RFID-based Sensor Integration in Aerospace

Béla Pátkai, Duncan McFarlane
Auto-ID Lab, University of Cambridge, UK

Report Abstract: This report addresses the emerging challenges of the fusion of RFID and sensors in the aerospace industry. Keeping in mind these two focal points the study elaborates on the potential and limitations of applicability, briefly surveys ideas, requirements, related work, available technology and services. The overall aim of this work is to provide an unbiased review on the topic in addition to proposing research and technology projects aiming at the smoothening and catalysis of the integration process.

AUTO-ID LABS AEROID-CAM-009 ©2006 Copyright

Published 23 November, 2006. Distribution restricted to Sponsors until 23 May, 2007

Contents

1. Introduction

1.1. Overview

The integration of Radio Frequency Identification (RFID) and sensors — or sensor data — is generally considered as an imminent step in the field of RFID. Preliminary ideas about its benefits and applications were presented in [2]. However, neither its design nor its implementation is a trivial task despite some preliminary ideas, technological opportunities and a few applications with working examples. Since this report is particularly concerned with the aerospace industry, it has to be emphasised that without community effort this development will be very slow and unmanageable, as the major benefits of this technology can be exploited only when information is exchanged between the different players of the industry.

In case of RFID technology, locating the geographic position of mobile objects is the result of *information fusion* as the unique ID on a tag is only a number; the association of this number with a location has to be done separately. Integration of sensors with either the tags (hardware integration) or their data streams (virtual integration) will lead to a higher level of synergy and more technological possibilities. These possibilities and prospective application scenarios need to be evaluated carefully as this area of research is new and RFID-related issues in themselves represent challenging problems.

The general aim of the Aerospace ID programme is to *remove barriers to wide scale automated ID deployment through timely and effective R&D in the aerospace industry and to synchronise research with industry initiatives.*

The sensor integration theme aims to find out:

- how to integrate ID data with other sensor information in aerospace applications; and
- how to gain added value from the available technological potential.

The rationale of the research theme is that:

- ID and sensor data needs to be efficiently integrated into real time data-capture systems; and
- the synergetic potential of combining ID technologies with other sensory information (for example, ID and temperature, ID and location) needs to be properly exploited.

The basic equation of the theme is:

RFID + Sensors = Identity + Location + State

This report emphasizes the fact that this area is underdeveloped, therefore it aims at answering three basic questions:

- *What was done* in this field so far?
- *What are the requirements in the aerospace industry*?
- *What can be done in the future*?

1.2. Distinctive requirements in aerospace

Integrating ID technologies with sensors is generally considered as desirable. However, existing applications are mainly found outside the aerospace industry and the most frequently mentioned example — the temperature sensor on the tag — is a rather simple one.

The aerospace industry is different from other industries in a number of ways, some of most apparent ones are:

- Product lifetime is much longer (decades vs. months, often 20–50 years)
- Product complexity is typically higher
- In contrast with other industries, after-sales service (maintenance, repair, overhaul, part exchange) is as important as the supply chain side
- Extreme environmental conditions exist
- Risks and safety issues are much more important
- Regulation, certification, standardization and documentation are significant issues
- Costs in general are much higher

These requirements provide the motivation for intensified research on problems specific to the aerospace industry, including the integration of sensors and RFID.

1.3. Related research themes

The sensor integration theme of the Aerospace ID technologies programme is one of five others investigated at the Cambridge Auto-ID Lab. These research themes are closely related to each other and all of them benefit from the work done in the others. Therefore the relationship of sensor integration to the other themes is briefly described in the following sections.

1.3.1. Application matching

The *application matching* theme aims at supporting end users in the selection of ID technology by a software tool that matches requirements with available ID technology [3]. These are not restricted to RFID; barcodes, contact memory buttons, magnetic and optical stripes are also considered along with more complex smartcards. If ID technology selection is a difficult task requiring expert help, then the combination of ID with sensors is even more complex. Sensors themselves, tags, integration methods (both hardware and software) have to be chosen carefully. The ID selection support tool provides some help for making these choices. Adding sensor integration related data and capabilities to this tool at a later stage of its development would be a challenging task due to the number and variety of sensors available in the market and the complexity of the matching process.

1.3.2. Lifecycle ID and data management

Providing parts with unique serial numbers allows part owners to link data and gather useful information about them. However, the collection of data throughout the lifecycle of the part is not a simple task. It requires efficient storage, representation, access control and use of authentication methods [3]. In case the collection of sensor data is important for part owners, a greater amount of data needs to be managed and more attention has to be paid to authentication and access control, as the data may reveal sensitive information or imply wrong decisions. Extending the original scope of this theme can also drive new applications in aerospace, for example advanced aircraft health monitoring and management.

1.3.3. Data synchronization

There are many ways of storing data on and off RFID tags and also for reading and writing data between tags and other data storages. Data synchronization was recently identified as a research problem and recommendations were made for several scenarios [5].

In Figure 1.1, a basic classification of these data synchronization scenarios is depicted from the always online solution to the occasionally disconnected one requiring a protocol for preserving the integrity and authenticity of the data.

Storing sensor data on tags adds complexity to the synchronization scenario because:

- The amount of data to be synchronized can be much higher
- The amount of data can influence the selection of the synchronization scenario

- Filtering can be considered at the synchronization protocol level
- Fine-grained time synchronization of sensor data can be difficult
- Data overflow has to be handled

The following chapters will be discuss how different synchronization scenarios can get around some of these difficulties.

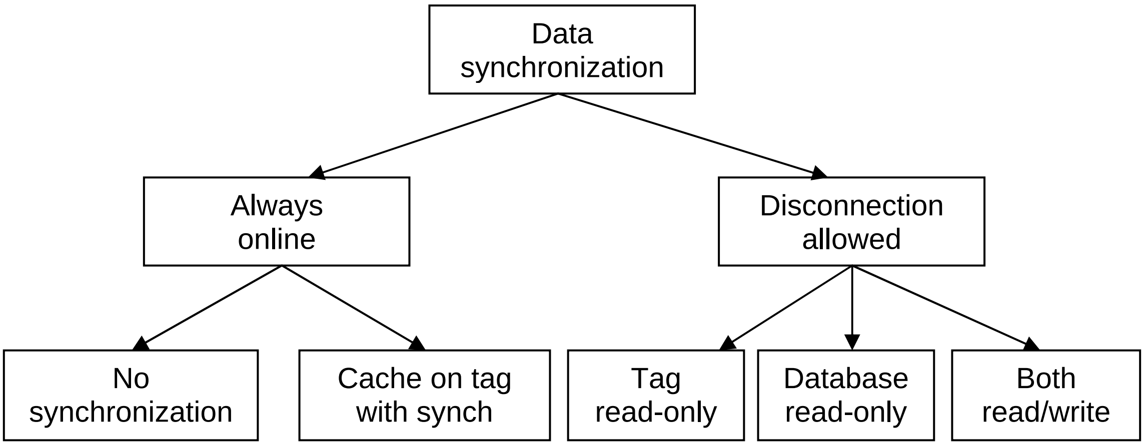

Figure 1.1: Classification of data synchronization scenarios

1.3.4. Track and trace

Tracking and tracing is the identification of the current state and the past states of a part, respectively. The requirements of the aerospace industry were analyzed in [6] and case studies on the potential of tracking and tracing were published in [7].

In case a part has a unique ID, the ‘state’ usually means location in either a supply chain or in the custody of an end user. Adding more ‘state’ information by linking sensor data to the part creates new opportunities for tracking and tracing. When querying tags or information systems new types of questions can be asked about the state of uniquely identified objects; the only limitation is the existence of an appropriate sensor on the object or in its environment.

1.3.5. Security

Security issues are ubiquitous in all the research areas of the Aerospace ID programme. In case of the sensor integration scenarios discussed in the following chapters, it is inevitable that in the future various organizations will share sensor data related to their products and services with each other. Sharing large amounts of data also means that information, which was not intended for sharing, may be ‘mined’, hence the additional dimension to security and access control in RFID-based sensor integration.

As the condition of a part is well reflected in the sensor data stored on it (or in a related database), it also makes sense to pay special attention to the authentication of that data.

1.4. Report structure

This report aims at establishing a common understanding of the research field of RFID-based sensor integration in the aerospace industry and its research community. The structure of the report shown in Figure 1.2 briefly describes the technical potential, compares the two main integration scenarios and discusses some of the important application areas. The document is concluded with proposals for future research activities.

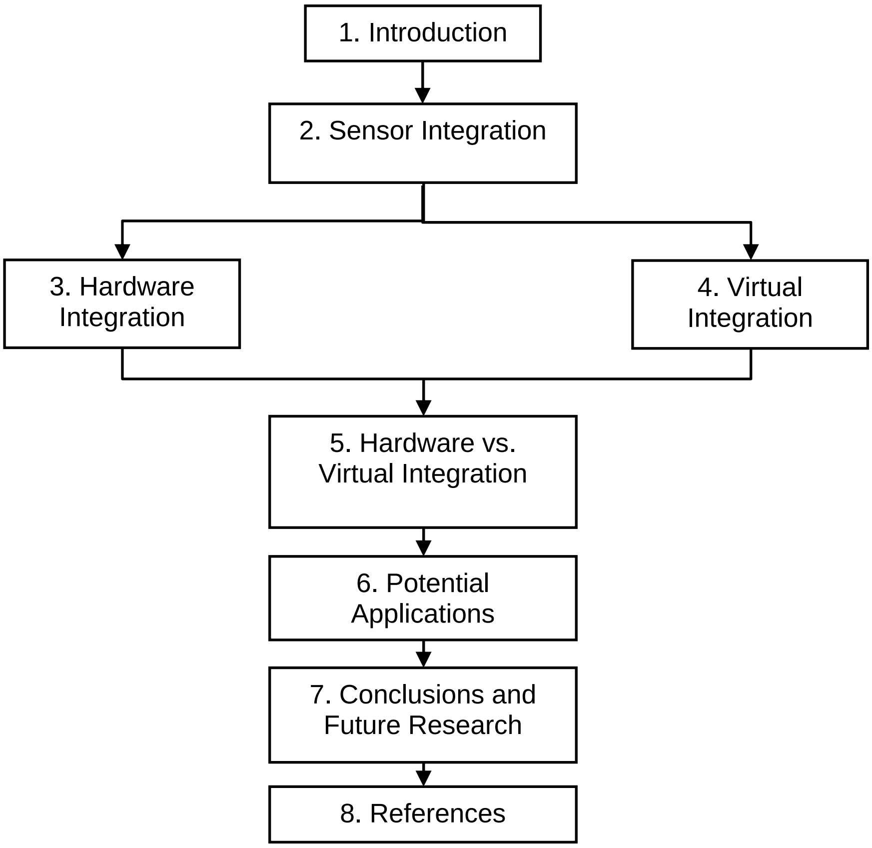

Figure 1.2: Report structure

2. RFID-based Sensor Integration

2.1. Sensor fusion

2.1.1. Definitions of sensor fusion

Using a combination of sensors instead of just one and making more informed decisions on that basis is called *sensor fusion.* A more formal definition is given in [8]:

“Sensor fusion is concerned with the combination of how to combine data from multiple (and possibly diverse) sensors in order to make inferences about a physical event, activity, or situation.”

The research community has referred to the same principle with different names, for instance, “multi-sensor data fusion” and “data fusion”, but sensor fusion is the most commonly accepted one. Information fusion expands this view and provides a broader field of research as it is reflected in the definition given in [9]:

“Information fusion encompasses theory, techniques and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources (sensor, databases, information gathered by humans, etc.) such that the resulting decision or action is in some sense better (qualitatively or quantitatively, in terms of accuracy, robustness, etc.) than would be possible if any of these sources were used individually without such synergy exploitation.”

2.1.2. Challenges of sensor fusion

Despite the obvious advantages of sensor fusion, combining sensor output and making more informed decisions is not without its challenges. Some of the major problems are:

- Sensor deprivation: The breakdown of a sensor when data is missing
- Limited coverage: Spatial or temporal limitations of sensor readings, for example when the sensor is far from the object or measurements are rarely taken
- Imprecision
- Uncertainty

One of the aims of sensor fusion is to overcome these problems by using multiple sensors. Ideally the resulting sensor system has the following characteristics [10][11]:

- Robustness and reliability: Due to their inherent redundancy (some sensors can even fail without affecting overall information quality)
- Extended spatial and temporal coverage
- Ambiguity detection: Contradictory values are easier to find from multiple measurements
- Indirect measurements: When a physical quantity cannot be directly measured it can be calculated from others (for example, corrosion sensing through a combination of humidity, temperature and stress sensors)

These challenges and expected benefits were listed here because they are also motivating the integration of sensors with unique identification technologies.

2.2. Integrating RFID and sensors

'RFID-based' sensor integration means that RFID tags — passive or active — are added to the sensor fusion scenario. In this case, in addition to the state of the object, its unique identity is also known, providing access to all the information associated with it throughout its lifecycle.

The integration of RFID and sensors can be done in at least two distinct ways:

- Hardware integration: The sensor(s) is(are) connected physically to the RFID tag, and sensor data is read by the RFID reader
- Virtual integration[1]: Sensor data is collected independently of the RFID tag, and the integration process involves the reading of the RFID tag and accessing another data source

2.2.1. Classification

The integration of sensors and their observations is a vibrant field of research in itself — known as either *sensor fusion* or *sensor integration* — and is a subset of the scientific field of *data fusion.* Limiting this field to the integration of RFID with sensor data provides a strong focus for research. Since RFID tags are classified in five different classes and the categorization of sensors is a complex task in itself, the integration of the two provides a great number of integration scenarios. To overcome this complexity, a basic classification is used in Figure 2.1 while a detailed description of the set-up is used when necessary.

---

[1] Virtual integration could also be called “logical integration”.

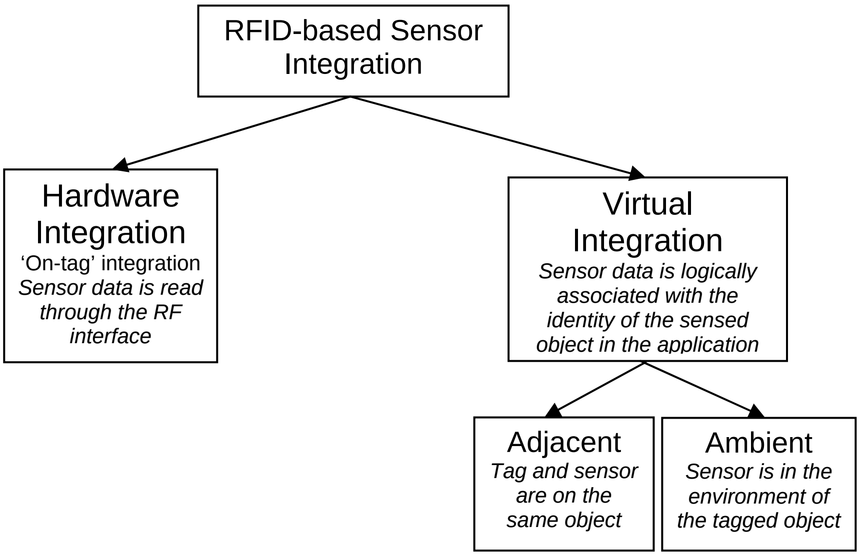

Figure 2.1: Basic classification of RFID–based sensor integration

The primary difference between the two main categories in Figure 2.1 is that in case of hardware integration *sensor data is communicated through the air interface of an RFID tag,* while in the case of virtual integration *sensor data is associated with the identity of the sensed object independently of the RFID tag's data communication.* These two categories are fundamental because they require a different infrastructure and technology. Virtual integration assumes the application of networked RFID (assuming a back-end database).

The virtual integration of 'adjacent' sensors is considered a relatively trivial task whereas 'ambient' sensors may not be in the immediate vicinity of the observed object, hence using their data is not a trivial task and involves more than just the consideration of data accuracy.

To describe an RFID-integrated sensor system precisely, a number of aspects have to be considered and documented. The following list of some of the characteristics of the integrated systems demonstrates the complexity of detailed classification:

- RFID tag related
    - class of tag (Class 1–5)
    - type of ID (EPC, GID, SGTIN, SSCC, GLN, USDOD)
    - read range and rate
    - memory type and size

- Application related
    - measured quantity
    - number of sensors
    - users of sensor data and access control
    - decisions based on sensor data
    - relative importance
- Sensor hardware related
    - power/battery details
    - calibration issues
    - weight
    - dimensions
    - installation, mounting and connectors
- Sensor data related
    - type of sampling method:
        - periodic
        - event-based
    - type of data synchronization
    - data filtering
    - accuracy
    - range
    - resolution
    - amount of data
- Environmental conditions (e.g. temperature, pressure, vibration, strain)
- Manufacturer
- Related standards (sensors or measurements)

2.2.2. Integration scenarios

In Figure 2.2 an iteration of the possible RFID-based sensor integration scenarios is shown. The boxes with capital ‘S’ are sensors connected to physical objects. The tags — of different classes — read by the interrogator (or RFID-reader) represent hardware integration while the sensor connected to the network by wires or sensor networks represent virtual integration. In the leftmost part of the figure a sensor is read by a human and documented on paper. This reading can later be associated with an RFID reading and the result can be input to a computer manually. The ‘application’ at the top of the figure needs to use data and various services to find objects by their unique identifier. The Object Naming Service (ONS) has a static pointer to the object while the ‘discovery services’ are able to trace the object’s path

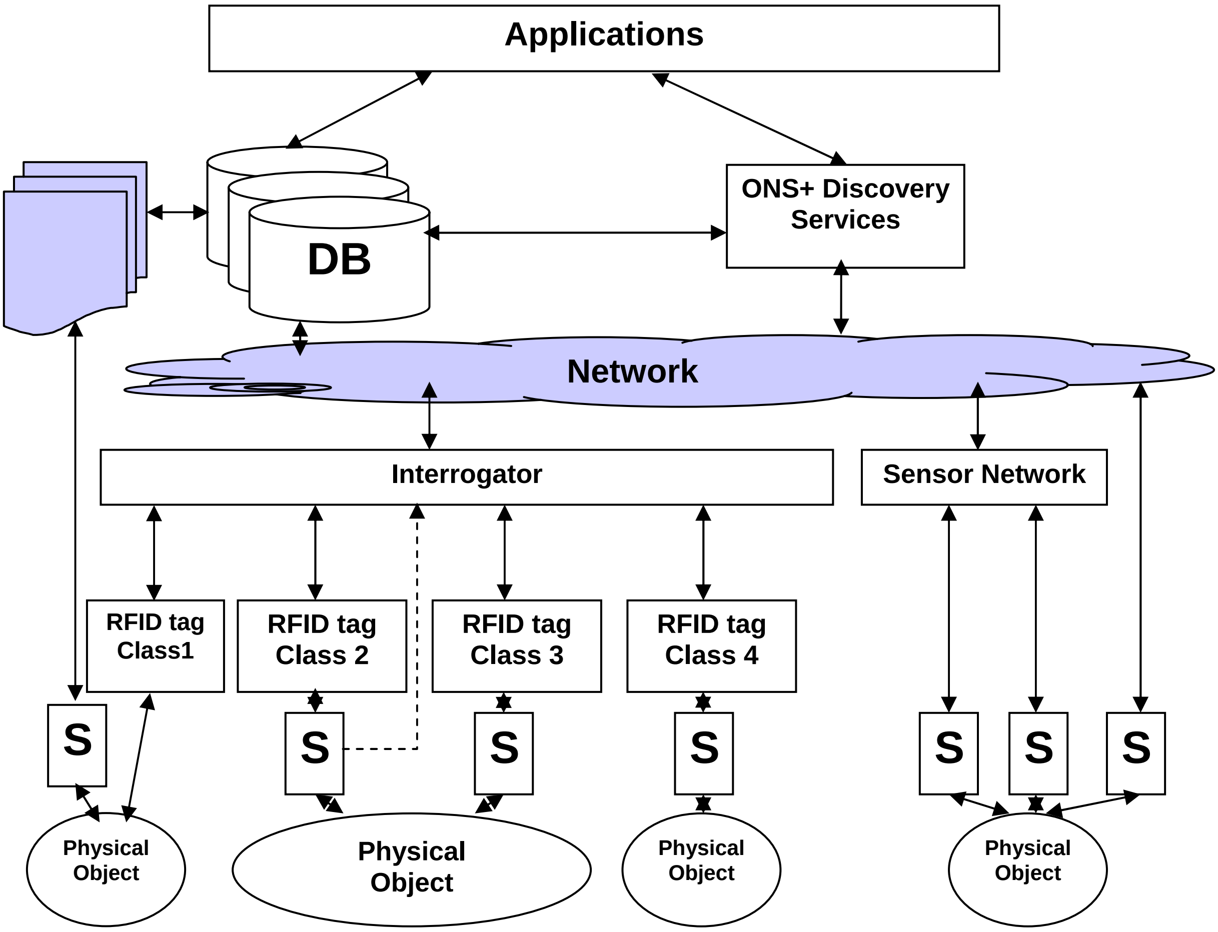

Figure 2.2: RFID-based sensor integration possibilities

throughout its lifecycle and collect information from different organizations. These concepts will be revisited in Chapter 4.

3. Hardware Integration

This chapter briefly reviews the most common sensors and their hardware level integration with RFID chips.

3.1. Sensors in aerospace

The basic classification in Figure 2.1 breaks down integration possibilities into hardware and virtual integration. The reason for this distinction is that the two types of fusion require different tools, standards, applications, methods and a different development path and provide different benefits.

The type of sensors does not play an important role in this review — as it is data-centric and abstract — but the specific needs of the industry may result in a wide range of requirements for data. The following sensors are frequently used in aerospace:

- Movement (tilt, acceleration, shock)
- Light/photoelectric
- Flow
- Force
- Strain
- Temperature
- Pressure
- Audio (ultrasonic, acoustic emission, lambda waves)
- Humidity
- Proximity
- pH
- Magnetic and field strength
- Ion concentration
- Flexure of liquid substances (for example, to check contamination of fluids by measuring how their flexure changes)

- Global Positioning System (can be considered as a complex location sensor)

In addition to these basic measured quantities, there are many things not measurable directly. For these a combination of sensors and inference methods/models are used and they represent a substantial area of research.

3.2. Single tag systems

Single tag systems are based on an RFID tag and one or more sensors connected to them. Data from sensors is read through the tag's air interface.

The simplest hardware integration method that can be used by RFID tag and sensor manufacturers is to design and build their own integrated product, and connect a sensor or several sensors to the RFID tag by using the tag's available memory blocks to store sensor data. This means that the tag has to be at least Class 2, as Class 0/1 tags do not have free memory available for sensor data, with the exception of Class 1 Generation 2 tags.

Figure 3.1 shows a typical design of the integrated circuit in a tag and is used to illustrate the relative simplicity of lower class RFID tags. In case of sensors with analogue output, the design has to accommodate analogue-digital conversion, but in most applications the integration should not be a serious design or technological problem.

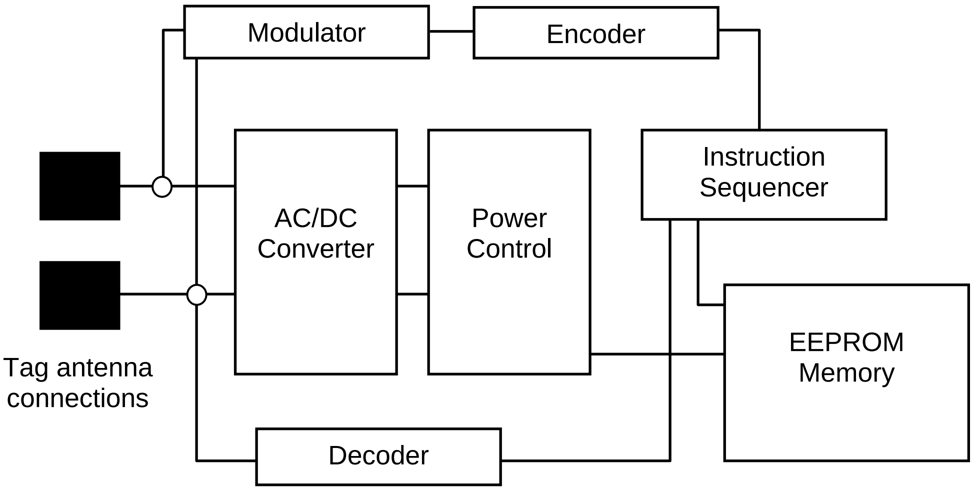

Figure 3.1: Typical tag IC design (based on [1])

In case of Class 2 tags, the interrogator (reader) provides the energy for the sensor and all the other circuitry. Therefore sensing is only active when a reader is in range, and this is a serious limitation to its functionality. In case the sensor has its own power supply, the integrated system falls into the Class 3 category. Class 3 and 4 tags (semi-passive and passive) are good candidates for sensor integration as they have a power source, a longer read range and significantly more memory, not to mention Class 5 tags which are essentially readers themselves.

The use of on-tag integration is not yet widespread and is often represented by integrated temperature sensors. It is generally assumed that in the near future many more sensor tags will appear in the market.

It is also possible to integrate tags and sensors from components readily available in the market. In contrast to on-tag integration (described in the previous paragraphs), manufacturers do not usually design the RFID tag by keeping in mind the integration of sensors, but obtain them as external components and connect them to the tag. Due to the fragility of simple Class 2 tags, they are not suitable for such purposes. However, the use of Class 3–5 tags is more feasible.

Similar to the previously mentioned possibility of on-tag integration, data saved from sensors to tags does not have to be formatted, but its processing requires the knowledge of its syntax and semantics. In case of a custom product, the data downloaded from the integrated tag by the interrogator (this is very simple to realize by a single *read* instruction) can be post processed at various stages — in the reader, the middleware or at the back-end database. Standardization work around on-tag sensor data formatting has not yet been done.

3.3. RFID-sensor networks

The previous two hardware integration possibilities have considered solutions that are completely up to the tag manufacturers or producers to build, even if they use some standard components. In case of a greater number of sensors, such a customization might become problematic, because the sensors themselves have to be integrated first after which the fusion and serialization of the data has to be designed to ensure compatibility with the tag's memory module. Also, custom solutions do not provide access to common design methods, reliability standards and easy part interchange that is necessary for achieving a low price.

The IEEE 1451 family of standards establishes the necessary interfaces and protocols for sensors, actuators, microprocessors and instruments to cooperate harmoniously. The Transducer Electronic Data Sheet (TEDS) allows the self-description of the individual sensors and, by connecting through one of the standard wireless (1451.5) analogue or digital interfaces to the network, they can provide data to the chosen destination. These standards do not provide any RFID functionality, they integrate sensors only. However, if integration of a greater number of sensors is required, the use of these standards is very convenient. The sensors/actuators in this scheme are known, and a 64-bit identifier is assigned to them. However, changing the sensor to a new one is not a registered event in this scheme, as the identifier would remain the same. In case the unique identity of the sensor is important, it is possible to link the ID of the sensor network node and the unique ID of the sensor to keep track of any changes.

In the aerospace industry, it is likely that this feature will be appreciated when tracking the lifecycle of sensors. Sensor data can be saved and associated with the unique ID of the sensor. So if one fails, or has calibration problems, then the individual sensor that took faulty measurements can be identified.

Active tags use the ISO 18000 family of standards for wireless communications. Other standards suitable for establishing wireless sensor networks (not necessarily including RFID) are IEEE 802.11 (Wi-Fi), IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (ZigBee) and IEEE 802.16 (WiMax). All these standards provide anti-collision features to enable collision free, concurrent communication between the nodes.

4. Virtual Integration

Virtual integration of RFID and sensors is the association of sensor data and RFID-based identity independent of the wireless interface of the tag. It means that sensor data is collected independently of the RFID tag, so the integration process involves reading the RFID tag *and* accessing another data source. Virtual integration mostly assumes the application of *Networked RFID* (often referred to as NRFID), which is the combination of a unique identifier (for example, an Electronic Product Code/EPC) stored on a tag and a back-end database storing complementary data related to physical objects. Practically it means that the tag is at least sometimes ‘online’, that is, connected to a computer network. Data is transmitted to and from the tag and additional data is stored at the back-end.

Networked RFID is not the same as virtual integration as hardware integrated tags can also be networked and synchronized.

A virtually integrated scenario requires a number of components, hardware, software and standards. In the next section, the requirements for these components are described and in section 4.2, EPCIS — the only available candidate standard — is introduced. This aims at addressing all the requirements of virtual integration of sensors with RFID. This report describes only the two basic scenarios — a combination of gradually introduced standard components and EPCIS — and does not aim to predict the path of future development.

4.1. Components of virtually integrated systems

Virtually integrated RFID-sensor systems do not necessarily have to comply with any standards; it is possible to build custom solutions internally in an organization. However, products and parts often change owners, especially in the aerospace industry, and have a long lifecycle. Therefore, using a standard way of handling part-specific information has obvious advantages.

Requirements for system components were studied in detail in [12], where the electronic pedigree and authentication issues for aerospace part tracking were investigated.

The most important components for virtual RFID-based sensor integration are:

- Networked RFID tag (any class) with unique ID
- RFID reader with wireless protocol
- Sensor(s)
- Back-end database and server hardware
- Authentication: to provide assurance of the identity and the authenticity of the part itself
- Access control mechanism for sharing data between organizations
- Filtering mechanism: to get rid of unnecessary data from the sensor data stream
- Query interface: for data search involving identity, ownership related and sensor data
- Data security mechanism
- ONS: Object Naming Service, a pointer to the current owner of a part
- Discovery service: locating data throughout organizational boundaries

These services can be implemented in a variety of standard and non-standard ways. The next section presents one of its possible incarnations as proposed by EPCglobal.

4.2. EPCIS

In Figure 4.1 a summary of the EPCIS (EPCglobal's Information Services) candidate standard is shown. The purpose of this figure is to illustrate how the issues of sensor integration can be solved by a single standard architecture.

EPCIS has some core services including: *ONS*- that provides URLs to authoritative information for a given Electronic Product Code (EPC): *Discovery Services*, which provides secure serial-level pointers across the supply chain to trusted partners; and two others which are not mentioned to keep the figure simple: *EPC Manager Number Assignment*, which is an offline service for allocating an identifier to a subscriber business to be used on its tags; and *Subscriber Authentication* to identify the user who is trying to access online services. In the current EPCIS standard proposal, sensors and sensor data are not particularly emphasised as they are only indirectly integrated through the writable data blocks of RFID tags. However, sensor data can be freely read and processed at all levels of the system — from low level filtering to application level processing.

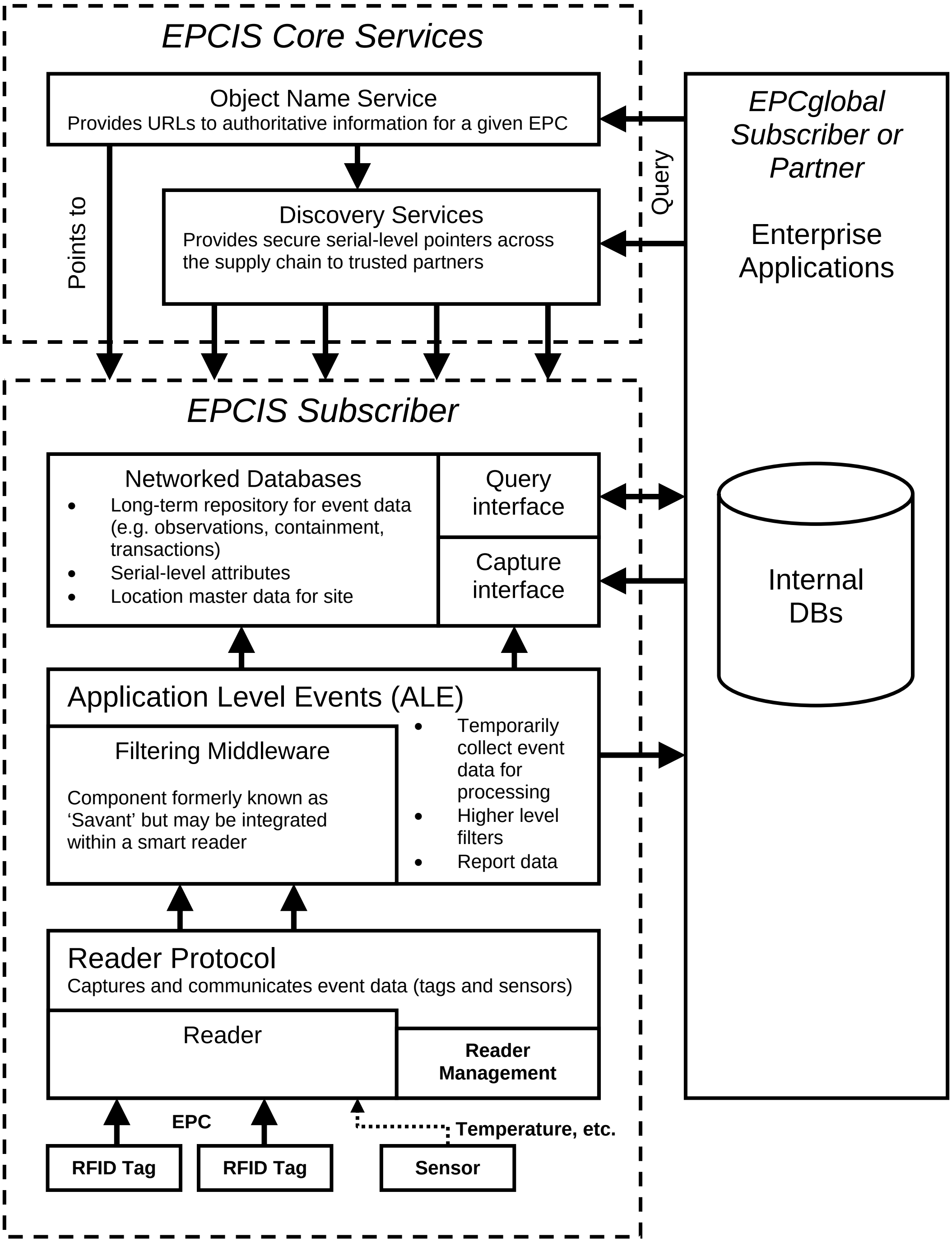

Figure 4.1: EPCglobal Information Services

Application Level Events (ALE) is the component where the conversion of data into events takes place. This can be considered as a secondary filtering. The user of the data has to define the important events that need to be captured and processed further.

5. Hardware vs. Virtual Integration

The most fundamental difference between hardware and virtual integration is their basic architecture and the applications they can provide for. Hardware integration in its pure form — the combination of the two approaches is of course possible — provides sensor data about the sensed object. Its limitations are the size of memory on the tag and the read rate between the reader and the tag. These limitations are valid even when we network the tag and save its data into a database. The advantages of hardware integration are demonstrated when the tag and its data travels with the part and no networking is available. Stored data on the tag can be retrieved by a reader anywhere at any time, without a network connection. At the same time, this limits the availability of data to that on the tag; any other data collected throughout the lifecycle of the part — about the part itself and about its environment — is unknown.

Hardware integrated sensors require batteries with an especially long life (several years in typical aerospace monitoring applications), which are currently impractical. In case the data is rarely synchronized with paper documentation or databases, data loss due to battery loss or failure has to be considered.

In case of virtual integration end users are not limited by tag manufacturers, because data from any sensors can be saved in a database and managed by software. This provides significant freedom over hardware integration as in this case, integration is performed through software means that can be carried out by a great selection of developer tools. At the same time, memory size and read rate are not constrained by the interrogator’s read rate, as the capacity of databases is practically unlimited and data transmission in case of wired systems is higher by at least an order of magnitude.

The data gained from virtually integrated sensors provide possibilities for obtaining ambient sensor data and information about the configuration of assemblies and their properties. As explained in the following sections, many applications will be driven by this flexibility of sensor data integration, through increasing the complexity of sensor fusion methods used for processing the increased amount of data of various origins and quality.

6. Application Areas

Identifying an object uniquely and knowing its state at the same time has a variety of advantages which are summarized in Table 6.1. This table gives simple and illustrative examples of queries that can be made if integration is done.

	When the part has **RFID**	When the object has **Sensor**	When the object has both **RFID and sensor(s)**
Temperature sensor	*Where has the part been in the last month?*	*What is the temperature of the part?*	*Has the part been exposed to excessive heat in the last month?*
Vibration sensor	*Did a certain airline use this part last December?*	*Is the part vibrating due to a fault?*	*Has any specific part been vibrating* ***besides this part*** *due to a fault when it was owned by a certain airline last year?*
Humidity sensor	*Was this part repaired more often than other parts of the same kind?*	*What is the humidity in the storage facility of a specific airline?*	*Was this part repaired more often than other parts of the same kind because the humidity in the storage facility of a certain airline is usually high?*

Table 6.1: Type of questions possible to ask about objects and environments

These examples illustrate only the potential of sensor integration, and many more applications are going to be recognized once a networked infrastructure is implemented. The availability of vast amounts of data and data sources is, however, a double-edged sword: too much data can overwhelm the users but at the same time, it can motivate fundamentally new ways of sensing and monitoring.

In the next sections three of the potential application areas are described. These were identified when preliminary discussions were conducted within the aerospace industry.

6.1. Aircraft sensors for health monitoring and management

Sensor data on-board aircraft is used not just for operation and manoeuvring, it also provides useful information for *vehicle health management*. Figure 6.1 summarizes the stages of the lifecycle of an aircraft from design to maintenance and data flows (through RFID, sensors and data buses).

Currently the data in most latest-generation aircraft is fed into an on-board database and regularly downloaded to a laptop or ground station. A fraction of this data can be sent to ground services during flight, but this is seriously limited by the bandwidth and cost of in-flight communications.

Since passive RFID was first certified in 2005 in aircraft and the testing of active tags is being done, we can expect that very soon these tags will be part of the data integration scenario on aircraft and in related information systems. The configuration of the aircraft will be known more precisely, parts will have a unique ID and on-board data can be more meaningful in the light of lifecycle data collected about parts. Whenever a part is exchanged between aircraft, not just the usually-required documentation will travel with the part; depending on the type of integration, sensor data on the tag or a link to the database of the previous owner where more information is available, will also travel. In addition to actual sensor data, ambient

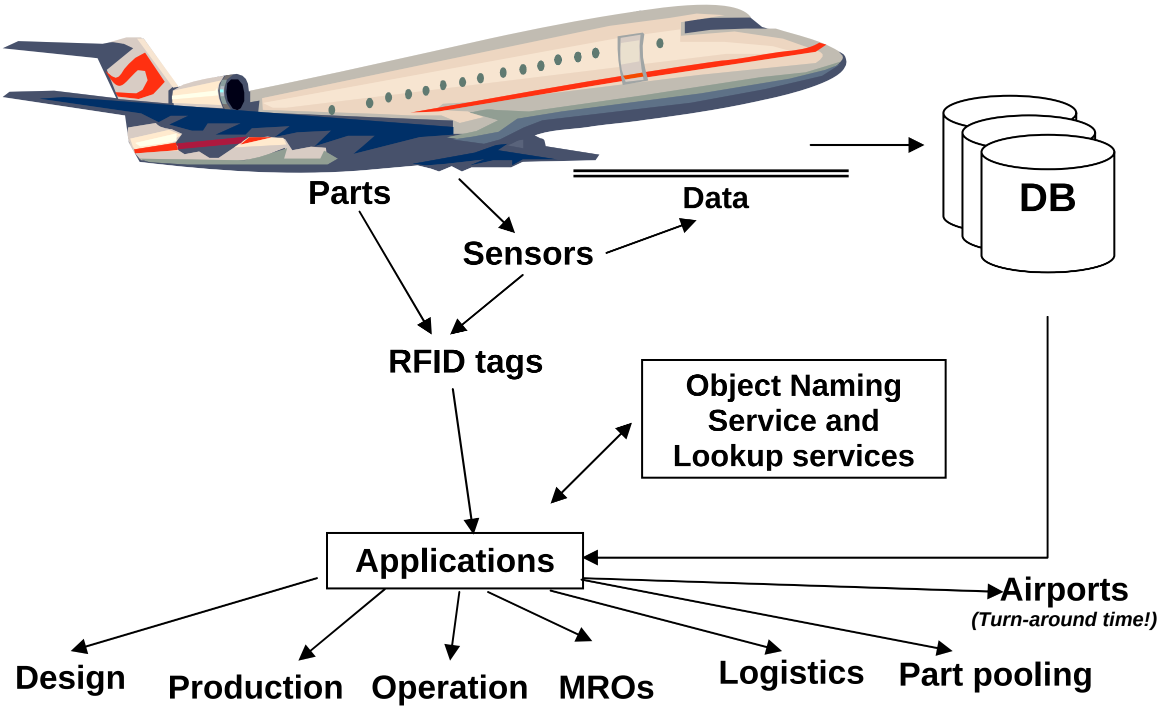

Figure 6.1: Overview of applications

measurements can be taken into account and used in queries, and on the basis of configuration data, the state of neighbouring parts and environments can be checked as well.

As aircraft parts have a very long lifecycle in comparison to parts in other industries, it is expected that maintenance and repair will benefit the most from sensor integration. The collected data should also be very valuable for part designers who get very little feedback on their designs.

The requirements and potential of sensor integration for vehicle health monitoring and management will be investigated further in subsequent case studies within the Aerospace ID Technologies Programme.

6.2. Auxiliary sensors

The internal data flows are depicted in more detail in Figure 6.2, where the classical, wired data buses (one or more, depending on the aircraft) are extended with RFID tags (both passive and active, illustrating future scenarios) and auxiliary sensors.

6.2.1. Retrofitting

Any changes in aircraft wiring are expensive and complicated due to regulations, certification requirements and technical limitations. In case of old aircraft or in case of temporary inspections, it is important to have an option of not wiring in new sensors — and consequently avoid the time consuming and costly certification process. A flexible method for mounting sensors and keeping track of their data and identity is desirable. An extended networked RFID-based sensor system would have such features.

6.2.2. Aircraft testing

Aircraft testing requires a great number of sensors that do not remain in the aircraft, hence wireless sensors can be installed temporarily and RFID can be used for registering the tagged part and for associating data with it. The testing processes themselves could be improved significantly by using RFID and managing data efficiently in a user-friendly manner.

6.2.3. Temporary monitoring of aircraft parts

Particular locations inside aircraft are difficult to inspect and sensors may not be available in these environments. As interviewees have pointed out, the area under the galley is difficult to inspect, and leakage and humidity can cause structural corrosion problems in the long run. A viable approach seems to be that the structures have RFID sensor tags attached to monitor humidity. These tags would not necessarily need to be queried in-flight, so inspection could occur periodically. They would be faster to inspect, and the simpler inspection should improve aircraft availability.

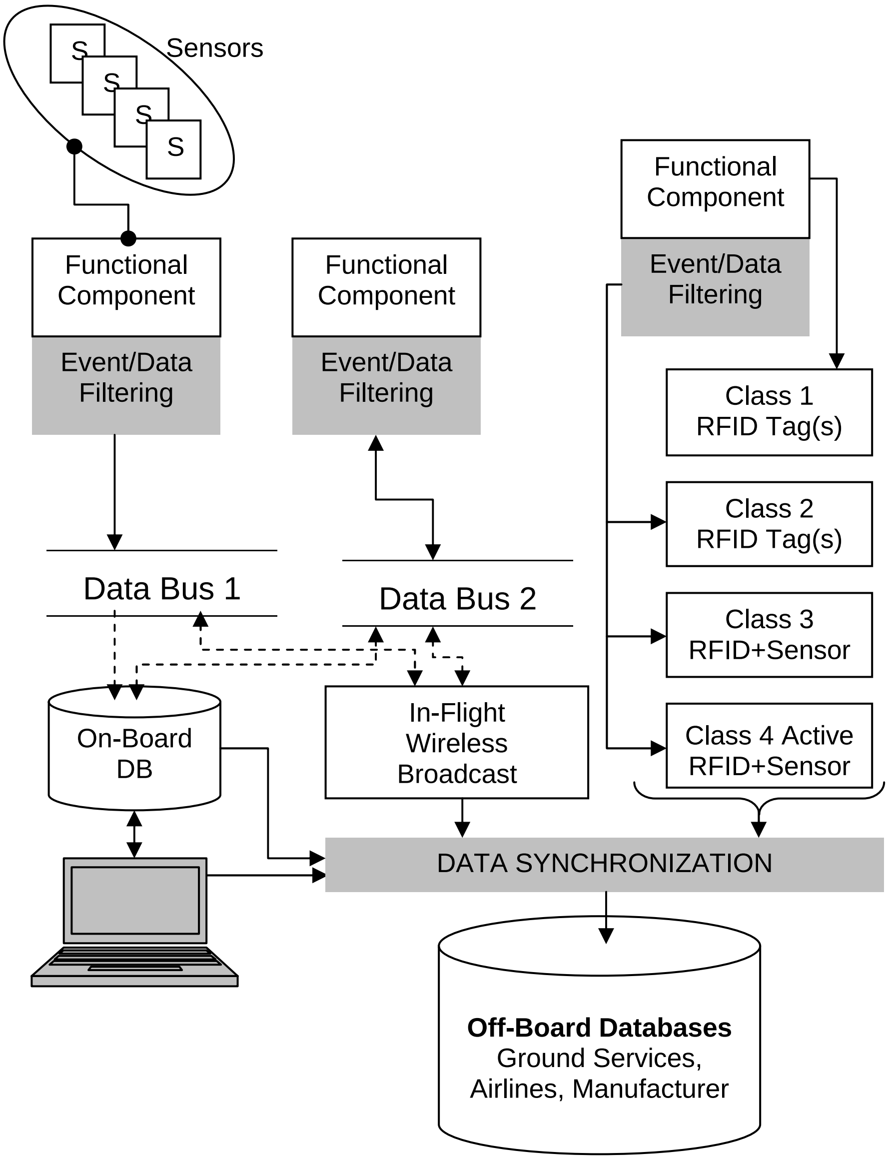

Figure 6.2: Extension of generic aircraft data flow scheme with RFID and data synchronization

The tags would need to operate over a range of several meters in an environment which may be partially occluded by metal surfaces. This suggests that passive tags might not be sufficient due to low read range, hence semi-passive or active tags could be used. The temporary monitoring process can also be enhanced by using hand-held computer-based readers and custom software applications.

6.3. Logistics

Secure containers and their tracking is one of the early applications of sensor fusion. But they are also a platform for future development, especially for networked RFID and sensor integration. There are several products on the market and even more under development, as post 9/11 security measures and the problem of shrinkage is of growing concern in logistics processes. In case of containers, the unavailability of external power supply is one of the most important limitations.

In handling catering and perishable products, monitoring integrated sensors with RFID will enable users to ask about warehouse or storage space conditions. For instance, sensors with RFID can provide answers to the question ‘Which of these items should not be in this space due to inappropriate temperature?’ Also, it can be traced back later whether and where exactly the object has experienced conditions that caused damage.

Aircraft spare parts of high value require monitoring, as the airworthiness may have to be preserved over large distances, long storage intervals and extreme environmental conditions. A combination of temperature, humidity and acceleration sensors can observe whether the part was dropped and if it has exceeded temperature or humidity limits.

6.4. RFID-sensor ‘mash-ups’

The term ‘mash-up’ has recently become popular in relation to the so-called ‘Web 2.0’ technologies. The availability of data on the Internet motivated several new applications that *combine* data sources and services. These combined services are often ’disruptive’, allowing the emergence of extreme productivity [2]. The analogy to these software mash-ups is the ‘internet of things’, where the identity of physical objects and associated data is available for further use. It can be expected that after a networked RFID-sensor infrastructure is in place, end users — as it is the case with Web 2.0 — will invent new applications to increase productivity and decrease the complexity and drudgery of their work. Just as in case of the

---

[2] Good examples include Google combining its calendar and map application online. When choosing a location for a meeting a map can be inserted into an appointment or email. Another example is Sony’s new GPS that stores the location of the photographer, and by combining the date on photos and the recorded date as well as location information in the GPS, it adds location and map labels to all the photos.

computer or the Internet, the boom of applications will have to be preceded by technology development and investment.

7. Conclusions and Future Research

The general conclusion of this report is that the integration of the world of RFID and that of sensors is an imminent step in technological development with significant potential. However, this development will not be easy and fast, especially not in the aerospace industry that is carefully regulated, where tools and methods have to be certified and the introduction of a new service or product can take several years.

To take this development further this report proposes that the following areas of research should be addressed:

1. Data on tag
    - requirements analysis for sensor data formatting, filtering and compression
2. Application matching
    - developing guidelines or an extension to the application matching tool to support the selection of RFID-integrated sensor solutions
3. Vehicle health monitoring and management
    - case studies on the requirements for RFID-based sensor integration in vehicle health monitoring and management
    - road-mapping the development path for integrated vehicle health monitoring and management systems, also considering a gradual introduction of the technology in a feasible way
4. Auxiliary sensors
    - case study on the requirements for RFID-based sensor integration in aircraft testing, with a focus on process improvement
5. Part pooling
    - case study on the requirements for RFID-based sensor integration in part exchange
6. Lifecycle data management
    - Cooperation with the lifecycle data management development group on demo/pilot activities by adding sensor data to the scenario

7. Sensor fusion
    - scientific investigation of the timeliness, time synchronization, accuracy and modelling problems of RFID-based integration of sensor data
    - finding applications for sensor fusion in accuracy and certainty improvement, ambiguity detection and extended spatial and temporal coverage
    - reproduction of lost data by statistical techniques

8. References

[1] Kleist, Robert A., Chapman, Theodore A., Sakai, David A., Jarvis, Brad S. 2006, *RFID Labelling – Smart Labeling Concepts and Applications for the Consumer Packaged Goods Supply Chain,* Printronix.

[2] Brusey, James, Thorne, Alan, 2006, *Aero-ID Sensor Integration: Scope of Work,* Auto-ID Lab, University of Cambridge, UK.

[3] Sharp, Ed, 2006, *Technology selection for Identification Applications,* Auto-ID Lab Cambridge, UK.

[4] Harrison, Mark, Parlikad, Ajith Kumar, 2006, *Lifecycle ID and Lifecycle Data Management,* Auto-ID Lab, University of Cambridge, UK.

[5] Suzuki, Shigeya, Harrison, Mark, 2006, *Data synchronization specification,* Auto-ID Lab Japan and Auto-ID Lab Cambridge UK.

[6] Kelepouris, Thomas, Theodorou, Lila, McFarlane, Duncan, Thorne, Alan, Harrison, Mark, 2006, *Track and Trace Requirements Scoping,* Auto-ID Lab Cambridge, UK.

[7] Kelepouris, Thomas, Baynham, Tom, McFarlane, Duncan, 2006, *Track and Trace Case Studies Report,* Auto-ID Lab Cambridge, UK.

[8] Hall, D. L., 1992, *Mathematical Techniques in Multi-Sensor Data Fusion.* Artech House, Norwood, Massachusetts.

[9] International Society of Information Fusion, http://www.inforfusion.org/mission.htm

[10] Bosse, E., Roy, J., Grenier, D., 1996, *Data Fusion Concepts Applied o a Suite of Dissimilar Sensors.* Canadian Conference on Electrical and Computer Engineering, 1996, 2:692–695.

[11] Grossmann, 1998, P.. *Multisensor Data Fusion.* The GEC journal of Technology, 5:27–37.

[12] Harrison, Mark, Shaw, Andy, 2006, *Electronic Pedigree and Authentication Issues for Aerospace Part Tracking,* Auto-ID Lab Cambridge, UK.