# Identification and Condition Monitoring of Mobile Objects by ID-based Sensor Integration – A Case Study

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*Abstract: The complex task of identifying and monitoring mobile objects remotely — for example, perishable goods, containers, vehicles and machine parts — requires the efficient integration of sensors and a number of other technologies. This case study aims at analysing the requirements for such an integrated system and evaluating the functionality, applications and applicability of the GlobalTrak™ product of the System Planning Corporation against these requirements.*



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# Contents

# 1. Introduction

Integrating ID technologies with sensors is generally considered to have great potential in the aerospace industry. However, existing applications are mainly found outside this domain and the most frequently mentioned example — a temperature sensor on a tag — is a rather simple one, far from the complexity expected to appear in advanced integration scenarios. The integration of sensors with identification is analysed in this case study by first summarizing the technology requirements and then introducing and analysing the rapidly evolving GlobalTrak product of the System Planning Corporation in light of these requirements.

The relevance of this paper to aerospace is that this industry has different, and usually more demanding, requirements than other industries. Some of the most apparent ones are listed below.

- General requirements
  - Elevated risk and safety issues
  - Highly regulated environment
  - Time-consuming and expensive certification
  - Importance of standardization
  - Typically high costs
  - Inter-process dependencies critical
- Logistics-related requirements
  - Security of high value assets (condition monitoring and counterfeiting detection)
  - Airborne monitoring (no wireless communication on board)
  - The critical process of reverse logistics of parts and their scheduling
  - More documentation and paperwork
- Aircraft-related requirements
  - Much longer product lifetime (decades vs. years, often 20–50 years in case of aircraft parts)
  - Typically high product complexity
  - In contrast to other industries, after-sales service (maintenance, repair, overhaul, part exchange) is at least as important as the supply chain side

- Extreme environmental conditions
- Maintenance on aircrafts needs to be scheduled, minimized; and unscheduled maintenance needs to be prevented, if possible
- New technologies need to be certified by 'parallel proof', that is, phased in by continuously double checking decision quality, before the technology or decision support is accepted on its own

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

## 1.1. Aims of the case study

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 synchronize research with industry initiatives.*

All the case studies and research reports in this programme keep this focus while analysing problems and solutions. The general aim of this case study is to *analyse the integration of Auto-ID technologies*[1] *with sensors based on industry requirements, and the potential of a concrete product.*

The specific aims of the case study are:

- Providing an overview of:
  - State-of-the-art technology for the integration of Auto-ID and sensors
  - General applicability of sensor integration in aerospace (product development, supply chain, logistics, tracking, tracing, condition monitoring and security)
- Summarizing requirements and challenges for:
  - Auto-ID and sensor integration
  - Supporting specific applications
- Describing the GlobalTrak product:
  - Features and potential
  - Solution for technological challenges
  - Applications
  - Evolution and future

[1] Auto-ID meaning barcode, magnetic and optical stripes, RFID or memory buttons with ID

- Analysing the GlobalTrak product:
    - How it satisfies the requirements of the aerospace industry
    - How it is evolving as a platform for general applicability

## 1.2. Report structure

The structure of the case study depicted in Figure 1.1 shows how the general requirements and technological challenges for sensor integration are analysed by comparing them to the implemented and planned features of the GlobalTrak product. Section 2 is based on the Aerospace-ID programme reports on sensor integration [1] and [2].

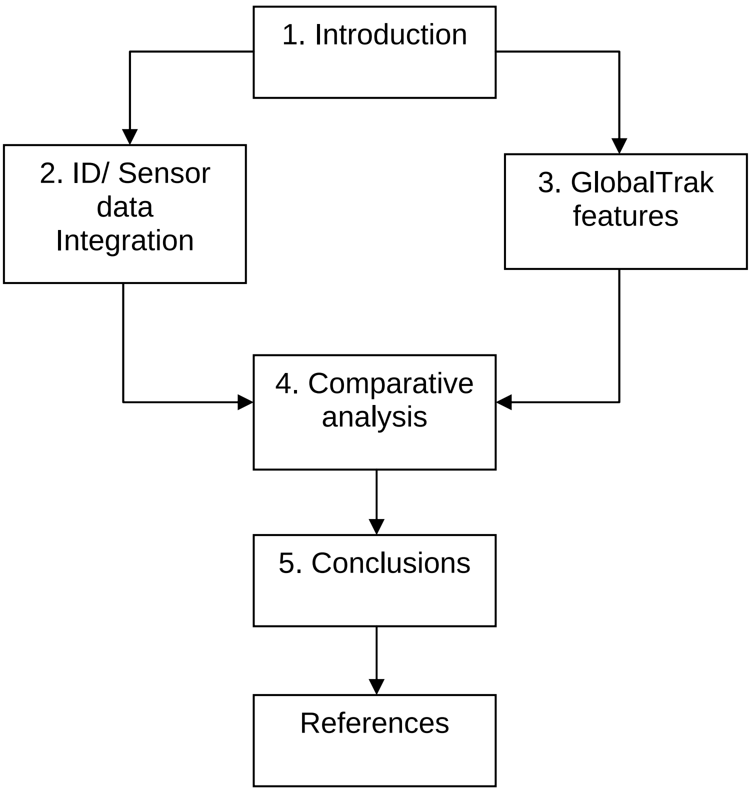


Figure 1.1: Report structure

# 2. ID-based Sensor Integration

## 2.1. Definitions

This section provides some definitions, aiming to clarify the ID-based sensor integration.

### 2.1.1. 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 [4]:

*"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 [5]:

*"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. Auto-ID technologies/Unique identification

Assigning unique natural numbers to objects and people is a very old invention, but the distinctive features of the recently developed Auto-ID technologies have increased the potential of this idea much further. Automating the unique identification process by answering '*What? When? Where?*' can have a dramatic effect on the efficiency of manufacturing, supply chain, retail, service and support processes.

### 2.1.3. ID-based sensor integration

ID-based sensor integration is a subset of sensor integration and refers to the synergistic combination of ID systems, such as auto-ID systems with other sensory systems, aiming at the estimation of the state of uniquely identified items and products and hence, at more informed decisions. More specifically, sensor systems have traditionally been used in condition-monitoring applications, while the killer application of auto-ID systems is track and trace. As a result, ID-based sensor integration enables tracking and tracing not only the location but also the condition of items through their lifecycle.

ID/sensor data integration requires the association of the subset of the collected sensor data that correspond to the condition of a particular product with the corresponding unique product ID. By the term subset, we refer to the subset of sensor data that correspond to the sensing parameters that affect the condition of the product, the subset of the above instances of sensor data that were collected during a specified period of time as well as the subset of sensor data instances that derive from a function of sensor devices, which measure the same sensing parameter, and are located at a particular site, such as a warehouse. The subset of sensor data that need to be associated with the condition of the product depend on different parameters, such as the configuration of the hardware deployed relevant to the products to be monitored.

## 2.2. Applications

The integration of identity with condition — ID-based sensor integration — has at least three key areas of applications that were identified in the Aerospace-ID technologies programme:

1. Aircraft sensors (combining data from sensors with their identity, that is, lifecycle data management, information sharing, queries involving not just identity but also condition, including ambient sensor data)
2. Auxiliary sensor installation (that is, sensors not staying with items for their full lifecycle)
    a. Aircraft testing (thousands of sensors may need to be deployed, identified and their data merged)
    b. Temporary monitoring (for example, aircraft galley area is problematic to monitor)
    c. Retrofitting (avoiding the trouble of messing with existing wiring and data buses)

3. Logistics (container monitoring, tracking and safety, cargo space sensors in aircrafts, ensuring airworthiness of shipped parts, sharing data externally)

## 2.3. Classification

The integration of ID and sensor data can be classified in numerous ways, based on different criteria. In an attempt to classify ID-based sensor integration, we can distinguish the following approaches, **based on where ID and sensor data are associated.**

Approach 1: Hardware integration

Approach 2: Logical integration

In case of hardware integration, sensor data is associated with the identity of the sensed object at the hardware level. Moreover, product ID and sensor data are transmitted synchronously through the same interface to the upper layers of the architecture. Hardware integration can be realized through the use of sensor tags mounted on the object whose condition needs to be estimated. In this case, sensor data generated by the on-board sensors clearly correspond to the condition of the tagged item. Another way of realizing hardware integration is by transferring sensor data from external sensors to the memory of the RFID tag or an on-board product memory.

On the other hand, in case of logical integration, sensor data is collected independently of the product ID data (independent devices, transmitted through different channels and/or asynchronously). Sensor data can derive from sensor devices, sensor nodes or from other data repositories and are associated with the product ID either at the middleware layer, data repository layer or the application layer.

ID sensor data integration can also be classified **in terms of whether integration is done in advance or on demand after a query.** We can distinguish between two approaches:

Approach 1: Materialized integration

Approach 2:  Virtual integration

The materialized approach physically integrates all relevant data in advance in a central database, the so-called data warehouse, which promises significant advantages regarding ease of use and performance, especially for queries involving large amounts of data. However, the data warehouse needs to be regularly updated with new data.

The virtual approach, also called mediator, identifies and queries the relevant sources and assembles the results returned by the sources to a final result. Up-to-date data is obtained, however at the price of high effort at query time.

To describe a particular sensor integration scenario, a number of aspects of the system have to be considered and documented, leading to further classifications, which are the following:

- **Hardware-related classification**
  1. Type of auto-ID technology to be used
  2. Hardware intelligence (on-board processing)
     - classification of RFID tags
     - classification of PEIDs (Product Embedded IDs)
  3. Independent or hybrid auto-ID and sensor technologies (that is, sensor tags, sensor on-board the RFID reader)
  4. Networking capability of devices (that is, sensor devices vs. sensor nodes)

- **Application-related classification**
  1. Type of sensing parameters to be measured
  2. Product mobility

- **Configuration-related classification**
  1. Number of sensor devices that measure the same sensing parameter located at a particular logical location.
  2. Location of each sensor device relative to the product location:

     2.1. always co-located with the product (that is, sensor tag on board the product)

     2.2. not always co-located with the product
        a. ambient sensor + mobile product
        b. aggregation sensor + mobile product

- **Data source-related classification**
  1. Number of data streams from physical layer to back-end system
  2. Centralized vs. distributed databases
  3. Product-embedded information vs. networked information
  4. Data sharing mechanisms (that is, peer to peer)

## 2.4. Technology challenges

In this section we describe the technological challenges that need to be faced in the realization of ID/sensor data integration.

### 2.4.1. Communications

Integrated systems consist of multiple RFID tags, sensors and other components — they need an interface to communicate with each other. In case of RFID tags a standard air interface and protocol is used to communicate data. If wireless sensors are used, the choice of a wireless standard is necessary and several important issues, such as power consumption, circuitry complexity, number of allowed nodes, bandwidth, operating frequency, legislation issues, international usability and protocol features need to be taken into consideration.

### 2.4.2. Power management

Mobility and the use of battery power is the key challenge for power management. In case a monitored item needs power at least occasionally when disconnected from the mains, a battery is necessary. An example of this is aircrafts between disconnection from the ground station and before the jet engines start to provide power. In some cases this gap is longer and power management becomes an issue.

Another example is the monitoring of containers when sensors and communication devices need to be powered, often for several years. The careful design of on-board software needs to address battery efficiency.

### 2.4.3. Data management

The raw data generated by sensors is not meaningful without processing and interpretation. In most applications there are several steps of data collection, filtering and processing. Part of this can be taken care of at the hardware level and the rest at the middleware or application level. Depending on the intricacy of the required filtering mechanism this may require the software to use complex algorithms and significant computational power.

#### 2.4.3.1. 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 [3].

In Figure 2.1 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. This classification was originally developed for RFID systems, but it is also relevant to sensor integration.

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

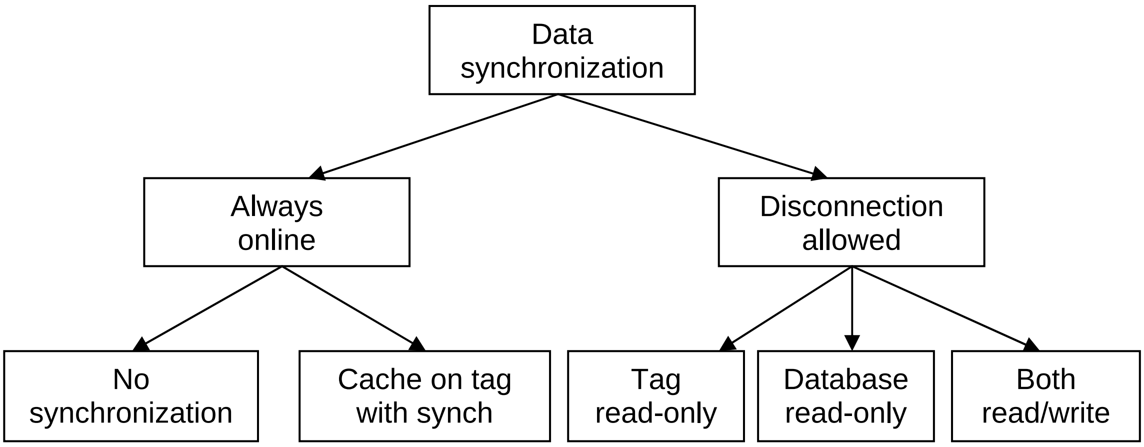


**Figure 2.1: Classification of data synchronization scenarios**

# 3. GlobalTrak™ Product

## 3.1. Overview of functionality

GlobalTrak[2] is a condition and location monitoring solution of the System Planning Corporation (SPC) providing continual visibility of mobile objects. The product idea was conceived in 2001 and since then four generations have been developed. Figure 3.1 shows the so-called 'GlobalTrak box', which will henceforth be referred to as 'the box', including a satellite- and a quad-band GSM modem and sensors that take relevant measurements of the monitored entities' condition.

**Figure 3.1: GlobalTrak boxes of generation 3 and 4**

GlobalTrak was originally developed to solve container tracking and security problems and it is currently deployed on shipping containers, hence its features aim at relevant challenges. The monitoring box is "Marine Environment Certified", it is shock resistant (up to 30g) and is resistant to environmental conditions that a shipping container is expected to endure.

It usually uses an on-board battery to supply power to the satellite and GSM modems, on-board circuitry and sensors. It is integrated with VI Agents' VI SixD™ *Managed Network*

[2] More information about GlobalTrak can be found at www.globaltrak.com

*Application Services*™ software platform to provide response center application functionalities including business intelligence, analytics, value network process integration and information sharing.

SPC was awarded a patent for the unique features of the GlobalTrak product.

The currently marketed generation 3 box is depicted in Figure 3.2 with all available connectors.

The GlobalTrak box does not require any external readers to obtain the data recorded by the box. As Figure 3.3 shows, the monitored container (or any object it is attached to) communicates with the Information Management Bureau (IMB) through satellite, SMS, or

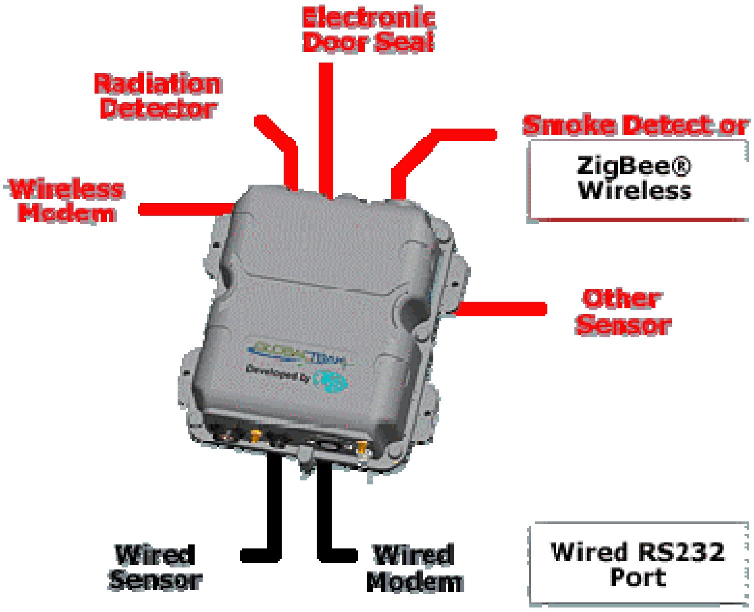


**Figure 1.2: GlobalTrak generation 3 functionality**

mobile phone (GSM) connection. Within SPC's IMB, VI SxD collects, fuses together, and processes GPS and sensor data to provide system level analytics. Response center users or remote customers access information using an Internet browser to display location data and use other application functionality and analytics.

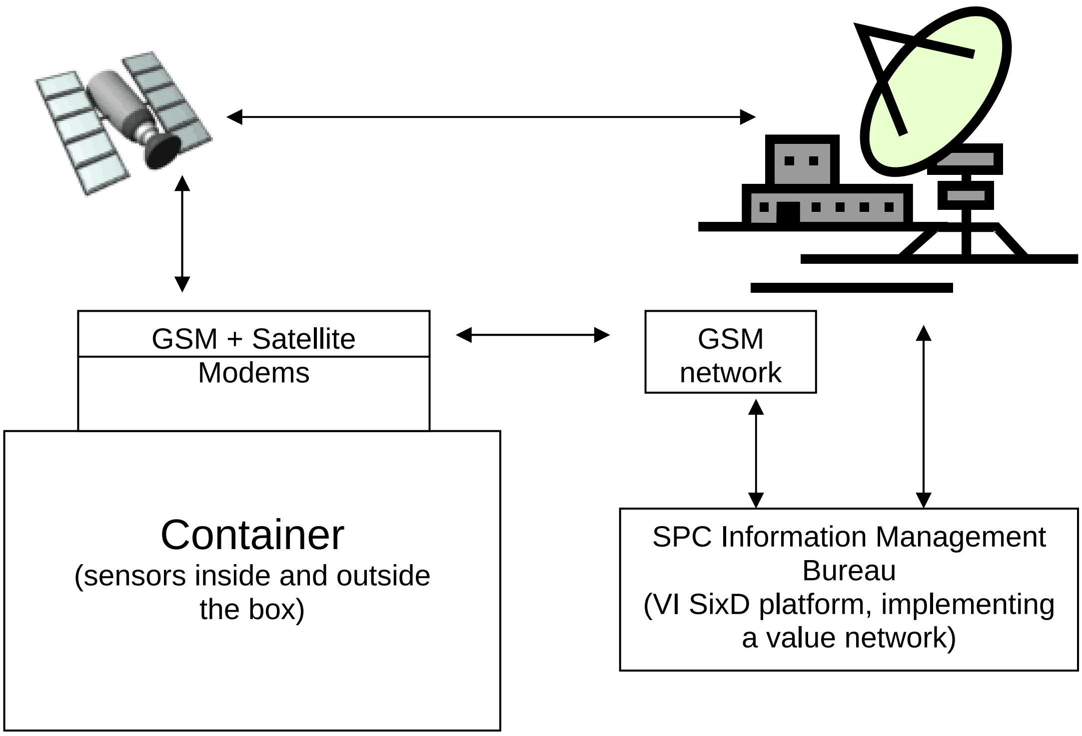


**Figure 3.3: Conceptual sketch of the full GlobalTrak system**

## 3.2. GlobalTrak features

### 3.2.1. Unique identification

To monitor individual items the use of a globally unique identity number is necessary. In case of GlobalTrak this number is the unique ID of the satellite modem. The Digital Signal Processor (DSP) on board is running a software application on board that uses this ID to let the IMB know the condition and identity of the container.

Since a container, or an aggregation of objects, can have multiple items associated with it, the unique ID represents all these items. Even if these items have their own unique identity, the IMB can temporarily associate them with a common ID and their physiological condition determined by the sensors. Depending on where the unit is mounted to, its unique ID can be associated either with an object identifier, such as a container, or with an environment identifier, such as a truck. In the first case, the generated sensor data is used to estimate the condition of the container (for example, open door) and its contents, whereas in the second case, the generated sensor data is ambient data. It needs to be pointed out that the deployment of the unit in item-level tagging applications is constrained by the items' dimensions.

In case the IMB needs to interface with other IT systems, the identity of containers and their contents can be converted to any other serialization systems.

Some of the fielded containers with GlobalTrak are equipped with a barcode reader, and generation 4 boxes can have an RFID reader attached to them. These options not only allow the solution to handle standard and ubiquitous identification tasks, but also to represent a challenge for the power-management subsystem. The communication of unique IDs and RFID/barcode data is through the satellite or GSM connection and is processed by the IMB.

### 3.2.2. Sensor integration

The GlobalTrak box makes use of several sensors and fuses them together locally in order to provide device level analysis to determine if any of the previously defined events relevant to end users has occurred. Some examples of these events may be:

- Open door
- Container is tampered with
- Temperature in container reaching an extreme
- Container is moving/idle
- Container resonates
- Shock
- High radiation
- Humidity reaching critical level

Some of these events are based on a single measurement, but some others need the input of several sensors to make a reliable conclusion. For example, detection of tampering requires the fusion of multiple sensors. Depending on customer requirements, the type and number of sensors varies in applications, but the most typical sensing tasks are:

- Door position
- Temperature
- Acoustics

- Light
- Tampering

In case of a special monitoring task, the sensors and sensor fusion methods are selected and tested individually and deployed by SPCs development team. In theory it would be possible to use customer-installed and even plug-and-play sensors, but the current product and service model aims at uncompromised reliability by keeping such extensions in-house.

VI SixD receives GlobalTrak box generated alerts and alarms. These device generated alerts represent one class of events. VI SixD also fuses together multiple data streams of information provided by users, systems, and trading partners in order to provide additional levels of intelligence and analytics. VI SixD system generated alerts represent a second class of events that provide a complete view of the events and information in order to provide more comprehensive analytics and intelligence.

### 3.2.3. Communication

The GlobalTrak box has two main communication problems to solve: the communication inside the container or, in case of other monitoring tasks, in the immediate environment of the monitored object; and the communication between the box and the IMB.

The first task is handled by either a wired or a wireless air interface.

The wired solution offers more reliability and less power consumption without the need for a separate power source, but offers less flexibility. On the other hand, a wireless link to sensors is more flexible to implement, but is subject to battery issues, necessity of certification and the need for more testing.

For wired communications, the RS232 serial communication interface was implemented in the box because it is a well-known and easy-to-use standard. For wireless communications, the SPC team had done extensive testing and development work. Initially the Bluetooth (IEEE 802.15.1) standard for wireless communications was used, but due to its high power consumption it had to be changed to the ZigBee (IEEE 802.15.4) standard. The ZigBee standard also handles more wireless nodes than Bluetooth.

A new development of the box implements a multi-hop (ad hoc mesh network) ZigBee sensor network, so if at least one of the containers has satellite or GSM capability (for example, in a large cargo space inside a ship) the other containers can communicate and exchange data through that container.

The second communication issue is between the box and the IMB. This challenge is met by the use of OrbComm's satellites and a quad-band GSM mobile communication card. The satellite communication function is only used when there is no GSM coverage (for example, on the sea) to save costs.

Currently the data communication between the box and IMB is simplex, that is, data flows only upwards — from the box to the IMB. However, duplex operation is possible with the help of a simple software implementation.

### 3.2.4. Power management

Depending on specific applications, the box is either battery powered or uses a rechargeable battery that is charged when the container is plugged into a power source. In some cases, for instance when the container is constantly cooled, power supply is not a significant issue.

The rechargeable batteries typically have 5Ah performance, while the non-rechargeable ones up to about 13Ah. The latter ones offer approximately three years of battery life in a typical monitoring application.

Alternative batteries – fuel cells and radioactive batteries – would provide better battery performance, but container monitoring applications are sensitive to the use of hazardous materials in any form. Some applications even prohibit the use of the GlobalTrak box and its sensors inside the container; they have to be mounted on the outside.

The on-board DSP schedules sensor and communications events. The DSP software can optimize sleep and wake times of the box and its sensor nodes, that is an effective way of increasing battery life. Also, the choice of an efficient wireless protocol provides significant advantages. Power management is an important challenge in designing a mobile asset monitoring system.

### 3.2.5. Data management

The data generated by sensors is at first processed in the box. Low-level operations are taken care of by the MCU, while high-level tasks, including communication and data filtering, are done by the DSP. An on-board EPROM stores some of the event data. This memory module can be upgraded whenever necessary.

The data sent to the IMB should only cover relevant events with practical importance. Within the IMB, VI SixD is also capable of filtering out unnecessary or meaningless data as well as fusing the location and sensor data with other business process information to provide more comprehensive analytics and intelligence.

Neither the size of the on-board EPROM nor the bandwidth of the satellite or GSM data channels have ever posed constraints in applications.

One of the reasons the VI Agents VI SixD platform was selected by SPC for the implementation of the IMB was its user friendliness and the ease with which it can interface with an arbitrary IT system. Interfacing is done by the exchange of XML documents.

### 3.2.6. Future versions of GlobalTrak box

This section summarizes the ideas about future versions of the GlobalTrak box. The future versions of the GlobalTrak Unit are likely to be characterized by the following functionalities:

**Sensors outside the GlobalTrak box:** In an attempt to reduce the size of the GlobalTrak box, a number of sensors will be transferred outside the box. Sensor data from the external sensors will be transferred to the GlobalTrak box, associated with the unique ID of the box and then communicated to IMB.

**ZigBee network of GlobalTrak boxes:** Research is done on establishing data communication among the GlobalTrak boxes through a ZigBee mesh network. Each box will have the role of a sensor node and a single box in the network will have the role of the sensor gateway collecting the associated ID and sensor data from each box and transmitting them to IMB.

**Introduction of RFID technology:** The objective is to use both fixed and handheld RFID reader inside or outside a container in order to monitor and account for the inventory of its contents, such as cases or pallets, which are supposed to be tagged. In this case, a fixed reader may be activated only when the container door opens (open door sensor), detects changes in the container aggregation events. Research has been done on establishing data communication between the RFID reader with the GlobalTrak box, so that RFID data will be transmitted along with GlobalTrak box data (unique ID = container ID, sensor data) through satellite or cellular communication to IMB.

## 3.3. Applications

The primary application of the GlobalTrak box is in container security and condition monitoring. The underlying technology, however, can take care of many more condition-monitoring tasks as the analysis in the next section points out. The key issue in supporting new applications is whether they require problem-specific knowledge and increased need for product support.

## 3.4. Classification

The GlobalTrak monitoring unit enables hardware integration of ID and sensor data, because all data either deriving from the RFID reader or external sensors are transmitted synchronously through the same interface to IMB. Futhermore, the GlobalTrak box, (due to the on-board data management system) has the capability of generating events either pertinent to the container (open door) or items inside the container, by combining RFID data with sensor data. However, IMB, which incorporates the software of VI Agents SixD and can hence enable the logical integration of ID and sensor data streams if required. More specifically, VI Agents SixD can fuse multiple data streams across the supply chain. In case of the GlobalTrak product, IMB can receive data from multiple GlobalTrak monitoring units, independent sensors, RFID readers as well as manually input data and logically associate them if required. For instance, logical integration might be required to estimate the condition of a product that has been stored in a warehouse equipped with ambient sensors and then transported in a truck equipped with a GlobalTrak monitoring unit. In this case, RFID events, such as the entrance and exit of the object to/from the warehouse and the truck respectively as well as sensor data derived from the ambient sensors and the GlobalTrak monitoring unit, will need to be associated at the IMB level.

As far as materialized versus virtual integration classification is concerned, the GlobalTrak box currently falls into the category of materialized integration, as all the generated data or events are integrated in advance at a centralized database. However, the IMB's use of VI SixD also provides for virtual integration of the GlobalTrak box data and events with other process information supplied by other data streams of information.  This may include other GlobalTrak boxes as well as other sensor feeds.  In addition, other business process information such as trading documents (e.g. purchase order, bills-of-lading, ASNs, and POD documents) may be fused together to provide a more comprehensive understanding of the scenario and events surrounding the shipment and container.

# 4. Comparative Analysis

The aim of this case study is to analyze the versatility and potential of a concrete sensor integration solution applicable in the aerospace industry. Table 4.1 summarizes the previously implicitly described requirements for ID-based sensor integration and comments on some specific issues.

**Table 4.1: Analysis of GlobalTrak features**

| Feature | Implemented in GlobalTrak (Yes/No/~partially) | Comments |
|---|---|---|
| Unique identification of observed entity | Yes | The satellite modem's ID serves as a unique ID for the observed container and all of its contents. |
| Integration with RFID | ~ Yes | It is possible to deploy an RFID reader in the container, but battery limitations and the inefficiency of backscattering has to be considered. |
| Real-time availability | Yes | The box can be accessed anywhere where there is either GSM or OrbComm satellite coverage, that is, practically everywhere on the globe. |
| Aggregation of entities based on ID | ~Yes | Barcode or RFID reader, or manual data input allows aggregation of item numbers with the satellite modem's ID. |
| Power-management strategy | Yes | The DSP software was designed to save as much battery power as possible. |
| Data synchronization (preventing data loss) | ~ Yes | Though previous requirements have not motivated the use of a complex data-sync method, data loss is prevented by being nearly always online. |
| Data filtering | Yes | This can be done at both the DSP/hardware level or in the IMB. |

**Table 4.1 continued…**

| | | |
|---|---|---|
| Standard interfacing to sensors | ~Yes | In case of wireless sensors the ZigBee standard is used, in case of wired ones it depends on the type of sensor. |
| Sensor fusion for decision support | Yes | For example, in case of tampering detection several sensors are fused to provide a reliable event. |
| Integration of arbitrary sensors | Yes | There are no limitations on the type of sensors, except unreasonable battery, size and bandwidth requirements. |
| Plug-and-play sensors | No | Not implemented. |
| General applicability | Yes | Currently the box is used for container security and condition monitoring applications, but it could also be used for integrated system health management. |
| Easy integration with other IT systems | Yes | The use of the VI SixD platform allows easy integration by XML documents. |

 

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# 5. Conclusions

Using the GlobalTrak container monitoring product of the System Planning Corporation, this case study has analyzed the general requirements and the technology potential of ID-based sensor integration. The analysis shows how an application-specific tool can satisfy most of the general requirements and used in a number of areas in the aerospace industry. Based on these results it can be expected that platforms for the integration of ID-based data will emerge.

# 6. Acknowledgements

The authors would like to thank the support of Joe McKinney and his colleagues from the System Planning Corporation – www.sysplan.com – and Tim Shideler and Kurt Kammerer from VIAgents – www.viagents.com – for their valuable comments on the subject of this report.

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