna. This method is more popular in HF products. The last but not the least method for chip connection is strap-connection. Strap connection has benefits in some applications, since it offers a wide bandwidth. It is also a very fast technology for manufacturing RFID tags. The strap connection however is capacitive. Therefore it limits the methods how the batteries and other DC circuits can be connected to the tag.

Sensor

The sensor is an essential component in the RFID sensor tag. The sensor might be integrated into the RFID chip or it might be connected to it separately via bus. If the sensor is integrated into the IC, the whole package can be assembled to the antenna by using conventional manufacturing methods.

In some cases the sensor can be separate from the IC. Then it will communicate with the RFID IC via bus. This is also practical in cases where the current consumption of the tag is desired to be as minimal as possible and some power source is used. This way only the sensor draws current from the power source when tag is not in reader field.

Substrate/antenna

The substrate for sensor tags can be manufactured by using the same methods that are used today. The most common method for antenna manufacturing is etching. Other methods for antenna manufacturing are foil stamping and printing methods by using conductive ink or paste. For these the foil stamping can be used to manufacture UHF RFID tags. For foil stamped antenna, the IC and power source can be connected as described earlier. Conductive inks and pastes however are not widely used in UHF application, since they cannot achieve high reading distances yet.

2.5.2 Manufacturing process for the sensor tags

Currently manufacturing technologies exist for manufacturing sensor tags. The problem however is that, will the available manufacturing technology and wanted delivery format meet each other. Meaning, if the available machinery in the factory is not suitable for manufacturing the sensor tag, the decision to start manufacturing sensor tags won't be made. Therefore the sensor tags should be manufactured in a method which is the most compatible with current manufacturing methods. This means that in this stage, the sensor should be integrated into the RFID IC.

Substrate can be the same PET that is commonly used to manufacture RFID tags. The used manufacturing method limits the available substrate materials to few. The substrate material should be flexible, cheap, able to tolerate high temperatures and also inherit low dielectric

constant. Antenna structures in sensor tags can be manufactured by using etching techniques. Also foil stamping and printing by using conductive ink/paste can be used.
Battery should be manufactured to the substrate by using printing techniques. If it is not possible, the battery can be manufactured separately and placed to tag afterwards. This brings cost and complexity to the tag manufacturing process.
ICs can be flip-chipped, wire-bonded or connected by using normal soldering processes. Flip-chips can be connected by using ACA or NCA materials. IC can also be connected by using strap connections. For an example by using high-speed strap attach machine. Alien technology uses high-speed strap attach machines in their RFID tag assembly. If normal ICs are used then wave soldering and reflow soldering is also available. All these different manufacturing methods are suitable for manufacturing RFID sensor tags. But it should be noted that all parts of the sensor tag should be connected to the structure by using the same technique. This is necessary if manufacturing is wanted to keep simple and cheap.

3 Wireless sensor data communication

For practice purpose, the market demands appliances and systems to have more capabilities, flexibilities with improved performance. Sensor combined with transceiver or even embedded microprocessor is a good candidate for information collection and control. Once a mesh network is formed, it would no doubt significantly increase human's ability of built-in intelligence.

Nowadays, sensors have been widely used in most industry areas all over the world [66]. The manufacturers are seeking low-cost, smart sensors which could provide advanced applications with more convenient interactivity. On the other hand, the concept of "internet of things" has led the application to supply chain system and the ability of getting circumstance information has gathered more and more interests. People are finding a way to integrate the functions of sensors, transceivers and application software, based on which, the supply chain transparency is expected to be greatly improved in the not so distance future.

However, there not been such a set of common interfaces established for the entire network. The solution is still under investigation. Nevertheless, the IEEE P1451 project, which is an open industry sensor networking standard, can maybe bring some consultable ideas. It defines both processing and communication methods, with the purpose of making every sensor node easily plug and play.

IEEE P1451 defines a Transducer Electronic Data Sheet (TEDS) together with a 10-wire digital interface between the sensors and the microprocessor [67]. The TEDS is scaleable and takes the responsibility of describing the manufacturer's identification, model number, serial number, data code and calibration of the sensors. Naturally, the TEDS provides not only the unique ID number of sensor node but also details of its environment, thus it realizes the self-description. The 1451 interface also defines the Smart Transducer Interface Module (STIM). At most 255 sensors or actuators could be connected to a STIM and the STIM is connected to a network node called NCAP (Network Capable Application Processor).

As to the distributed system architecture, the existing RFID air interface could be applied to pass sensor data to the host after some modifications. There could be two options. The first possibility is to regard the reader as the NCAP and the tag as the TIM. The second one is to consider the single tag with high performance to be the integration of NCAP and TIM, which is similar to the realization of WSN (wireless sensor network). Finally, the readers (1st option) or sensor nodes (2nd option) are connected to the network and they can communication with each other. Nevertheless, the interoperability is the key.

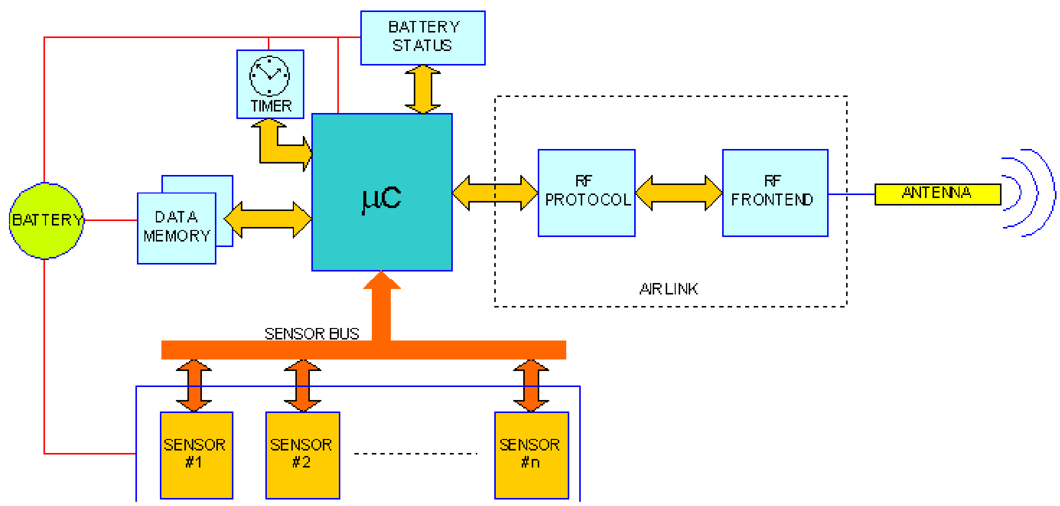
The number of TIM (tags) is usually huge in practice. It is hard to reliably identify vast objects in a short time if the 1st option is applied, because a reader is only able to communicate with a single tag at a time and tags can't be assumed to hear one-another. To make the communication efficient, anti-collision protocols are proposed. The presenting anti-collision protocols include two kinds of major algorithms, they are, tree-based deterministic algorithms and slotted aloha -based probabilistic algorithms.

The tree-based deterministic algorithm, which is determined by the value of tag identifiers, is further divided into memory algorithms and memoryless types. Similarly, the slotted aloha-based probabilistic algorithm, which is determined by the number of tags, includes ID-slot algorithms and bit-slot algorithms. According to the performance evaluation so far, the anti-collision algorithm, one of the tree-based memoryless algorithms, seems to be more efficient than others in the number of queries-response and the bits transmitted.

4 Features and Requirements of sensor enabled RFID tags

Overall structure and required technical features of sensor enabled RFID tags are discussed in this chapter. Focus is on UHF semi-passive sensor-enabled tags although many issues are similar with active RFID tags.
From a hardware point of view a sensor-enabled RFID tag can be represented by the block diagram depicted in Illustration 7.

Illustration 7: Generic sensor tag block diagram



Each block can be present in the tag as a separate electronic component or can be integrated with other blocks to form an integrated device. Whatever the physical implementation could be, Illustration 7 shows the logical components from which a sensor-enabled tag should be composed of.

1. Antenna

RFID tags and, among them, sensor-enabled tags communicate with interrogators using a digital RF link through an antenna, a transducer between the electronic and the radio-frequency world. In sensor-enabled tags, the RF link does not derive power from the battery because communication is obtained through the modulation of the antenna's impedance between two opposite conditions (high and low impedance); each condition causes a different power reflection so that interrogators may determine which bit is currently transmitted by the tag by simply "measuring" the back-scattered power.
Typical applications for this kind of tags require an expected reading-range of 5-10 meters while tag's dimension should resemble as far as possible those of a normal passive label, therefore the antenna should be designed in order to obtain the best compromise between the reading distance and the antenna's geometrical dimensions.
Another important thing is the RF band covered by the antenna: as products may travel among different countries ruled by different UHF regulation and frequency plans it should at least be guaranteed for the antenna to work properly in the 860 MHz – 960MHz spectrum.

2. RF Front-End

The RF Front-End could be considered as a sort of transceiver which works as a bridge between the analogue electrical domain coming from the antenna and the digital electrical domain required by the RF protocol block. Like any transceiver it is composed by a transmitter and a receiver part:

- The *transmitter* modulates the antenna's impedance according to the input received from the RF protocol block (back-scattering modulation). The most widely used modulation technique are ASK, FSK and PSK with digital data encoded using NRZ, FM0 (bi-phase space) or Miller scheme. Bit rate can vary from 40 Kbit/s up to 640 Kbit/s.
- The *receiver* is responsible for the separation of the baseband waveform from the modulated carrier and for the subsequent conversion of the analogue baseband waveform into a digital signal. Modulation is performed through DSB-ASK, SSB-ASK or PR-ASK technique while data are encoded typically using Manchester, Pulse-Interval Encoding (PIE) or Pulse-Width Modulation (PWM) schemes. Bit rate is usually lower than in transmission with the highest bit rate usually not greater than 160 Kbit/s.

Table 9: UHF Protocols Modulation and encoding schemes

Protocol	**Forward Link (Reader to Tag)**		**Reverse Link (Tag to Reader)**	
	Modulation	**Encoding**	**Modulation**	**Encoding**
ISO 18000-6A	ASK	PIE	ASK (Backscattered)	FM0
ISO 18000-6B	ASK	Manchester	ASK (Backscattered)	FM0
EM 4223	ASK	PIE	ASK (Backscattered)	FM0
EPC C1G1	ASK	PWM	ASK (Backscattered)	F2F
EPC 1.19	ASK	Manchester	ASK (Backscattered)	FM0
EM 4222	ASK	PIE	ASK (Backscattered)	PPM
EPC C1G2 (ISO18000-6C)	DSB-ASK SSB-ASK PR-ASK	PIE	ASK (Backscattered) PSK (Backscattered)	FM0 MILLER

If we focus our attention on tags based on the EPC C1G2 protocol, which is at the moment one of the most successful RF air-link protocols in the UHF domain, "reader to tag" modulation is performed using DSB-ASK, SSB-ASK or PR-ASK. DSB-ASK is probably the most frequently used in the past by the interrogators but PR-ASK is now becoming a standard option too because of the narrow band occupied by the transmitted signal; in any way protocol conformance requires that a tag shall demodulate all three modulation types.
As for the reverse link both FM0 and Miller encoding technique should be supported (even if this not mandatory) because the first guarantees higher data rate which will be necessary to download as fast as possible all the data samples acquired by the tag while the second will be used especially in Dense-Reader Environment.

1. RF protocol

Protocol management is handled by the RF Protocol Block which includes all the logic needed to support the commands defined in the air protocol and all the hardware necessary to drive the RF Front end. The minimum sets of commands which should be requested to a sensor tag are:

- *Inventory commands* are required to uniquely identify the tag among other passive or sensor-enabled tags. In the case of the EPC C1G2 protocol these commands are: *Select, Query, QueryAdjust, QueryRep, Ack* and *Nak*.
- *Memory-Access Commands* are required to access memory and to set or retrieve information about tag status, custom data, sensor configuration and sensor data (*ReqRn, Read, Write, Lock, Kill* and *Access* in the case of the EPC C1G2).
- *Sensor-Access Commands* are required to access sensors in a more abstract and faster way without using the basic Memory-Access commands (a detailed list of Sensor-Access command is given in the

D1.1.2 document *Specification of a common platform for sensor-enabled RFID tags*) [106].

2. Battery

The main difference between a sensor enabled and a passive tag is that the first requires a power source other than the RF energy field to exercise sensor functionality even when the tag is not under the interrogator's field. However, because of the use of the back-scattering technique for data transmission from tag to reader, the battery is used only during data logging activities and there is no necessary power consumption during the communication phase.
Typical constraints which must be considered in the choice of a battery for RFID applications are cost, temperature range and capacity; each of these parameters can heavily affect the final design.
Usually the battery is one of the most expensive parts of the entire tag and its cost is directly related to capacity and temperature-range characteristics; to minimize the impact on the tag's final price the capacity should guarantee a tag's operating life of at least 5 years. Moreover temperature range should go from at least –20 °C up to +80 °C to accommodate for the different environments which a sensor-enabled RFID tag may experience during its lifetime. Unfortunately extremely low or high temperature concur on the reduction of battery's life so battery capacity should be evaluated considering temperature's worst case.

3. Battery status

The battery status is not a mandatory block but such functionality could be useful to estimate the residual tag's autonomy; in fact the battery-charge status after a certain amount of time depends on the tag's history and could be significant different from the value obtained considering rough constant power consumption in worst case condition.
For the time being the price of a sensor-enabled RFID tag is significantly higher than the price of a passive tag, the possibility of an on-line measurement of the battery-charge status could be an important factor for cost-reduction strategies.

4. Data Memory

Data memory is the place where all data retained by the tags are stored. In particular tag's identifier, user data, sensor configuration parameters and acquired data samples should all reside in the Data-Memory area. Data memory should be persistent in order to guarantee that no data loss can occur when a tag enters a very hard environment with low battery-charge condition.
Another important characteristic is the overall memory demand of the four types of data: Identifier, user data, sensor parameters and data samples. The last is by far the most space demanding. In typical RFID applications a sampling rate in the order of minutes over a continuous sampling period of some weeks is a quite common request; as a consequence Data memory should be at least some Kbytes in length.

5. Logic

The logic block interfaces the data memory with the RF protocol handler and sensor devices providing the intelligence needed for modes of operation and data-logging management.
Sensors-enabled tags in fact should have a set of operational modes which should be selected by the user on the base of the particular application where the tag is employed. For example it should be possible to set the *logging status* (enabled, disabled), the *sampling time* (the time interval between two consecutive sample acquisitions) and the *data-logging* mode (continuous, threshold driven, event driven, etc.).
The logic block should retrieve the tag's operational settings from Data memory and drive the sensors accordingly to the customer settings. When a sample is acquired the value measured by the sensor is read by the controller and stored into a separate section of the Data memory block; data samples are subsequently transferred by the logic block to the RF protocol block after a specific interrogator request issued on the air RFID link.
The logic block should be fast enough to satisfy the interrogator's requests without introducing a significant delay in the tag's response and it should also have a very low

power-consumption mode (less than 1µA) to obtain negligible power consumption during idle period (for example between two consecutive samples) thus contributing in this way to the increasing of battery life.

6. Sensor Bus

The sensor bus is the physical link between the logic block and sensor devices. In the future more than one sensor will be probably available inside one single tag so the sensor bus should allow for multi slave - single master communication; moreover the bus should be as simple as possible in order to keep its cost low, should not require any specific additional electronic components for the connection between devices and the bus (for example transceivers) and should be a standard widely supported by sensors.

Fast data rate or long-distance communication are not a critical issue because data-logging activities are usually performed with very low sampling rate, each sample is usually composed by a limited number of bytes (2-4 bytes typically) and the sensor is situated in close proximity of the logic block.

I2C or *SMBus* are two of the best candidates for the sensor bus network: they are two-wire serial buses, there's no need for a chip select or arbitration logic, making them cheap and simple to implement in hardware.

They also support *multiple master – multiple slave* communication and both masters and slaves can receive or transmit data bytes. Standard I2C or SMBus devices operate up to 100Kbps, but if needed a fast-mode data rate is defined in the I2C standard to allow exchange of data up to 400Kbps; both protocols are however fast enough for current and future data-logging requirements. Finally their cost and complexity don't scale up with the number of devices on the bus.

7. Timer

RFID sensor-enabled tags require at least a timer which must be used to synchronize all the data-logging activities with a high precision reference clock; in particular it must provide the reference for the determination of the sampling time and for the update of the internal date/time registers.

The timer must be insensible of temperature variations and remain stable even in the worst case conditions; as product's tracing along the supply chain may require, in some cases, a logging period of a year or even greater, time tolerance shall not exceed 10-20 ppm.

8. Sensors

Sensors are the heart of a sensor-enabled RFID tag; different kinds of sensors have been already described in the earlier chapters. From an architectural point of view, sensors should interface easily with the logic block sharing - when possible - a common bus to allow for easily scaling of number of sensors hosted on the same tag.

Temperature, *humidity* and *shock* sensors will be the first kind of sensors to be employed in the market because of the advantages that can be derived from their use in the supply chain. Probably there will be more than one sensor of the same type in each sensor enabled tag (for example we can imagine a tag with two temperature sensors onboard, one to measure the temperature of the external environment and one to measure the product's inner temperature).

However there are currently very poor example applications for the use of sensors in conjunction with RFID tags so it is not easy to determine which characteristics will be required by the market.

Things are much clearer for temperature sensors where a temperature range of –20°C - +80 °C with a temperature resolution of at least 0.5°C seems a common request. But real requirements depend strictly by the specific application and at now no indication can be provided for the characteristics of the other two sensor types.

5 Ambient intelligence with sensor-enabled RFID tags

This chapter introduces the notion of Ambient Intelligence (AmI) and the manner in which sensor-enabled RFID tags are helping the realisation of the vision of ambient intelligence. The chapter also serves to highlight the bridge between sensor-enabled tags developed in the BRIDGE project with the BRIDGE Work Package one demonstrator aimed at showcasing smart-objects and ambient-intelligence to illustrate the potential and implications of the sensor-enabled RFID tags in AmI systems. Apart from describing the technologies involved, the chapter will also provide present and future perspectives for sensor-enabled RFID tags in AmI.

5.1 An Introduction to Ambient Intelligence

Ambient intelligence is a user-centric paradigm embedded in the work presented by Norman in [68] and ubiquitous computing presented in its current form by Mark Weiser [69]. AmI model works pervasively, non-intrusively and seamlessly to the user [70].

The general notion of an ambient intelligent system is based on a seamless interaction between users and distributed computing devices in a manner that is both natural and intuitive to a human being to provide various services and support to users. Such a visionary system is based on a ubiquitous computing framework where technology will eventually become invisible and embedded in our natural surroundings while silently performing the activities that provide seamless services to both humans and business processes, where it is pervasive but non-intrusive.

A large number of disciplines can be associated with the area of ambient intelligence. Some of the key technologies needed to enable AmI are outlined in Table 10.

Table 10: Enabling technologies of Ambient Intelligence.

Computing	Low cost computers that consume little power or harvest the power required from, for instance, thermal or vibration sources in the environment, in an increasingly small scale.
Networking	Needed to glue the computing devices. This network infrastructure needs to be ubiquitous in nature, be scalable (it should be easy to add or remove computing devices) and be accommodative of mobility (needs to provide for cases where the output of computing devices may more with the user).
Sensing	Sensors capable of operating either passively or using low power in increasingly small scale.
Software	Built on the computing devices and the network are the software systems implementing ubiquitous computing applications to provide seamless services.

The paradigm of ambient intelligence (AmI) [71] has taken a new focus with various developments in the technological areas identified in Table 10.

Ambient Intelligent systems aim at creating intelligent spaces where users have the ability to obtain services provided in a pervasive but non intrusive manner. While Ambient Intelligence builds on various technologies, three key technologies are ubiquitous computing, ubiquitous communication and sensing technologies. Ubiquitous computing implies integrating computing devices into everyday objects such as clothing or white goods while ubiquitous communication enables these smart objects to communicate with each other using novel wireless technologies. Sensing hardware allows the automatic recording of observations made in an environment, such as temperature, humidity or pressure. Users are then able to use intuitive and intelligent user Interfaces to access services and, control and interact with an environment with distributed intelligence in a personalised manner.

A significant development in ubiquitous computing and wireless networking arena is low cost Radio Frequency Identification (RFID) devices and the integration of sensor technologies to such devices with the growing maturity in RFID technology. Similarly, the growth and possible use cases for RFID technology have lead to the development of distributed information systems capable of providing ubiquitous communication.

Emerging sensor enabled RFID technology, coupled with developments in distributed information systems, can be utilised for architecting ambient intelligence. The following sections will discuss and illustrate how sensor-enabled RFID tags are an evolutionary development in ubiquitous computing with revolutionary applications in the domain of ambient intelligence capable of providing new business models and opportunities for novel businesses while providing significant benefits to humans. First and foremost, we will provide an insight into the capabilities of these technologies that aid in yielding to the vision of ambient intelligence.

5.2 Enabling Technologies

RFID technology is capable of providing automatic and unique identification as well as a pervasive computing platform. The integration of sensors to RFID tags enables developing context awareness. The implication of integrating sensors to RFID tags, together with distributed information systems, creates technological opportunities for developing AmI applications today.

The following section will provide an overview of sensor-enabled RFID technology and distributed information architecture in their roles as enabling technologies for ambient intelligence.

5.2.1 RFID Technology

RFID has existed in various forms since WWII [72], however it has now reached a level of maturity for wide scale use as an automatic identification technology. It is increasingly being used in situations requiring automatic data capture such as supply chain logistical applications, manufacturing and wireless access and payment systems.

Due to their wireless capabilities, objects labelled with RFID tags are potentially capable of offering their identification in a fully automated environment. Thus, there are a number of significant advantages to using RFID systems for individual object tracking and management compared to traditional identification methods such as bar codes. Unlike the optical bar code, RFID tags do not require line of sight for operation. Furthermore, while bar codes need to be read manually one at a time, RFID interrogators can read multiple collocated tags at the same time. The collocation reading ratio can reach up to several hundred tags per seconds with proper anti-collision techniques. Also, since RFID tags store their identification code in small memory chips, they are capable of storing more information than just serial numbers, leaving the door opened for storing additional product data or sensor derived data for other applications.

The foundation of today's popular RFID standards are based on EPCglobal's RFID standards [73] based on the unique identification code called the Electronic Product Code (EPC). The EPC, described in EPCglobal's Tag Data Standards [74], is an identification scheme designed to support the needs of various industries by accommodating both existing and new coding schemes.

The EPC Global standards consider various kinds of tags distributed into a set of classes, from the passive tags (class 1 and 2) to the battery powered active tags. Tags and the standards that support them are foreseen to augment in complexity and functionalities with time as shown in Illustration 8[1]. Currently RFID technological maturity is around passive RFID tags, although increasing innovation is developing commercial solutions based on battery assisted and active tags (see Chapter 2 for details on state-of-the-art).

[1] Reproduced with permission of Auto-ID Lab Korea

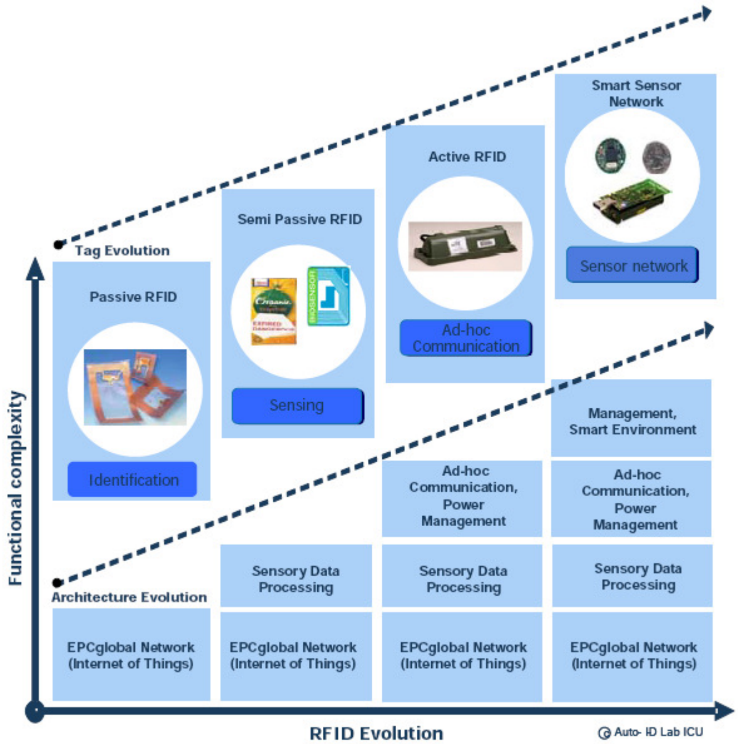


Illustration 8: RFID Evolution.

The significance of RFID technology for ambient intelligence traverses across the entire tag complexity hierarchy, from its passive to semi-passive to active realisations shown in Illustration 8[1]. While passive and semi-passive RFID tags require no external power to transmit their unique ID, active RFID tags can communicate autonomously. The choice of the proper RFID technology depends on the ambient intelligence application that needs to be implemented, and factors such as tag costs, range or wireless networking influence the decision.

5.2.2 Sensors

Sensors are devices that convert real-world conditions into electrical signals – analogue or digital - according to the attributes that they are designed to monitor. Sensors are a type of transducer, since they transform one type of energy into another. Examples of sensors according to the energy transfer they perform are:

- electromagnetic (example: magnetometer, radar),
- chemical (example: carbon monoxide sensor),
- acoustic (example: seismometer),
- thermal (example: thermocouple), or
- optical radiation (example: light detecting diode).

There are many types of sensor techniques for recording a given condition (Some examples are detailed in section 2.3). There is also a big range of commercial sensor devices, whose suitability depends on factors such as price, size, accuracy, resolution and energy consumption. Chapter 2 introduces a range of commercially available sensors.

5.2.3 Sensor-enabled RFID devices

Integrating automatic identification and sensors at the hardware level not only provides an identity to an object but also provides information regarding the condition of the object carrying the sensor-enabled RFID tag.

As exposed in the previous section, RFID and sensor technologies constitute the base for obtaining the information that will empower the ambient intelligent systems. The objective of this information is to monitor the identity and condition of the objects that form part of the AmI system.

There are alternative ways of combining the automatic identification information with sensor data that does not rely on sensor-enabled RFID tags. For example it is possible to merge ambient sensory data provided by a sensor-rich space to identities of objects entering that space by detecting when objects enter the area. However, this scenario might prove difficult to implement since detection systems must be placed on the boundaries of the space. Moreover, architectural logic must be put in place for merging both independent streams of data (sensor data and automatic identification data). Furthermore, sensor data could be deemed inaccurate since the transducers could be located at a considerable distance from the monitored objects.

Sensor Enabled RFID tags offers an elegant, accurate and relatively easy to implement solution. Objects could directly provide their own condition or context, which simplifies the infrastructure and augments the quality of the information.

Although sensor data could be thought of as just another piece of information about a product, such as its identification number, its nature is very different: First, unlike an ID, sensor information can vary over time while still representing the same phenomena. Second, sensor values are not as localized as identification is, and while the ID of two products is unique and non-transferable, their sensor information may not be. These characteristics make systems that handle both ID and sensors potentially complex, but also give cause for a wide variety of AmI applications that exploit the augmented streams of product and environment data.

5.2.4 Information infrastructure

Networking sensor-enabled RFID tags with a supporting networked information infrastructure leads to objects comprising all their physical attributes with additional information support. The role of RFID is to provide a unique ID pointer to networked data related to the product. In essence, RFID is a linkage between an object, its condition and awareness of its environment and, its representation in the digital domain. The digital existence leads to a number of consequences for users and businesses alike, for instance self managing products: RFID acts as the wireless connection between the product and complex decision processes based on sensory inputs to build a user driven environment. As an example, consider a washing machine whose program selection depends on the type of clothes that are loaded (both material and wear). In this case, the cloth IDs would be read by the machine and transmitted to the information infrastructure. Business logic would search specific clothing manufacturers or other on-line databases for details on the washing machine loads, and would decide the fittest washing program to perform. Illustration 9 shows a simple diagram on the information flows that this example implies.

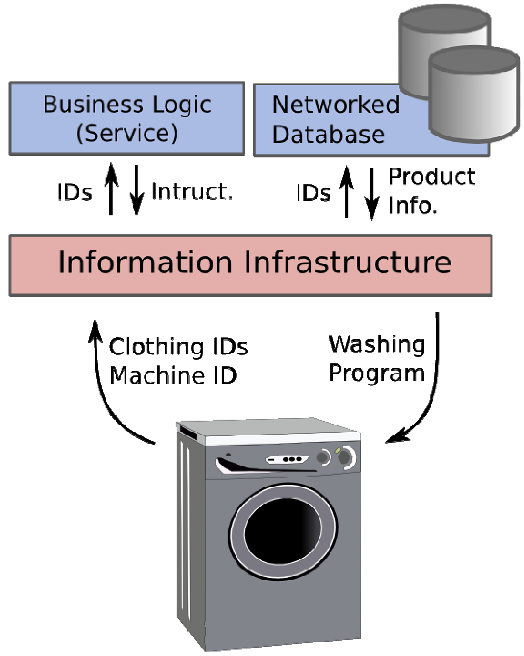


Illustration 9: Example diagram on how to use an information infrastructure for product servicing

The networking infrastructure is a key component in transforming our reality into the digital domain for building AmI applications. If the ambient intelligence applications that we are creating must extend beyond the local domain, a suitable mechanism for sharing information among collaborating parties must also be established. Considering that the sensor information can vary over time and may need to be updated regularly, our communication systems and information architectures can be complex and difficult to realize.

However, around the EPCglobal's Electronic Product Code, a whole architecture framework, as a collection of interrelated standards for hardware, software and core services, is specified. This information infrastructure is called the EPC Network architecture framework [73].

The EPC Network aims to extend the reach of the Internet to physical objects, and it is often termed “the Internet-of-things”. The advantage in this approach is the use of existing Internet-based communication protocols for data transfers. The EPC Network is built to network RFID systems to provide the link between a physical object and its digital representation in cyberspace.

The EPC Network can provide collection, storage and sharing of not only an objects digital representation but also its condition and awareness using the sensor information associated with it. Unfortunately, the current EPCglobal standards do not consider sensor data collection, treatment, storage and discovery. Presently, only the unique identifier (EPC) is communicated wirelessly from RFID tags to the networking infrastructure. However, the EPCglobal standards were designed to be extensible and flexible, and there is an increasing amount of research that is focusing on how to modify them to incorporate sensor data [75] [76].

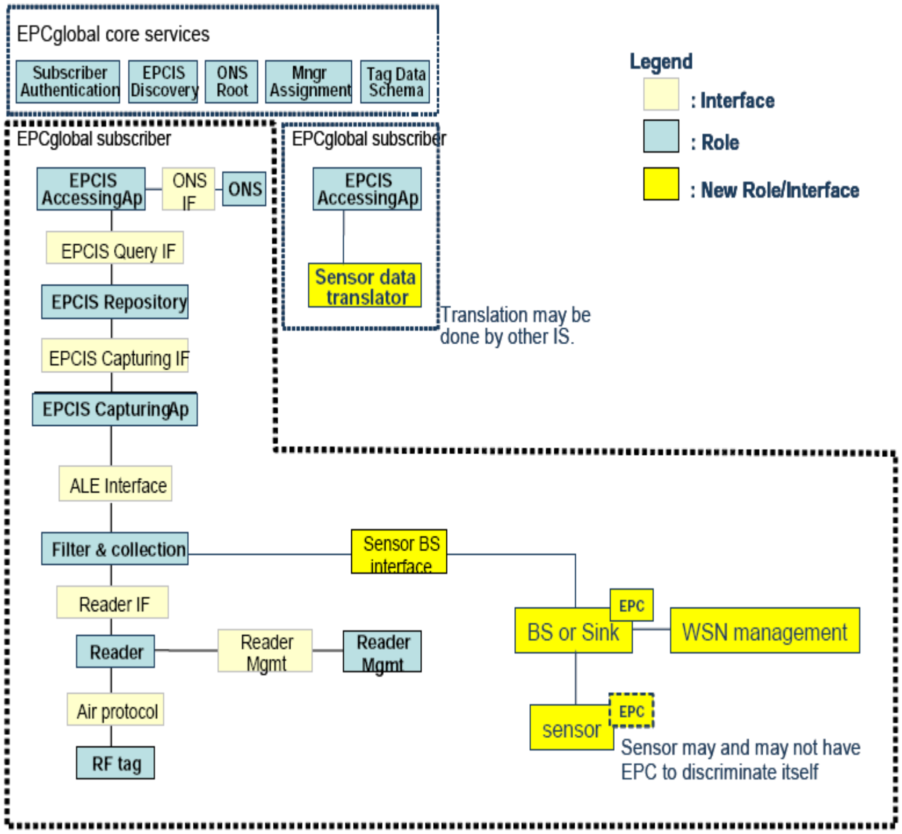


Illustration 10: Example of Sensor integration on the EPC Network.

Illustrations 10[2] and 11[2], proposed by Mitsugi et al. [75], show various ways of integrating sensor data into the EPC Network. Illustration 10 considers sensor data obtained from various facilities where the RFID tagged objects are stored or are in contact with. Illustration 11, on the other hand, considers a fully integrated scenario where sensor and RFID data is transferred through an aggregated transport layer, which communicates heterogeneous data sources with higher level repositories.

2 Reproduced with permission of Auto-ID Lab Japan

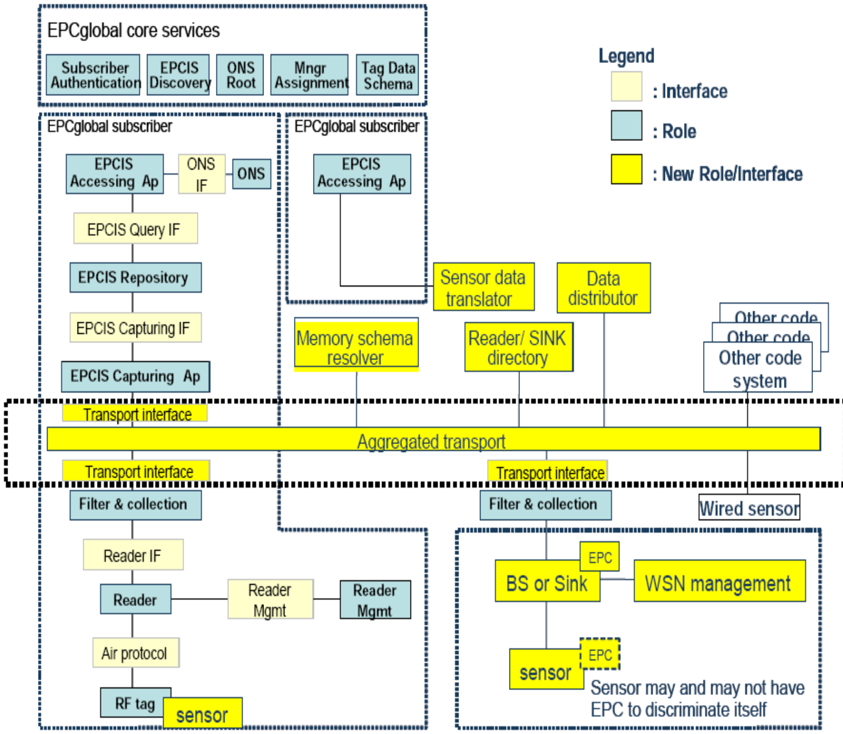


Illustration 11: Example of Sensor integration on the EPC Network.

As briefly illustrated above, the current EPC standards are flexible enough to accommodate the integration of a sensor data stream or accommodate other possible extensions. The distributed nature of the architecture, its ability to link the physical world to the digital domain, the standardised interfaces for access and the extensibility of the EPCglobal Network makes it suitable for a ubiquitous network for supporting AmI. However, other information infrastructures (such as DIALOG [77] or WWAI [78]), capable of collecting, storing and distributing sensor and identification data, could be used as the glue that forms the information infrastructure.

5.2.5 Technology convergence

We have introduced the notion of AmI and outlined a ubiquitous computing and network infrastructure. Converging the technologies that we have been discussing is revolutionising the manner in which we look at everyday objects because of the possibility to network objects and use their interaction and data for enhanced servicing to the end user. The following section will outline the concept of such a 'smart object' and discuss *context awareness*, two of the building blocks that can be leveraged to realise the vision of AmI.

5.2.5.1 Smart Objects

"Smart Objects" (SO) could be defined as technologically advanced products that can store data, self identify and make decisions about themselves, communicate with other objects and at some instances perform some action. In [79], a specification of Smart Objects was introduced that classifies them in a simple but useful way, with the objective of providing a common ground for their design, development, deployment and use. The technologies described in that document that enable smart objects are very similar to the technologies required for ambient intelligence. We would like to briefly analyze, thus, how Smart Objects can contribute to the ambient intelligence concept exposed so far.

[79] classifies SOs according to four parameters that a SO could implement. The first characteristic is providing its own identity (or "I") or storing any other data, the second is begin able to sens physiological conditions ("S"), the third is being capable of making

decisions for itself or other devices ("D") and the fourth is networking, to reach or receive information through wireless networks. ("N"). These characteristics may be combined in a variety of ways, although of course we could say that the more characteristics the SO meets, the smarter it is.

The objects in an AmI environment could be seen as "Smart Objects" and given the complexity of the ubiquitous computing devices (RFID tags or sensor nodes) that we embed into objects, we can compromise the level of intelligence that we distribute between the device and the networking capabilities that can communicate with the information infrastructure and other objects. The distinction between each approach is invisible to the user, since one of the main properties of the information infrastructure is that it can support a variety of physical implementations.

5.2.5.2 Context Awareness

Context-aware systems aim at using context to provide relevant information and services to the users, where the relevance is dependent on the user's task. Context itself is the information that characterizes the situation of a person, place or object and that can be considered relevant for the interaction of the user and the system. The availability of context and thus context-aware systems are central to the paradigm of ambient intelligence.

Information related to context can be obtained from a wide range of sources, but the role that sensor technologies play in forging a representation of the reality is especially valuable. Moreover, it is imperative to identify the sources of information in order to quantify their relevancy, and depending on the extent of the system, a distributed infrastructure to organize and process all the data is also of great importance.

Sensor-enabled RFID systems can provide an important source of information to characterize the context of interest. Furthermore, the infrastructure that collects and manages RFID sensor data can be a source of information for a context-aware system. Illustration 12 shows an overview of how users and infrastructure could be connected to the context-aware system. By obtaining identity and sensor data through a subscription to the information infrastructure, modules such as the inference engine, context modelling and data discovery would benefit from pre-processed context data. Other sources of context information and other modules would also be plugged into the context-aware system, while the user benefits from all the enhanced flow of information in a transparent way.

Illustration 12: Ambient Intelligence and Context-Aware Systems

5.3 Architecting Ambient Intelligence

The main purpose of this chapter is to deliver the vision of ambient intelligence with sensor enabled RFID tags. As such, in this section we will describe both present and potential future on AmI applications where the emphasis is on the concepts and technologies exposed in this chapter.

This section is divided into three categories. The first category, titled "condition monitoring", aims to describe the benefits of ambient intelligence in the supply chain context, which is perhaps the most traditional range of applications from an EPCglobal architecture point of view. The following section provides an insight into areas, more traditionally related with

Wireless Sensor Networks, but that we believe could benefit from the inclusion of RFID technology. The final section presents an example scenario that shows how the technologies introduced in this chapter can formulate ambient intelligence systems using smart objects and context awareness.

5.3.1 Condition Monitoring

The original aim of the EPCglobal RFID standards (and for much of the RFID technology in general) has been to create business value by augmenting visibility and traceability along the supply chain, as well as providing benefits to retailers such as better inventory control and on-shelf availability. In addition to the increased visibility and traceability, supply chain applications can benefit from the AmI that is provided using sensor enabled RFID tags by applying monitoring capabilities for condition-sensitive products. A clear example is the monitoring of temperature values needed by products taking part in cold-chain applications.

Within the supply chain, the benefits of ambient intelligence may span over a wide variety of applications and areas such as manufacturing, storage and transportation. For example, RFID, together with sensors and networked infrastructure databases, can provide accurate and easily accessible item information which might substantially influence decisions in logistics, life cycle and health management applications, where monitoring the condition of mobile and in-storage assets is important.

Predictive maintenance or condition-based maintenance optimizes maintenance schedules by providing continuous automatic equipment monitoring. Monitoring the range, time and location of certain product conditions can be useful in case of warranty and liability claims, as well as to provide valuable information for their quality control. The availability of real or near real-time information on the status of safety-critical assets may avoid hazardous situation and prevent the loss of high-cost items. Finally, tracing the usage and maintenance history of a product can provide information about its end-of-life destiny, and reduce costs by reusing, refurbishing or recycling.

Much research has been done in the area of supply chain condition monitoring [80], as well as few commercial applications from companies providing sensor enabled RFID tags and integration solutions (Chapter 2). For example, the Logistics and Maintenance Applied Research Center, at Georgia Tech, developed a system to monitor containers with high value assets such as airplane engines [81]. Other projects for high value asset monitoring have been undertaken by BP [82] and the US Navy [83]. Chemicals monitoring [84], theft prevention [85] or server rack temperature monitoring [105] are other examples of applications that can be realized by using ambient intelligence in the supply chain. Finally, as a prominent area of interest, several prototypes of ambient intelligent applications have been built for perishable products and the cold chain [86] [87] [88].

5.3.2 WSN related applications

The applications presented in this section have traditionally been attributed to Wireless Sensor Networks (WSN). Although WSN and RFID have been always considered as separate technologies, and hence they have followed separate research paths, the evolution of the RFID standards and applications is making clear that those paths are to converge at some point in the future. As Illustration 8 has shown, RFID tags with sensors, communication and certain smart capabilities are approximate in comparison to our current understanding of what WSN technologies provide. Nevertheless, from a WSN perspective, enabling universal identification of sensor nodes appears as an appealing new feature, since these devices usually exist in great numbers and they are difficult to manage. Furthermore, the non-existence of a standardized infrastructure that could allow data sharing among separate WSN is a problem that the RFID architecture could solve.

Environment monitoring is perhaps the most popular application of WSN and the one that has been reported more often. For example, sensor nodes could be deployed on greenhouses, farm buildings and crops in order to monitor animals and plants in real-time [89]. Forests, building and other areas could be protected from fires by deploying a network of nodes that would warn the fire-fighting authorities if a fire is detected [90] [91]. WSN could also be installed in mountains and islands to monitor weather conditions and animal life [92] [93].

Additionally, WSN also target other applications. In the realm of public infrastructures, for example, sensor nodes could be used to monitor water pipes and sewerage [94], traffic congestions [95], building integrity [96], monuments and historical properties, health care [97] [98] and so on. Research on military applications of WSN has also been quite extensive, including areas such as surveillance systems [99], underwater monitoring [100], vehicle detection, classification and tracking [101] [102], weapon shooting detection and location [103], robotics [104], and so on.

5.3.3 Example Scenario

In this section we illustrate a service scenario that aims at highlighting the potential of ambient intelligence utilizing the building blocks that we have introduced in this chapter; smart objects; context awareness based on sensor-enabled RFID tags and an information infrastructure. Let's first summarize some of the properties of ambient intelligence that we would like to emphasize with this scenario:

- User-centric services
- Collaboration of Smart Objects
- Context information bound to identity
- Pervasive infrastructure that bridges clients, service providers and context repositories

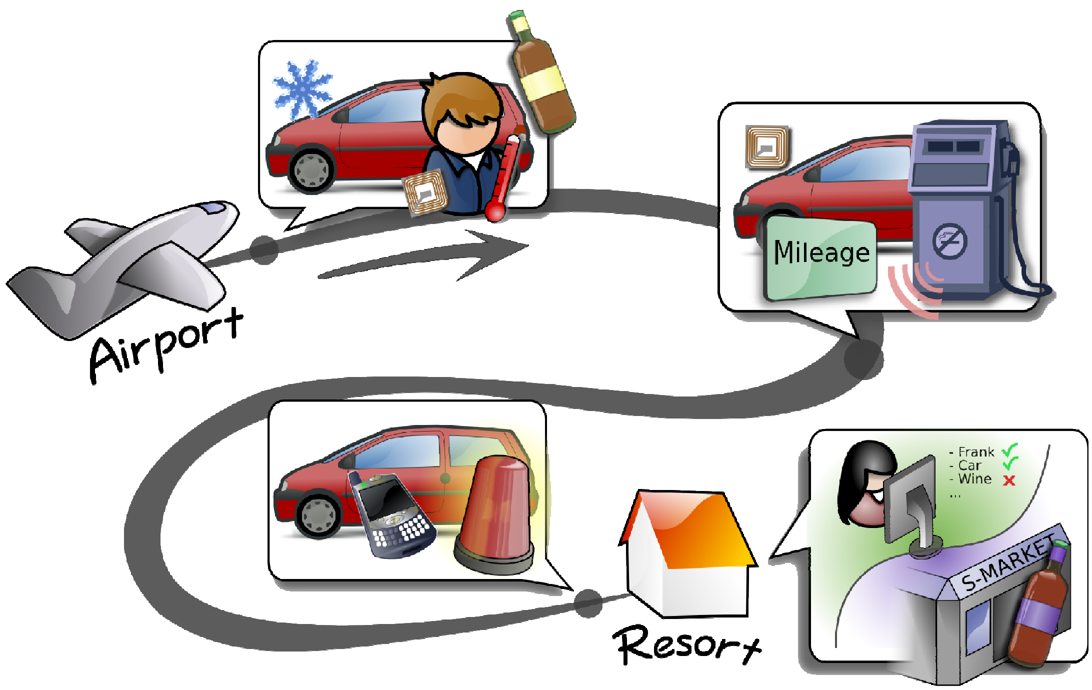


Illustration 13: Example of Service Scenario for ambient intelligence

Illustration 13 depicts an abstraction of our service scenario. Consider user Frank on the first day of his annual vacation. Frank's company owns few bungalows on the outskirts of Helsinki: a beautiful forest area that shines with the winter snow. This year, Frank's wife, Laura, is meeting a customer in the country, and they decided to meet later at the bungalow and spend a few romantic days before coming back to their normal lives.
Frank arrives at Helsinki international airport and proceeds to the car rental offices. He booked a car a few days ago with his company's credit card. Although it snows quite often during this time of the year, Frank does not feel cold when he enters the car parked in the airport's parking lot as the airport and rental office he just left are well heated. The car and Frank's clothing sensors discover each other the instant that he enters the car. The car's heating system is pre-programmed to start automatically when the temperature is below

20ºC. However, the temperature on Frank's smart-shirt indicates that his body temperature is still high, and hence decides to override the default programming and keep the heating turned off until his smart shirt indicates that he has cooled down.

Frank also carries a wine bottle in his luggage. The sensor tag that the bottle carries is also discovered and incorporated to the user-vehicle group.

The car is equipped with a LCD-GPS device to provide driving directions. By comparing Frank's ID (incorporated into his digital ID card), his profile and location, the car suggests a route to the bungalow avoiding traffic jammed roads due to the snow conditions. Frank accepts the offering and starts his trip to the accommodation.

On his way, Frank decides to stop by a gas station to refill the tank. The car LCD suggests him a set of gas stations on the way which support Frank's favourite mileage card. Upon arrival, the car discovers the gas station facilities. Since Frank is not familiar with the country's gas station system, he mistakenly stops in front of the wrong gas pump. Fortunately, the gas pump sends a message to the car's LCD inviting him to move the car to the following free pump. After a few seconds, one of the station workers, who was sheltered inside the office, comes out to the pump that the car occupies, carrying the mileage card reading machine.

At the bungalow, Laura has been checking Frank's progress from the airport. When the time is right, she orders some nice dinner from a local restaurant from the list suggested by an SMS message she just received. Laura notices that the bottle of wine that Frank is carrying has been suffering a poor temperature handling and chances are that the wine will be spoiled. She decides not to take any risks and goes down for a few minutes to the supermarket to get a new bottle.

At his arrival at the bungalow, the rented car is discovered by the house's garage. When prompted, Frank chooses to be noticed by his cell phone if somebody tries to tamper with the car. Frank then enters the house and meets his wife. The TV displays a set of Frank's favourite shows that were recorded at the house's server from the moment he booked the place.

Previous scenario implies a variety of services that are offered with total transparency to the user with many benefits. At most, the user must agree beforehand to receive that service or select it in real time. Furthermore, some of the services are spontaneous and are only possible due to arbitrary combinations of sensors, ID information and actuators that were not predetermined.

The Following is a brief analysis of the main services described by the scenario and how they are related to the technology explored in this Chapter and AmI.

- *User-centric temperature monitoring:* User and car entities discover each other when Frank enters the vehicle. Although the car has a temperature sensor itself, this value is overridden by the user's personal temperature information. This may be realized by sensor enabled RFID tags that identify the user, shirt and car and provide various temperature readings. By updating that information into a distributed information infrastructure, not only infrastructure services can be discovered, but the information can be shared by trusted partners for further local services, such as in the case of the wine bottle.
- *Personalized directions:* User's identity belongs to the group formed by the user and the car. Through this identity, services can be personalized according to the user's profile. For example, Frank's profile states that he wants to give preference to shops accepting his favourite mileage card.
- *Guidance on gas station:* Gas pumps belong to the gas station, which temporarily forms a Smart Object group with the vehicle when it enters the station space. Each pump offers its identity, and a sensor that determines when a car is stopped in front of it. Since the pump can read the car's identity, it is possible to retrieve the car's model information using its ID (for example, if an EPC is used for identity, this information could be retrieved by contacting the car manufacturer's EPCIS). Furthermore, the arrival of a car is transmitted to the station staff, who are delivered information they may need before

serving the user, for example, whether the customer is a member of the mileage service.

- *Car alarm service:* The user/car group of Smart Objects interact with the bungalow's garage the moment the vehicle is parked in the garage. Frank chooses to connect the car anti-theft system to his mobile phone by choosing from the car's LCD display when offered. The car uses sensor technologies to detect intrusions, and the information infrastructure bridges IDs, telecommunication services and condition monitoring.

This scenario deliberately contains several sub-scenarios that occur in different times and spaces but that follow a common time line. Thus highlighting and emphasizing the potential of a distributed infrastructure: the user space is populated with smart objects that can collaborate to produce context-aware resources and communicate with the system whenever possible. Although this scenario may seem well into the future, the technologies that realize it are described in this chapter and are partly being developed in the BRIDGE project Work Package 3 [96]. However, additional work needs to be done to make the technologies widely available at a reasonable cost. We believe that further hardware developments in the area of sensor-enabled RFID tags and network infrastructure such as the EPCglobal network and standards will enable ambient intelligence application scenarios such as those that we have described possible today.

6 Real life pilot project with sensor enabled tags

A very interesting pilot project pioneering the use of sensor tags has been developed by Fine Technologies[3] involving 200 CAEN A927 tags in year 2006. The project has been set up in order to monitor the temperature of vegetable products during the supply chain from the producer to the market.

The pilot has been set up with the main goal to facilitate sales, logistics and distribution from farmers to major grocery chains. The temperature is a very important issue for vegetable products: every time the product temperature rises, the shelf-life of the product reduces. So, continuous temperature monitoring is necessary to track down any problem in the cold chain. There are a number of systems to do it, but most of all they are tedious to be used and the data collection becomes a manual process, so not very useful for large scale applications. The RFID system using UHF temperature tags provides very easy data collection, is able to spread the information to the whole supply chain and is applicable in very large scale application.

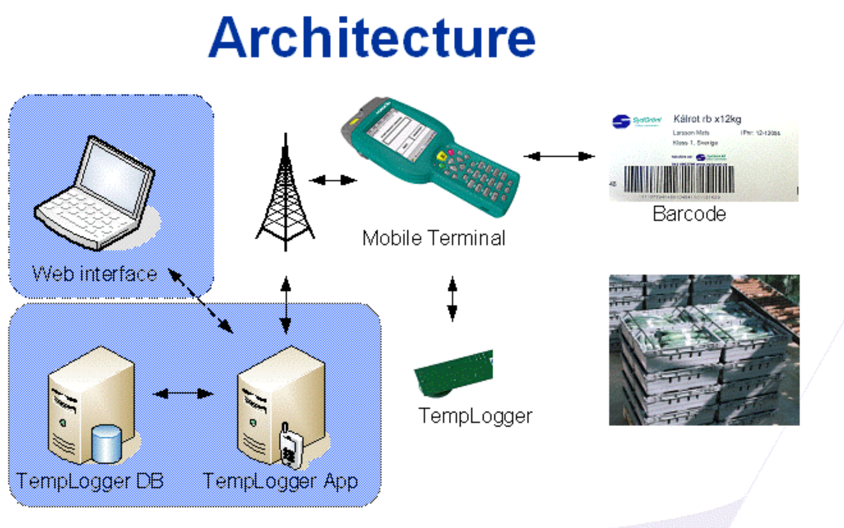


Illustration 14: Temperature monitoring pilot architecture.

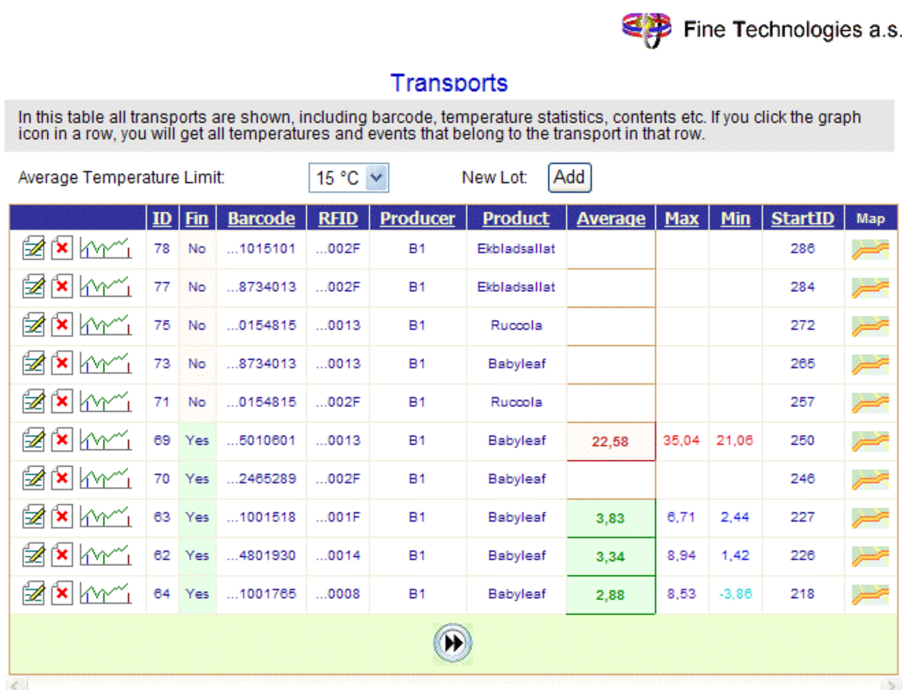
In order to facilitate the interfacing with the standard operations, it has been decided to associate the monitoring of temperature to the barcode system already present on each vegetable batch. The printed label barcode includes the information about the producer and the batch number. After the different batches are piled, a smart sense unit with RFID interface is placed and secured in each trace of the pilot (see Illustration 15).

The operator then reads the barcode of one of the trace of the same pilot with a handheld device: in the application a Nordic handheld device housing CAEN OEM reader has been used. Thereafter the operator reads the unique ID of the temperature logger with the same handheld device: a SW in the handheld device associates these two IDs. Automatically a timestamp is recorded for these two events and the unique ID of the handheld device gives the information on where the registration is made. In this way the temperature monitoring is started and it is combined with all the logistic data. When all the pilots have been recorded, the data are sent to the central server via GSM.

[3] Most of the contents for the present chapter have been provided from Fine Technologies.

Illustration 15: RFID smart sense placing

At the arrivals of the products to the wholesale, the pilots get unloaded for sorting according to the retail customer orders. Here the same procedure is repeated: using the handheld device, the operator reads the barcode of one of the trace of the same pilot together with the unique ID of the temperature logger. The data are sent again to the central station via GSM network; the temperature data are finally available for the whole supply chain and available for all the involved parts.
The central server includes the web based service in order to permit all the parties involved in the chain to get access to the temperature-history information which is provided as table and as histogram.


Fine Technologies a.s.

Transports

In this table all transports are shown, including barcode, temperature statistics, contents etc. If you click the graph icon in a row, you will get all temperatures and events that belong to the transport in that row.

Average Temperature Limit: 15 °C New Lot: Add

	ID	Fin	Barcode	RFID	Producer	Product	Average	Max	Min	StartID	Map
	78	No	...1015101	...002F	B1	Ekbladsallat				286	
	77	No	...8734013	...002F	B1	Ekbladsallat				284	
	75	No	...0154815	...0013	B1	Ruccola				272	
	73	No	...8734013	...0013	B1	Babyleaf				265	
	71	No	...0154815	...002F	B1	Ruccola				257	
	69	Yes	...5010601	...0013	B1	Babyleaf	22,58	35,04	21,06	250	
	70	Yes	...2465289	...002F	B1	Babyleaf				246	
	63	Yes	...1001518	...001F	B1	Babyleaf	3,83	6,71	2,44	227	
	62	Yes	...4801930	...0014	B1	Babyleaf	3,34	8,94	1,42	226	
	64	Yes	...1001765	...0008	B1	Babyleaf	2,88	8,53	-3,86	218	

Illustration 16: User interface screenshot

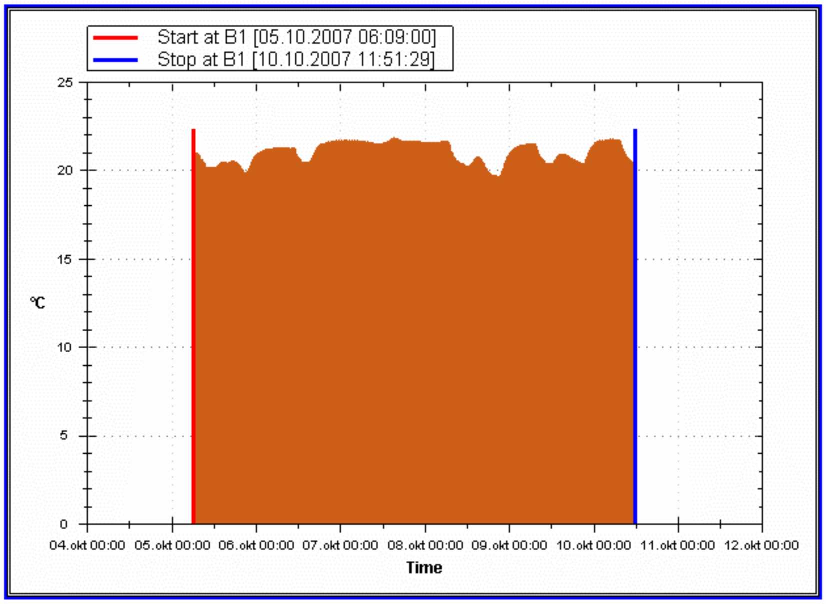


Illustration 17: User interface screenshot

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