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D4.6 Viability of WSN as ICT overlay for physical security detection

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1 Executive Summary

This deliverable aims to provide an introduction to the material management use case where Boston Scientific Ltd, Ireland look to leverage ICT-based COMPOSITION tools and technologies. This use case UC-BSL-3 demonstrates a need for a physical security and asset tracking implementation to fix knowledge gaps with respect to material management in the manufacture of Pacemakers and Implantable Cardiac Defibrillators. As laid out in D2.1 and as found out through questionnaires and interviews with industry partners owning the use cases it is desirable to implement a physical security detection system which utilises indoor locations systems and wireless sensor networks to provide relevant alerts and location information regarding high value components.

A state of the art review covers the latest trends in Real Time Location Systems, firstly covering the general theory behind it, then delving into the technologies currently employed for indoor location. The different methods are compared in order to determine the most likely optimal choices for the use cases giving initial recommendations. One issue with these systems is battery life expectancy of the wireless sensors and so energy harvesting techniques are examined to eliminate the need for battery replacement or at least extend battery life. For physical security detection and determination, a number of typical sensors used for security purposes are covered.

A general high-level specification of the final system is laid out in the final section. It will be through testing and further collaboration with Boston Scientific that this will be realised and a detailed specific implementation created.

2 Glossary of Terms

Acronym	Meaning
AOA	Angle Of Arrival
BAP	Battery Assisted Passive
BLE	Bluetooth Low energy
BSL	Boston Scientific Limited
EH	Energy Harvesting
GPS	Global Positioning System
ICT	Information Communications Technology
IMU	Inertial Measurement Unit
IOT	Internet Of Things
ISM	Industrial Scientific Medical
LED	Light Emitting Diode
LOS	Line Of Sight
LPWAN	Low Power Wide Area Network
MEMS	Micro Electro-Mechanical System
MES	Manufacturing Execution System
MPPT	Maximum Power Point Tracking
NLOS	No Line Of Sight
PB	Product Builder
PCBA	Printed Circuit Board Assembly
PIR	Passive Infra-Red
PU	Production Unit
PV	Photo Voltaic
RF	Radio Frequency
RFID	Radio Frequency Identification
RSS	Received Signal Strength
RTLS	Real Time Location System
SAP	SAP Production system
SMT	Surface Mounting Technology
TDOA	Time Difference Of Arrival
TEG	Thermo-Electric Generator
TOA	Time Of Arrival
UC	Use Case
UWB	Ultra Wide-Band
VEH	Vibrational Energy Harvester
WLAN	Wireless Local Area Network

Table 1. Glossary of Terms

3 Introduction

In the factories of the future, it is imagined that all important and valuable assets will be tracked across the factory. The end goal being one where smart automation systems could optimise any manufacturing facility by monitoring the production flow and the location of workers, equipment and raw materials (particularly portable and high-value equipment and materials). This impacts both direct and indirect cost: direct costs are attributable to the monetary loss if the asset is misplaced/stolen and not retrieved. Indirect costs relate to downtime and production delays caused by unavailability of the asset (e.g. test jig, component reel). Monitoring can be done using ICT through alerts when behaviour is detected (e.g. motion) and/or methods for easy location of any asset at any given time as required. In some cases it is sufficient to be made aware that some deliberate/unintentional/environmental event has occurred on or near equipment or infrastructure, in other cases it is important to be able to track down an asset at short notice.

This deliverable focuses primarily on physical security considerations for factory assets as a complimentary task to cyber-security considerations elsewhere in this work package. This will involve considering solutions and determining what sensory infrastructure is required to track high-value assets around a factory, detect when deliberate or accidental damage has compromised an asset, and methods to easily report this data or provide alerts when serious breaches of physical security have been detected.

So far, a key step agreed to serve the use case needs is to define and implement a Real Time Location System (RTLS) in Boston Scientific's production facility in Clonmel. To illustrate how the technology and the application are closely intertwined, this stage of the project involves researching the literature as well as examining the facility in order to match up an existing technology to the exact use case needs.

It some cases much can be learnt through 'sensor fusion', i.e. examining data from various wired and wireless sensors and its context to infer patterns/anomalies and determine if corrective action should be taken. It may be impractical to have a full, accurate asset tracking system in most factory environments due to cost, complexity and the RF environment but data from other sources can be used to determine likely location of the asset &/or detect anomalous behaviour. For example, expensive material or components moving suddenly or unexpectedly when there is no evidence in the system that such movement should be underway. Other methodologies are also realisable, e.g. lack of detection of motion means that a sensor tag has remained in the same location as where it was previously detected (e.g. bar code scanned). Adoption of indoor location tracking solutions will be a slow process which will be driven at first by the desire to track high value assets as the cost-benefit analysis is clearer. In future as the technology scales and matures it will be fitted to more common assets.

3.1 Purpose, context and scope of this deliverable

As outlined in D2.1 BSL experience the following challenges in management of material flow in the manufacturing process:

- Inventory mismanagement (location, misplaced, quality, quantity, mislabelled, obsolescence)
- Whether clusters of components go missing; and to find out if vendors are short-shipping deliveries
- Batch processing causing missing or misplaced batches
- Production stop due to delay of getting components from inventory to the Production Units (PU)
- Monitoring the parts on the machine
- Tracking expensive material from stores to product use
- Implementing sensors onto BSLs most expensive components and tracking factory throughput using sensors

Last year, BSL recorded 900k$ worth of scrap due to missing or damaged materials. The causes of this loss are many, but mostly known. The number of components delivered on reels is not always in conformity with the nominal specs; mostly there are fewer components than what is indicated and paid for. Components are also lost or damaged during reels' replacement, or simply misplaced during set-up.

Delays in bringing components from inventory to the Production Units (PU) occur because components suddenly run out or the inventory staff is not readily at hand or busy. This causes the production to stop until the needed components are present. Work in progress downstream is then stored; waiting for the process to continue.

Batch processing in e.g. cleaning or burn-in requires operators to assemble products in batches (in baskets or trays). Sometimes some of these baskets or trays get misplaced or moved to other positions in the plant without a record.

Many of these scenarios can be descried as 'physical security' issues in the context that material, devices, fixtures, baskets etc. that are subject to undergoing movement are lost, misplaced, wasted through miss-feeds, miscounting, short shipping, etc. Apart from the direct financial impact (value of the material/asset) there are other significant indirect financial impacts due to machines unexpectedly being short of components, test fixtures going missing and disrupting, production, etc. The use of ICT to track such assets can help reduce many such misplacements and can also potentially narrow down the time and location where anomalies arise creating a greater level of vigilance amongst operators. (Further details can be found in D2.1).

This state of the art review outlines a number of potential solutions or at least partial solutions to the materials use case. Similar methodologies can be applied for other 'physical security' applications. The specific deliverable tasks for this project (UC-BSL-3) follow in section 4. The use case requires a method to track high-value assets across the factory. This needs to be combined with software which should offer a visualization of the asset locations on the factory floor, as well as a methodology for loss determination.

The initial high-level specification will be mainly based on the results of the questionnaires received back from the industry partners and will be further refined as the partners collectively 'learn by doing'. The topics covered are a prior art/ state of the art technology assessment in this area & a viable specification for asset tracking for the use case. What we learn from this and future testing will be incorporated into D4.7 - Development and Installation of a WSN Physical Security System.

3.2 Content and structure of this deliverable

The prime motivator behind this collaboration is physical security detection; a large part of which is the desire to track high-value assets. This state of the art review will firstly examine the general principles employed in indoor location tracking. These general principles can be found in most technologies which aim to offer a solution to this problem and so are covered initially before the specific technologies are described. This includes a quick run-down of the standard itself, then some solutions found are discussed and examined for their suitability to the use case tasks.

This is then only a partial solution to the problem; a variety of sensors can be added to the system for physical security detection and determination: accelerometers to detect movement (e.g. drops, re-locations) of assets, occupancy to detect human presence, etc. Sensors can even be employed to improve the accuracy and robustness of an indoor tracking system. Since a wide variety of sensors can be implemented for the physical security use case a selection of several widely-used, relevant sensors are covered here briefly.

Energy harvesting which can be used in extending the life of wireless sensor nodes can be implemented in many applications. The need for frequent replacement of batteries is one of the biggest impediments to the wide scale use of wireless sensors. Because of this and the activities by COMPOSITION partner Tyndall to use energy harvesting to resolve this issue for such use cases, it will be examined in this review. Finally, a rough high-level specification is laid out which will guide testing and implementation of the WSN physical security system.

4 INTRA-Factory-3 Use Cases: Material Management

Boston Scientific is an international medical device developer, manufacturer, and marketer, whose products comprise of a wide range of speciality medical devices. This particular Boston Scientific facility in Clonmel, Ireland involved in COMPOSITION is primarily responsible for the manufacturing implantable pacemakers, ICDs (Implantable Cardioverter Defibrillators), and CRT-Ds (Cardiac Resynchronization Therapy Defibrillators). These go on to supply hospitals and health clinics in nearly 100 countries. Due to the very serious nature of the application, each device must undergo the most intense scrutiny with thousands of tests being performed on each device during manufacture and before being shipped. Manufacturing medical devices such as these is an intricate and intensive task, and this is carried out specialised equipment such as pick and place machines, reflow heaters, encapsulation machines, laser welders, etc. which cover the factory floor. The factory floor is treated as an ISO class 6 clean room to reduce sources of failure due to particulate contamination. It is a pressurised at 2 bars, workers constantly wear protective equipment and the air is heavily filtered and conditioned.

It is desired that high-value assets needed around the factory floor be tracked as they move around the facility as a physical security measure. The assets include high-value reels of components for the pick and place machine, bags of valuable metals such as palladium, test equipment, and PCBA batches in progress. A list of assets that need to be tracked has been provided here. The assets are spread across various production cells (units) in BSL.

Asset	**Associated Production Unit**
PCB - Springboard	PCBA Laser Mark
UHIGH	Siemens pick and place
ASIC FINE PITCH BGA	Siemens pick and place
ASIC BGA	Siemens pick and place
Cores	OM - Core assembly
Connector Blocks	OM - Core assembly
Caps	Electronic assembly
Cell	Electronic assembly

Table 2. List of Assets to Track

The following figure (Fig.1) is intended to give an idea of the general layout of the BSL facility. The production units highlighted in green give an idea of how dense this area of interest is. This is important as these will be the areas where tracking will be most desirable.

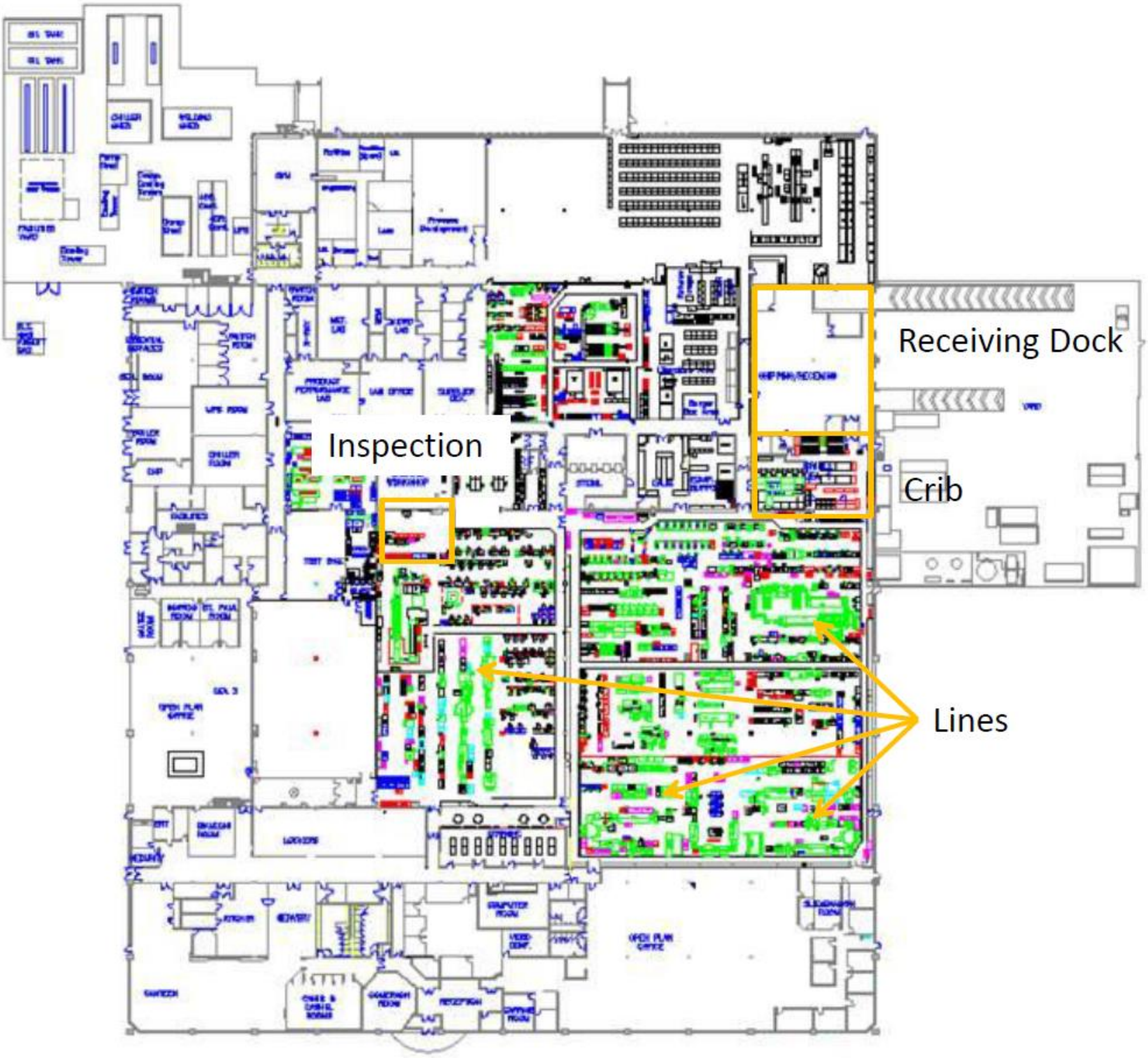

Figure 1. Floor Plan of Boston Scientific

Figure 2. Example of a component reel

The following are excerpts taken out of COMPOSITION deliverable D2.1 which contains all the tasks and deliverables for COMPOSITION. These are the tasks that are intended to be dealt with using the specification outlined in this state of the art review.

4.1 UC-BSL-3 Component Tracking

ID **Name**	**UC-BSL-3** **Component Tracking**	
Actors	• Visualisation Screen	
Actor goals	The goal of the Visualisation Screen is to display all components with their location.	
Pre-conditions	Components are delivered to the back door of BSL, are moved through the factory and are finally consumed by the Pick and Place machine on the production floor	
Trigger	An expensive component enters or moves within the factory.	
Post-conditions success	Components are tracked and a database is updated with the new data obtained from the tracking. All components should be visible on the Visualisation Screen.	
Post-conditions fail	Components could not be tracked and go missing. Database is not updated correctly. Components not visible on the Visualisation Screen.	
Description	**Step**	**Action**
	1	Sensors detect a component has entered the factory or moved within the factory.
	2	The sensors send component location data to the system.
	3	The system updates a database with the component location data and the time the data was obtained.
	4	The current component location data is visualised on the Visualisation Screen.

Table 3. UC-BSL-3 Component Tracking

5 State of the Art Review

The primary problem for the use case involves indoor location tracking of components so the methodology of Real Time Location Systems (RTLS) will be examined. The following have been used as general sources of information in writing this review: (Liu et al., 2007), (Liu et al., 2012), (Gu et al., 2009), (Malik, 2009), (Xiao et al., 2016), (Yassin et al., 2017), (Baharudin and Yan, 2016), (Deng et al., 2013), (Hightower and Borriello, 2001), & (Boulos and Berry, 2012). Detailed references available in section 8.

5.1 Wireless Indoor Real-Time Location Systems Basics

A Real-Time Location System (RTLS) enables a user to track, manage, analyse, and utilise the location information of assets. It is very clear how valuable an accurate & reliable RTLS technology would be to a wide variety of industries; from healthcare, construction, retail, businesses and manufacturing etc. In this case, the main focal area is factories. Tracking assets across a factory floor is one of the end goals of this project and so this is the type of technology which will fulfil the use case concerned with tracking in section 4.

There is huge potential value in RTLS but the key factors in this situation are improved material & asset management as well as loss/miss-location prevention. An ideal system would optimise the deployment of the asset (e.g. raw materials, equipment) for efficient operation by ensuring the asset is always where it is needed. Alerting the appropriate staff when the asset travels to an unexpected location could dramatically improve loss prevention and reduce direct and indirect costs.

There are different levels of RTLS that can be provided that vary in complexity, the amount of infrastructure required, and accuracy that can be provided:

Presence-based locating:	RTLS returns whether a tag is or is not present in the tracking area.
Locating at room level:	RTLS returns in which room a tag is present.
Locating at sub-room level:	RTLS returns the location of a tag down to a specific part of a room.
Locating at choke points:	Tag location is determined from observing tags moving through ‘choke points’ (doors, entryways, and exits) assuming the only paths that can be taken go through these choke points.
Locating by associating:	Tag location is returned as a proximity to another tag.
Locating precisely:	RTLS returns the measured tag location in 2D/3D space and overlays on a map of the tracking area.

Determining the best balance between the level of detail returned by the RTLS system and the complexity and infrastructure required is very important. A precise location system may be wasted if all that is necessary is to know if a tag is or is not present in a certain location. Every attempt to simplify the architecture to minimise costs and power consumption for energy harvesting compatibility should be made.

At the current point in time due to the immaturity of this technology there are a plethora of competing technologies and methods which attempt to provide a solution to indoor location tracking. The different types of RTLS all use wireless signals to determine the distance between 2 or more points e.g. Light (Infrared, camera vision), Sound (Ultrasound), or Electromagnetic waves (RFID, WLAN, and Various RF based technologies). Most RTLS work on quite a simple principle (there are many exceptions, but the basics will be covered initially). The objects being tracked are called ‘tags’, which themselves are a transceiver with a unique ID. To track these tags several transceivers called ‘anchors’ are set up with fixed positions in the tracking area. For systems that only require proximity localisation (room, sub-room level) it is only required that a connection is made between tag and anchor to determine that the tag is located in some proximity to the location of that anchor. For precise indoor tracking of position more complex methods must be employed.

Based on the geometric properties of triangles, triangulation is the standard localisation algorithm to determine the location of an object or tag in relation to the set of anchors that we assume can communicate wirelessly with the tags. Triangulation can be divided into trilateration and angulation. Trilateration is the range based method and using one of the many RTLS technologies discussed in this review, it should be possible to get the radial distance of an object from some fixed anchor point. If the distance from 3 or more separate anchor points is known then a simple algorithm can be used to find the approximate location of an object.

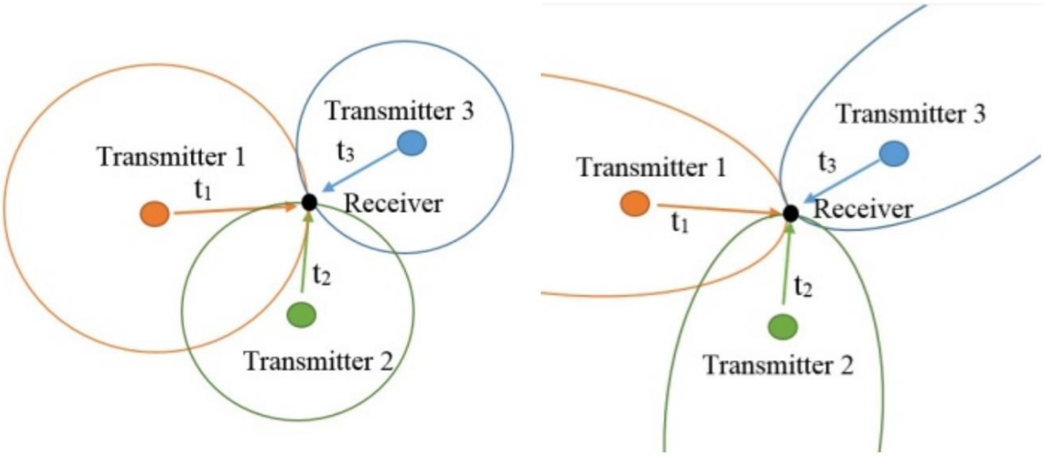

Figure 3. Trilateration based location sensing, TOA (Left) and TDOA (Right) (Mišić et al., 2015)

There are a few different sub-methods used in trilateration to get that distance from each anchor point. The most common of these is using the Received Signal Strength (RSS). This is quite simply the relative signal strength as detected by an anchor. Base data on how the signal strength of a tag changes with distance from the anchor can be used to derive an estimate of its distance from said anchor. Another common method is to use the Time of Arrival (TOA) of the signal, knowing the propagation speed of EM signals being the speed of light and acoustic signals being the speed of sound in air, one can work back to find the distance. Similar to this is Time Difference of Arrival (TDOA) which uses the difference in the time of arrival between several beacons which can offer more accurate and reliable results than the RSS technique in real world applications. This is due to the very unpredictable nature of how signal strength decays in an indoor environment due to reflection, diffraction, and scattering. The time of propagation of a signal is simply dependant on the speed of the signal (light speed) which is constant.

Another triangulation based method is angulation where the received signal parameters can be used to determine the incident angle of the signal itself. This can be done through the Angle of Arrival (AOA) method where there is an array of antennae in the anchor. The time of arrival or the phase of the signal that reaches the first antenna is measured and compared with the time of arrival at the second antenna and so on. If this difference can be accurately measured then the angle of arrival can be determined. If the signals are exactly the same then the direction of propagation must be perpendicular to the direction of the antenna array. The greater the time or phase delay between the received signals at the antennae then the greater the angle of incidence.

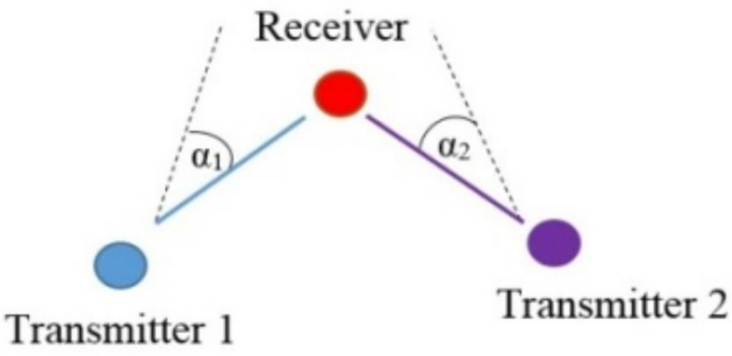

Figure 4. Angulation based sensing (Mišić et al., 2015)

In order to connect all the anchors and process the data being received by them, there can be many approaches to this. One common way is to have the anchors communicating with a central location-engine to perform the algorithms to determine the position of each tag within the tracking area. This takes the form of a computer running software which itself will interface with a dataset containing a list of all the current tags and their location, updating every time a new position update arrives from a tag.

Another approach to this may be to perform the algorithms on the tag which is usually done when the tracked object is a smart device such as a mobile phone where computation power is not a concern. Instead of sending out a signal to the anchors the tag/phone waits for signals from the anchors and uses any one of the methods mentioned above to calculate its own position in the indoor space.

5.1.1 RTLS Characteristics

The main aspects that are considered when comparing indoor positioning systems are as follows. These will be the main characteristics that will be examined to distinguish the relative performance of one existing solution over another.

Accuracy

Accuracy is the most important metric by which we judge positioning systems. How the error of positioning systems such as these is determined is by calculating the average Euclidian distance between the estimated location and the true location of an object. While generally the more accurate the system the better, often there may be trade-offs between accuracy and other characteristics such as complexity, cost, power consumption, scalability, the infrastructure required, etc. Because of this there needs to be some sort of compromise between suitable accuracy and other factors.

In determining accuracy of location systems, we only consider the value of mean distance errors. Precision looks at how consistently the system works and so is a much better indication of how robust it is. This is done by looking at the error distribution of the distance error between the estimated location and the true location measured over many different trials. This data would then form a probability distribution which can be used to compare the precision of systems.

Complexity

The complexity of RTLS can refer to either the hardware, software, or operation of the system. This review will mostly consider it as the computational complexity of the positioning algorithm. Each different method such as RSS, TOA, TDOA, etc. uses different algorithms to turn the raw sensed data (signal strength, time of arrival) into a position in 2D or 3D space.

If the location algorithm for each tag is performed server side the complexity is usually not an issue. It is only in cases where the tag processes the data itself where this can be a problem. Tags ae usually fitted with quite low-power microprocessors which may not handle highly complex algorithms quickly enough. This would give a low maximum location rate if the complexity is too high. If a high frequency location rate is desirable for this setup a low complexity algorithm is required to minimise average processing power.

Robustness

A highly robust localisation system is one where the system is mostly unaffected by the unavailability of some signals, or some received signals making no sense in the context of the system. Sometimes a receiver may be blocked temporarily or intermittently by something (e.g. people, assets, machinery, etc.) moving around. It is very desirable to have a system where something like this does not crash the system and it can work with incomplete information. Another sort of disturbance may be introduced from EM interference in the surrounding environment which can come from a wide variety of sources (mobile phones, thunderstorms, the Sun, etc.). A high level of noise such as this may reduce performance to a varying degree from increased transmission error rate to total loss of data. Again, a robust system would not be totally dysfunctional (to an extent) under such conditions.

Scalability

Having a positioning system that is scalable means that the operation remains the same from the smallest level to the largest, i.e. tracking a single tag in a small room has the same operation as tracking thousands around a large factory. Scalability covers two distinct properties; geographical scaling and density scaling. Geographical scaling deals with the area or volume that tags may be tracked, whereas density scaling deals with how many tags can fit into the tracking area. Increasing the density can cause the wireless signal channels to become congested, thereby more RTLS infrastructure is needed and more calculations need to be performed per second to track every tag.

Cost

The cost of an indoor positioning system should include not only the system itself but the costs associated with the time taken to install and maintain it and the space it occupies. With some technologies, there is a trade-off between achievable accuracy and the amount of infrastructure necessary. Some methods may require a large amount of infrastructure in order to get the best possible accuracy, and others may require very little and perform equally as well. The effort required to maintain the system is another factor of cost. Regular maintenance of a lot of tags could be a time-consuming process and would cost time in order to keep up (& related cost).

Power Consumption

Since this is a wireless system any active tag must need a power source, usually in the form of a battery. Ideally, the battery in a tag would be small (coin cell) and last several years. This is to be as unobtrusive as possible. If the active tag consumes a lot of power the tag's battery would need to be changed often which would be unmanageable for a system with thousands of tags. Or the battery size would have to be increased making the form factor of the tag bigger which is also undesirable in most cases. Again there are trade-offs associated with reducing power consumption including reducing location rate, complexity, and range.

5.1.2 RTLS Challenges

Despite 20 years of work on RTLS there are still numerous challenges to be faced (Gaffney, 2008). A subset of the most pressing issues is discussed here.

Tag Density

The number of tags in a small area or network cell is an important factor. For some applications such as asset tracking the number of tags in any given area will vary and having a large number of tags packed densely could be a challenging task for some positioning systems. This is largely due to the number of packets receivable by an anchor in the blink period (interval between sensing) is less than the total number of tags. To alleviate this problem high data-rates of transmission are needed as well as short packet lengths.

Battery Life

Battery life is another big concern. Ideally, tags should consume a very small amount of power so that they may be run with a small form factor battery (e.g. coin-cell battery) for a number of years depending on the desired application. Most systems if using a coin cell battery only last several months, this would be a big problem for a large-scale tracking system with many tags since it would involve excessive maintenance to replace all the batteries so regularly as well as imposing reliability risk (battery depletion and tags not operational as a result). This highlights the need for the system to be as unobtrusive as possible to the tracked processes.

A potential solution to the problem of short battery life would be to introduce energy harvesting solutions to this area. Covered in section 5.3 energy harvesting involves using ambient energies such as light, vibration, or heat and converting them into useable electrical power in order to extend the battery life of low-power wireless devices, usually wireless sensor nodes. This is a novel approach to this problem as no similar solution (for RTLS applications) could be found in the prior-art.

Channel Environment

The most significant challenge to any indoor tracking application is the channel environment. Most environments provide a great deal of interference resulting in greatly reduced received signal strength and impulse response as the transmitter travels further away from the receiver. This hampers the range and performance of RTLS noticeably. Concrete walls and metal structures & objects provide the biggest sources of interference, commonly found in most industrial environments. This adds an extra challenge in terms of system design.

5.2 Breakdown of Existing RTLS Technology

This section runs through existing technologies in RF based indoor RTLS (ref. fig. 5) that are based on the principles previously outlined. A brief insight into how they work and the benefits and drawbacks of each technique is discussed. Incorporated into the analysis is an examination of existing commercial solutions which can give an insight into the real-world performance. In many cases, real world performance data is not available and is instead based on testing in optimal conditions with Line-of-Sight (LOS) from tag to anchor and nothing that could cause interference or multipath effects. In cases where the testing environment is not stated it is assumed this is under optimal conditions. In reality performance levels will be significantly worse in real life applications and in many cases careful deployment site characterisation is desirable.

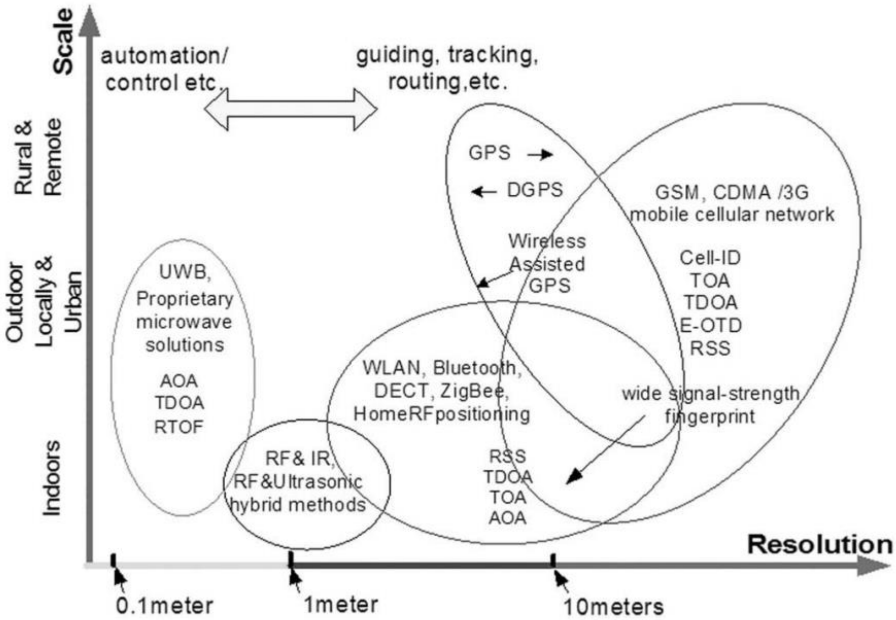

Figure 5. Outline of current wireless positioning systems (Liu et al., 2007)

5.2.1 RFID

Radio-frequency identification (RFID) utilises electromagnetic fields to identify and track tags with unique signatures that are attached to objects. The tags have information stored on them electronically which uniquely identifies each one. There is two main types of RFID tag, (i) passive and (ii) active. Passive tags make use of interrogating waves from a reader by modulating and reflective the waves themselves in order to operate 'powerlessly'. A passive tag is cheaper and smaller due to the lack of a battery. However, to operate a passive tag it must be illuminated with an EM signal roughly a thousand times more powerful than is used for signal transmission. This makes a major difference in terms of read distance possible for a passive tag. Active tags do have a local power source such as a battery and can operate much further away from the reader than a passive tag. An active tag periodically transmits its ID signal and may be read as far as 100m away whereas the maximum read range of a passive tag is typically less than 2m. Active RFID also has the advantage of small antenna size. Unlike the barcodes that it intends to replace as an identification method, the tag does not need to be within line of sight of the reader, so it may be embedded in the tracked object.

Lots of work has been done on RFID as an indoor positioning technology, mostly using active tags. There are various active RFID methods which use RSS analysis to determine position. These include SpotON (Hightower et al., 2000), LANDMARC (Ni et al., 2004), and VIRE (Zhao et al., 2007), as well as commercial solutions such as OMNI-ID's Power 100/115[1]. In general, these methods have decent accuracy, over a range of around 100 metres an accuracy of between 2 to 5 metres has been achievable. These methods are intended to suit tracking high value assets in harsh manufacturing environments meaning robustness is a key attribute although it is still susceptible to multipath & NLOS (no line of sight) effects. Low cost is another advantage this would have over other such systems; tags are relatively inexpensive (typically €5). The complexity of the RSS aggregation algorithm employed in the above methods can be an issue, where lots of RFID tags may be necessary to achieve a reasonable level of accuracy.

^1 - https://www.omni-id.com/pdfs/Omni-ID_Power_100_datasheet.pdf

5.2.2 UWB

Ultra Wide Band (UWB) uses a much larger bandwidth compared to other RF RTLS technologies. UWB systems are defined by the IEEE 802.15.4-2011 standard. The Federal Communication Commission (FCC) has defined UWB systems as those which have an absolute bandwidth larger than 500MHz and central frequency larger than 2.5 GHz, or have a fractional bandwidth larger than 0.2 for systems with a central frequency lower than 2.5GHz (Commission, 2002). In order to make UWB coexist with other wireless technologies, the power spectral density of UWB signal is limited and must not exceed -41.3 dBm/MHz for frequency ranges from 3.1 GHz to 10.6 GHz. Due to its large bandwidth property, UWB radio offers various advantages for the design of indoor localisation system.

UWB signals use short pulses. As a result, pulses belonging to different multipath reflections tend not to overlap in time. Therefore, the pulses do not interfere with each other and individual paths tend not to fade, unlike narrow bandwidth signals whose multipath components always overlap and incur fading, e.g., Wi-Fi, Bluetooth and ZigBee. UWB systems typically have top class range and accuracy. Large signal bandwidth, and consequently, the fine time resolution of UWB signals has the potential of achieving centimetre level ranging accuracy through signal TOA measurements (Sahinoglu et al., 2008). Low cost and low power transceiver circuitry are also achieved by this method. UWB operates in baseband modulation (Karapistoli et al., 2010) . A baseband signal can be transmitted without a sine wave carrier (almost "carrier-free"), which facilitates low cost and low power implementation. No Line of Sight (LOS) requirement is needed either. Less interference, higher penetration ability can be achieved compared to other wireless methods.

There are currently a wide array of commercial RTLS systems available that utilise UWB from companies such as Ubisense [2], Decawave [3], Zebra [4], Time Domain [5], & many more. The big advantage is the very good accuracy and precision possible as well as very low power consumption. The systems from the companies above typically reach accuracy as low as 15-30cm with very high precision, ideal for real-time indoor positioning. The low power consumption (in the range of 100's of µW) of UWB tags compared to other positioning technologies allows for longer battery life with smaller batteries, also giving the added benefit of smaller form factor.

Although promising, UWB is not without drawbacks. It is slightly more expensive than most systems, and scalability and robustness have also been found to be an issue. Despite this, it does seem to be the most widespread technology in terms of commercial systems. Several high-profile car manufacturers such as BMW, VW, Audi & Aston Martin use Ubisense's smart factory system as their RTLS solution of choice [6].

^2 - https://ubisense.net/en/products/Dimension4

^3 - http://www.decawave.com

^4 - https://www.zebra.com/us/en/solutions/location-solutions/enabling-technologies/dart-uwb.html

^5 - http://www.timedomain.com/#

^6 - https://ubisense.net/en/products/smart-factory

5.2.3 Bluetooth Low Energy

Bluetooth Low Energy (BLE) is a wireless technology developed by the Bluetooth Special Interest Group (SIG) and released with Bluetooth 4.0 which is aimed towards short range communication. BLE has been specifically designed with low-power control and monitoring applications in mind. The pervasive use of Bluetooth in modern mobile technology, (in mobile phones, laptops, headsets, cars etc.) give it an upper hand on technologies such as ZigBee & Z-wave in the area of low power, short range communications and interoperability since it is already such a widely used standard.

BLE uses the Industrial Scientific Medical (ISM) band which ranges from 2.4GHz to 2.4835GHz with 40 RF channels and 2MHz spacing between each channel. Since many different technologies operate around this frequency, such as Wi-Fi, methods have been created to overcome most interference that would arise. The newest Bluetooth versions feature Adaptive Frequency Hopping techniques (Golmie et al., 2003). This is done by pseudo-randomly hopping between channels at a rate of 1600 times per second with connected devices sharing a channel map that will be negotiated. If collisions are detected in certain channels due to other communications in the ISM band these are excluded from the list of available channels.

Because of its low power and short communication range BLE can be more suited to a proximity based systems, locating at a room or sub-room level. Bluetooth has a special proximity profile [7] built in which is designed specifically for short-range estimation between connected devices, and alert generation when the connection is dropped.

Low power consumption is achieved by several characteristics of BLE. It has a low peak power consumption during transmission, short packet lengths are used, and low duty cycle to reduce the number of transmissions. In (Gomez et al., 2012) lifetime of a TI CC2540 tag has been shown to be close to 1.8 years for a connection interval greater than 4 seconds, with an average current in the range of 10-20 µA.

In (Bae et al., 2016) a BLE tracking system is demonstrated for navigation of a hallway. A positioning accuracy of 1m was demonstrated with a pair of anchors placed roughly every 5 metres. This was improved to 0.6m using sensor fusion techniques with optical, magnetic and gyroscopic sensors. It was noted that the raw BLE signal is too sensitive during motion and reacts poorly to obstacles in the building, suggesting a lack of robustness and a necessity to add other sensors to aid the technique. This of course adds complexity for added robustness and accuracy.

^[7] - https://www.bluetooth.org/docman/handlers/downloaddoc.ashx?doc_id=239392

5.2.4 WLAN (Wi-Fi)

Another very popular technology and due to its widespread use there has been lots of work done in attempting to reuse existing Wi-Fi infrastructure to create RSS positioning systems. Based on the IEEE 802.11 standard WLAN is a dual band technology which can operate in the 2.4GHz band which it can share with Bluetooth among others, or the 5GHz band if interference with other systems is to be avoided. One big advantage to using WLAN is the relative maturity and huge amount of infrastructure readily available since this means very low implementation cost.

One such method that has been created is RADAR (Bahl and Padmanabhan, 2000). Developed by a Microsoft research team, RADAR employs a Nearest Neighbour in Signal Space (NNSS) location algorithm, based on Received Signal Strength (RSS), which can provide 2D position information which can be employed for location based applications. WLAN positioning systems such as these typically do not have a high level of accuracy due to the instability of the signal strength indoors caused by multi-path reflections and interference. Due to this, a 'fingerprinting' technique is often used with WLAN to improve performance. Fingerprinting as used in Horus (Youssef and Agrawala, 2008) & Ekahau[8] is a technique that characterises the RSS values from anchor points at locations all over the tracking area. This is stored in a database, and when a tag is being tracked it compares the RSS values it measures and the closest fit from the database. This proves to be more accurate than standard RSS methods, although in cases where there are people and objects moving around the tracking area this can throw off the measurements due to changes from the calibrated setup. The accuracy achieved is between 2 – 5m for the purely RSS methods (Liu et al., 2007), while fingerprinting such as (Kotaru et al., 2015) has demonstrated an accuracy of 0.7m in an office setting. Whilst promising, scalability could be an issue for some applications; having hundreds or even thousands of tags in an area would clutter the already heavily utilised 2.4GHz ISM band and interfere with Wi-Fi networks.

^[8] - https://www.ekahau.com/

5.2.5 ZigBee

ZigBee is a low-power wireless network standard that is targeted at the development of long battery life and low-cost devices. ZigBee, as with a few other wireless technologies, operates in the ISM band. It can use either 2.4GHz or 868MHz and communicates with a very low data rate as per the 802.4.15 specification for low power WPANs. It is a simple but quite flexible protocol that allows for high throughput and low latency when implementing applications with long connection intervals.

ZigBee has a number of advantages in the area of RTLS (Malik, 2009). There is a very large network capacity for ZigBee, supporting as many 65000 nodes in a network makes it very scalable. Low latency allows quick, real-time location of tags. It also allows for very good performance in harsh conditions, as the 802.4.15 standard allows for steady operation in low SNR environments. An example implementation (Fang et al., 2012) demonstrated good accuracy even under harsh noisy conditions. The low cost of ZigBee tags, as well as the excellent energy efficiency of operation (low transceiver power consumption, & near zero in standby) make it a very attractive technology to use to implement RTLS.

There are a few limitations found using ZigBee for indoor tracking. Similar to BLE and WLAN it has a reliance on RSS techniques covered previously that suffer from problems due to unpredictable environmental effects (obstacles, multipath fading, human movement, etc.). Also operating in the ISM band means possible interference with and from other ISM band technologies particularly in the commonly used 2.4GHZ band.

5.2.6 LPWAN (LoRa)

Low Power Wide Area Networks or LPWAN focuses on providing large cells for low-power battery-driven IOT devices. The driving force behind the creation of this type of wireless communication was to allow long range, low bit-rate communications between these devices which would be instrumental in the creation of a large-scale sensor network for the internet of things. LPWAN networks typically have a range of about 10km, a maximum bit-rate of about 1-50 kbps, and operate in either the 433MHz or 868MHz ISM bands (for Europe). It can also be used for indoor applications. Since this is quite a new idea there are presently a number of competing standards. Among the most promising of these standards is LoRaWAN which was created and is maintained by the LoRa Alliance [9].

Although there are no commercially available LoRa indoor positioning systems at present a number of recent studies have been done on the potential this technology has in this area. Using an RSS method to determine position in a LoRa network has been tested (HENRIKSSON, 2016) to poor results; achieving 8m accuracy within a range of 11m. TOA or TDOA are the likely optimal methods to achieve better results in future although it has been noted that the on-board clock for LoRa Devices is prone to drift making this unfeasible in the previous study. LoRa has released a new specification which allows for TDOA localisation of devices. The accuracy of this technique has been claimed to be down to about 15-30m for a typical LoRa network with nodes spaced 1.6km apart in a hexagonal layout [10].

^9 - https://www.lora-alliance.org/portals/0/specs/LoRaWAN%20Specification%201R0.pdf

^10 - http://www.scoop.it/t/the-french-wireless-connection/p/4053105090/2015/10/08/location-enabled-lora-iot-network-geo-lora-ting-your-assets

5.2.7 Inertial Navigation

It is possible using an Inertial Measurement Unit (IMU) to estimate the position of a tag using measurements taken by a combination of on-board MEMS gyroscopes, accelerometers and magnetometers. Many companies and groups have employed inertial sensors for motion tracking applications. In (Harle, 2013), some work on inertial navigation were surveyed. The accuracy of these inertial navigation systems using MEMS sensors ranges from 0.62m to 1.321m. In (Pittet et al., 2008) MEMS inertial sensors are used to track the human motion in indoor environments. The pure inertial navigation algorithm is used to compute the position. The error grows with time ranging from one metre to several metres.

It is possible and desirable to create a hybrid RTLS and IMU system. The benefit here being that the IMU would be able to provide location information when RTLS measurements are not able to be made in cases where the tag would exceed the range of the system or where severe NLOS conditions are present, and the RTLS corrects the estimated position drift from the IMU. These systems can be loosely coupled where the RTLS and IMU perform independent estimates of position. These measurements are fused to get a final position estimate. A loosely coupled UWB & IMU system has been tested in (Youssef et al., 2011). Here an extended Kalman filter was applied to compute the final result from the 2 sensors. This method was able to achieve an accuracy between 0.7m - 2.8m. In tightly coupled systems such as in (Bellusci et al., 2010), the raw sensor measurements from the inertial sensors and the UWB receivers are directly used for sensor fusion. In this case, the positioning found was about 10cm in accuracy.

Implementing something like this would be classified as sensor fusion which is discussed further in section 5.4. This will be looked into in defining a detailed specification for the asset tracking implementation as it appears the most promising solution in terms of accuracy, and power consumption as well as having strong robustness and decent scalability.

5.2.8 Comparison of Technologies

Below a table comparing each method using the metrics outlined earlier is outlined. This is devised to more easily see and understand the benefits and drawbacks of each technology relative to each other. The rating under a heading is taken by giving the typical accuracy/robustness/complexity/etc. of a method since slight variations may arise in sub-methods but this table is designed to give a general idea of performance. Where the ratings can be defined numerically they are given in table 5.

Wireless Technologies	Accuracy	Range	Complexity †	Scalability †	Robustness †	Cost	Power Consumption*
Active RFID RSS	3	3	3	4	4	3	3
Passive RFID (proximity only)	4	1	4	1	3	3	5
UWB	5	3	3	3	2	3	5
WLAN RSS	3	2	4	3	4	5	3
WLAN Fingerprint	4	2	3	3	2	5	3
Bluetooth	3	2	4	3	2	4	4
Bluetooth & IMU Fusion	4	4	2	3	4	4	3
ZigBee	4	2	3	4	2	4	4
LoRa	1	5	4	5	2	n/a	4
Inertial Sensor IMU	4	4	2	3	3	4	4
UWB & IMU Fusion	5	4	2	3	4	n/a	4

Table 4. Comparison of Indoor RTLS Technologies

Rating	Accuracy	Range	Cost	Power Consumption*
5	<0.5m	>200m	<1k€	<1mW
4	0.5m – 2m	50m – 200m	1k€ – 10k€	1mW-10mW
3	2m – 5m	20m – 50m	10k€-30k€	10mW-100mW
2	5m – 15m	5m – 20m	30k€ - 100k€	100mW-1W
1	>15m	<5m	>100k€	>1W

Table 5. Reference Value Table

[*] - Power consumptions can be significantly reduced through duty cycling, i.e. sensing and sleeping between sense modes. For energy harvesting compatibility would need to reduce to sub-mW for most applications.

[†] – Ratings could not be backed up numerically and instead have been designated based on informed opinion.

5.3 Power Saving Techniques

As mentioned in section 5.1 power consumption is a critical issue for RTLS. So, techniques that may reduce that power consumption or increase battery life by various means is desirable. A wireless sensor network (WSN) such as the proposed tracking systems above are only as reliable as the power source. Batteries, when used over a long period of time (e.g. several years), experience current leakages that drain the stored energy even when they are not used as well as potential degradation due to environmental factors. This results in unpredictable lifetime and failure rate of batteries operating at this time scale.

5.3.1 Energy harvesting

The problems associated with long term use of batteries for WSNs give a great platform for energy harvesting (EH) solutions to be implemented to increase sensor lifetime. A sensor node that can depend on energy harvesting as a power source should have a lifetime as long as the electronics used to build it. Using ambient energies to generate power has been used for decades in large scale with solar, wind, hydro, and thermal energy used to generate clean electricity on an industrial scale. Harvesting energy for low power applications gives a different challenge as the energy harvesting device has to be comparably small to fit the device. At present among the main relevant sources of ambient energy from which power at this scale can be generated are solar, mechanical (vibrational or strain), and thermal. Further reading on energy harvesting for wireless sensor networks can be found below [11-13].

Solar – The most mature and common of the different energy harvesting methods is solar power, i.e. using photovoltaic (PV) panels to convert incident light into power. This can be done in both indoor and outdoor environments. The effectiveness of solar power harvesting is highly dependent on the potential availability and intensity of a light source for the WSN application. For example, a PV panel illuminated directly by the Sun will generate roughly 100-1000 times more power than the same sized panel under indoor lighting. However, it is likely that indoor lighting is much more consistent and in some cases has 100% availability which is also an advantage. To ensure maximum efficiency in the use of a PV panel in low-power applications it is coupled with a Maximum Power Point Tracking (MPPT) circuit which regulates the output voltage to extract the most power possible. As with any EH implementation, the availability of lighting to the nodes must be carefully examined and modelled before it can be deduced whether solar EH is viable.

Mechanical – Vibrational, kinetic and mechanical energy generated by object movement is another energy source available to WSN energy harvesters. Areas where there is omnipresent vibration due to machinery and vehicles are prime locations for the use of vibrational energy harvesting. These are usually implemented using piezo-electric devices. The piezoelectric effect converts mechanical strain in a material into a voltage or current. This strain is induced in vibrational energy harvesters (VEHs) by hanging an inertial mass at the end of a thin piezo-electric layer. This structure has a resonant frequency at which it would like to vibrate to generate power most effectively, and this resonant point is tightly coupled by design to the frequency of vibration at the application location. This, of course, means the vibration used must be of a nearly constant frequency to generate any significant power via this method. This can also be implemented using electromechanical MEMS (Micro-Electro-Mechanical System) devices, inducing electrical currents through vibrating magnets.

Thermal – Current may be generated by a temperature difference between two terminals of a conducting material. The availability of thermal differences or gradients can therefore be utilised to generate electricity. The devices built to harvest this energy are called thermoelectric generators (TEGs). The ready availability of locations in industrial environments where temperature gradients are present makes this a very attractive technology for many applications. The power that can be generated depends heavily on the difference between the temperatures at the terminals of the TEG.

It is possible based on the application environment that any one or even a combination of the above can be used to power wireless sensors like the RTLS tags discussed in previous sections. Even if the device cannot be fully powered from energy harvesting, it could at least extend the life of a battery if a hybrid EH and battery power source is used. Some considerations that need to be made before implementing these techniques are the availability of the associated energies in the application environment and the potential added bulk of an EH system on top of the RTLS tag.

^[11] - https://www.tyndall.ie/energy-harvesting

^[12] - http://www.sciencedirect.com/science/article/pii/S1364032115012629

^[13] - http://www.machinedesign.com/iot/7-signs-now-time-energy-harvesting

5.4 Sensor Fusion

In examining prior art solutions, it has been recognised that the current state of RTLS technology may not be robust or reliable enough to deliver a satisfactory solution to the use case. However additional sensors may be useful in determining the instances of damages and loss with regards to physical security and some sort of event handling system that would need to be designed. A coupling of RTLS and a number of sensors may be the ideal solution. One example of this idea of 'sensor fusion' has already been covered in section 5.2.7 in which a hybrid RTLS and Inertial Measurement Unit is discussed where the IMU offers location estimates in cases when connection to the location system is unreliable or lost completely.

This sensor fusion methodology is also very useful in the implementation of the physical security detection system. By adding more sensors to the tags a more complete idea of the status of the tagged items may be deduced. As opposed to simply knowing the location of the item a whole new set of contextual data will be available for each additional sensor added to aid the detection of physical security breaches. The design of this system and use of these or other sensors would be unique and tailored specifically to the use case at Boston Scientific. Some types of sensors that may be used are as follows.

Occupancy – Also known as PIR (Passive Infra-Red) sensors, these sensors can detect presence by detecting the movement of objects that give off heat in the form of infrared radiation such as the human body. The PIR itself is made of two sheets of IR sensitive material which produce a voltage spike when there is a change in incident IR radiation. A Fresnel lens placed in front gives the sensor a much wider field of view and so it can usually detect occupancy within several metres with a variable field of view.

Gyroscope – A gyroscope is typically a spinning disc or wheel which maintains is orientation, unaffected by the tilting of the structure it is mounted within. It is able to do this by the conservation of angular momentum. This is useful in determining the orientation of an object. Today this is usually implemented using a MEMS gyroscope which uses vibration to determine orientation. The principle of operation is that a vibrating object tends to vibrate in the same plane even if the support rotates.

Accelerometer – An accelerometer is an electro-mechanical device that is able to measure acceleration in either one or several axes. There are multitudes of methods which can sense acceleration. Among the most common approach for MEMS accelerometers is to utilise capacitive sensing. A moveable electrode attached to a spring is placed next to a fixed electrode. Acceleration of the device causes displacement of the moveable electrode and the capacitance between the electrode and mass is inversely proportional to this displacement. The capacitance here can be measured and used to determine acceleration.

Light – The most common method of detecting light in the surrounding environment is the use of a Light Dependent Resistor (LDR). As the name suggests the LDR is made from a piece of semiconductor material (usually cadmium sulphate) which changes in resistance from several thousand ohms in complete dark to a few hundred ohms under illumination. The incident light creates electron-hole pairs in the semiconductor material which increases conductivity.

Magnetic – Magnetic 'reed switch' sensors can be used in a huge variety of applications that detect the presence of a magnetic field. These are widely used in security applications to determine if a door/window is open or closed. The 'reed switch' itself consists of two loose electrical connectors placed so that they are naturally slightly apart. The presence of a magnetic field causes them to come together and close the circuit. In some cases, it can also be used to detect any attempt to remove a tag if part of the magnetic loop can be permanently embedded into the asset (e.g. glued, screwed or simply presenting a metallic layer that forms part of the loop).

Pressure – MEMS barometers are also available in order to sense pressure of the surroundings. It works by using a membrane to seal a small pocket of air around a capacitive sensor. As the pressure changes in the environment the membrane (usually rubber) deforms, and the deformation can be detected by the sensor. This capacitive reading is then converted to a pressure measurement.

Bar-Code Scanners – Traditionally laser based bar-code scanners worked by connecting a laser to a small rotating prism. This scanning laser goes across the bar-code and a photo-diode detects the reflected light. The photo-diode allows the optical signal created from the dark and light segments of the bar-code to be converted into an electrical signal which can be decoded. Some more modern implementations can employ the use of cameras and image processing techniques to detect bar-codes.

Piezo-Materials – Piezo materials as mentioned in the energy harvesting section generate energy when put under strain. This effect may be useful in detecting tags being tampered with where if someone attempted to peel off a tag that adheres to an asset via some piezo-electric sensor a signal could be generated to detect this tampering.

6 Proposed Specification/System Design

In this section, a specification is outlined generally at a high level as there is much 'learning by doing' to be undertaken. There are still many unknowns as to what will and what will not work in the proposed environment when it comes to WSNs and RTLS for physical security. A disclaimer will be made wherever more testing is required to determine the viability of a suggestion. This can also act as a guide for the project in the coming months, highlighting what exactly needs to be tested in order to come to a final specification and design.

In general, it is critical to understand the process for each use case. This will give a much better understanding of the following:

(i) How often do the sensors activate? This can be determined by whether they are time-based, event-based or a combination of the two. For time-based, a reading is taken at a set interval no matter what is happening around it. This could be every second, 10 seconds, minute, etc. for as long as it is operational. This is quite a dumb method as it does not consider context such as whether there is any activity surrounding the tag, if it is currently being moved, or whether the facility is closed for the night. Event-based sensing uses extra sensors such as outlined in 5.4 to determine events like this and transmit information only when necessary.

(ii) Do sensors need to be active or can they be passive? If there is an opportunity to collect data passively it should be taken to reduce power consumption in the sensor nodes.

(iii) What is the desired use case of a sensor? Will it be for location tracking, physical security detection, or both? This will determine a lot about how the sensor node operates. What types of sensor are needed, how often they need to sense something, etc.

(iv) How the process and infrastructure can be leveraged and harmonised (e.g. data fusion with the MES to understand context and determine where an alert is required, e.g. use of bar code scanning system to provide updated location information of an asset to simplify the RF infrastructure requirements or calibrate the location tracking system)

(v) What are the ambient energies potentially available for energy harvesting solutions in order to increase expected battery life or eliminate the need for battery replacement.

The following diagrams illustrate the steps followed in BSL by materials and components through the factory:

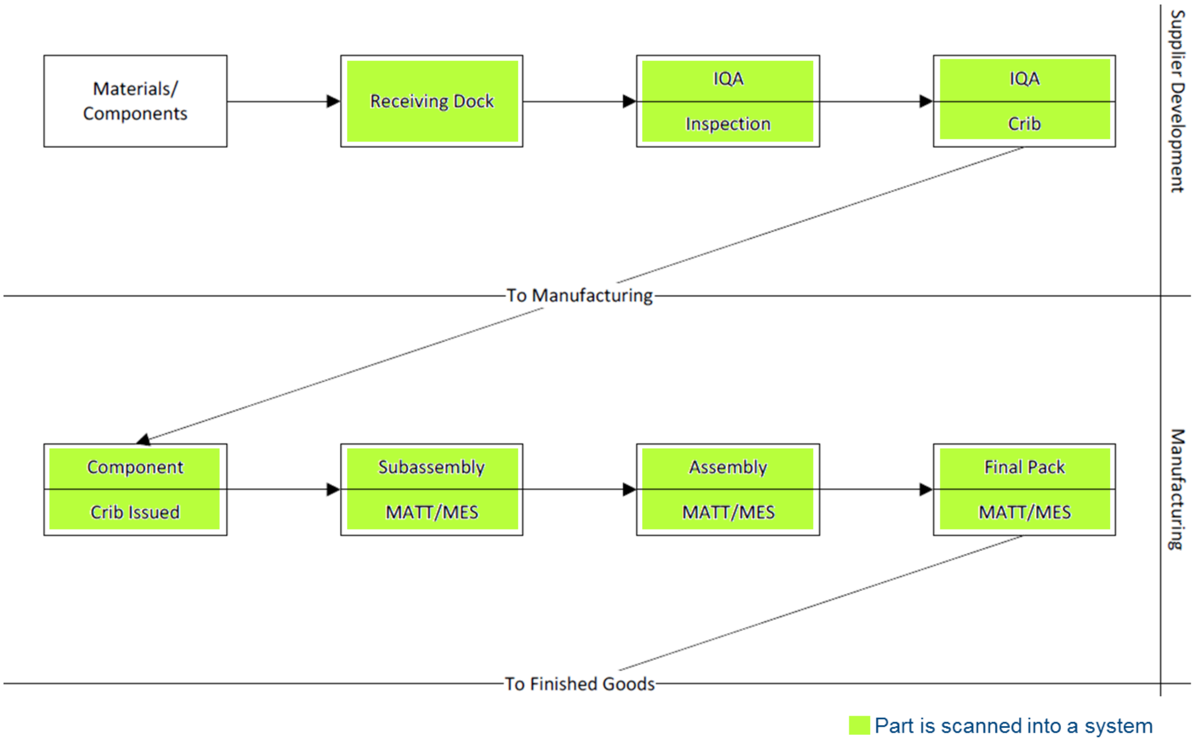

Figure 6. Material Path (I)

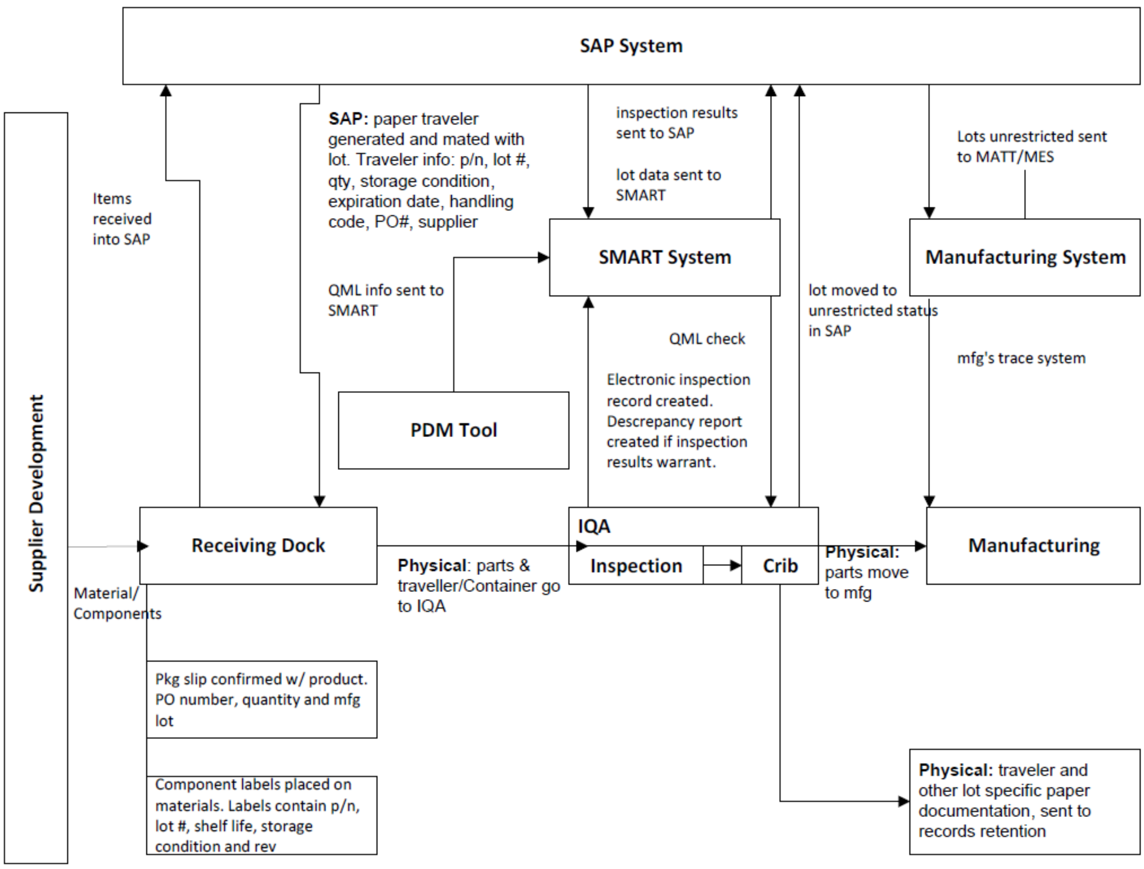

Figure 7. Material Path (ii)

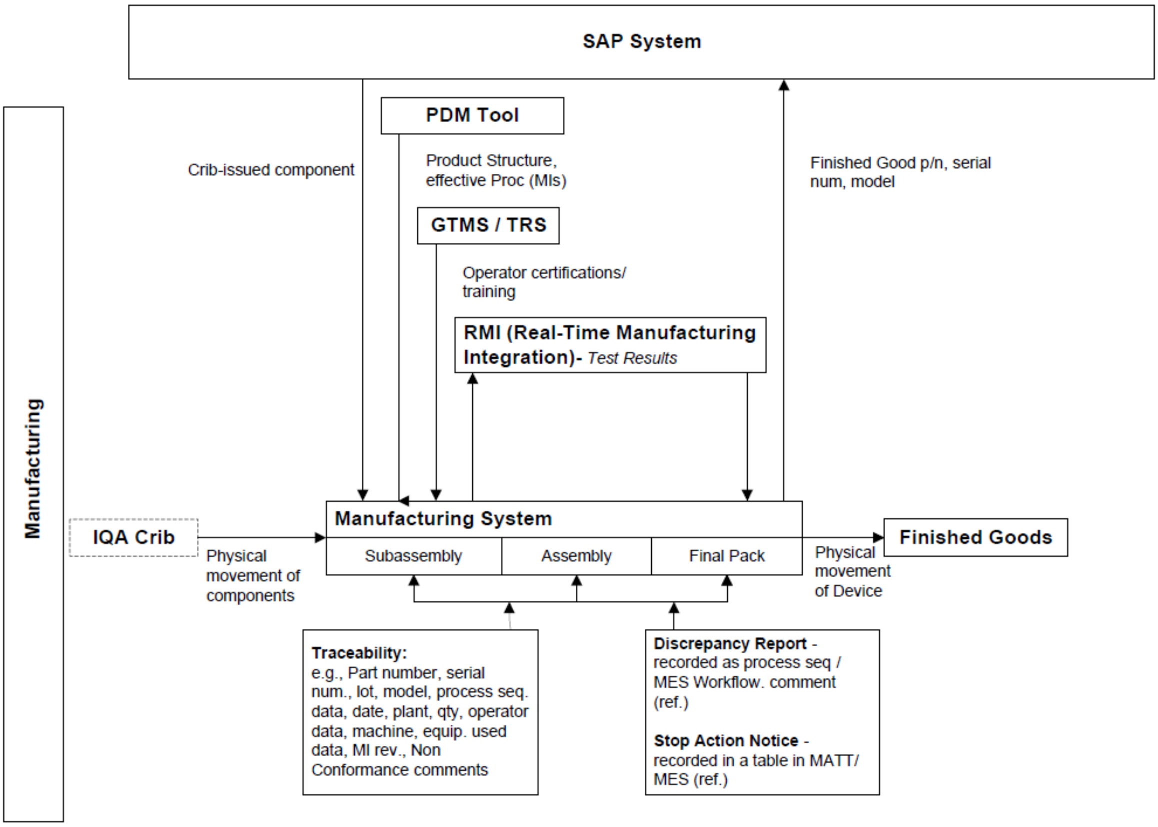

Figure 8. Material Path (iii)

Based on this the following is an example of a system that could be configured that leverages from the process already installed and meeting the application needs. As a disclaimer, this is by no means a final specification. This is a rough guideline based on learnings from the state of the art review carried out. There is still much more that needs to be learned through testing and further research. Throughout the project this specification will be adjusted iteratively and learnings captured in the final physical security use case report (D4.7).

6.1 Hardware

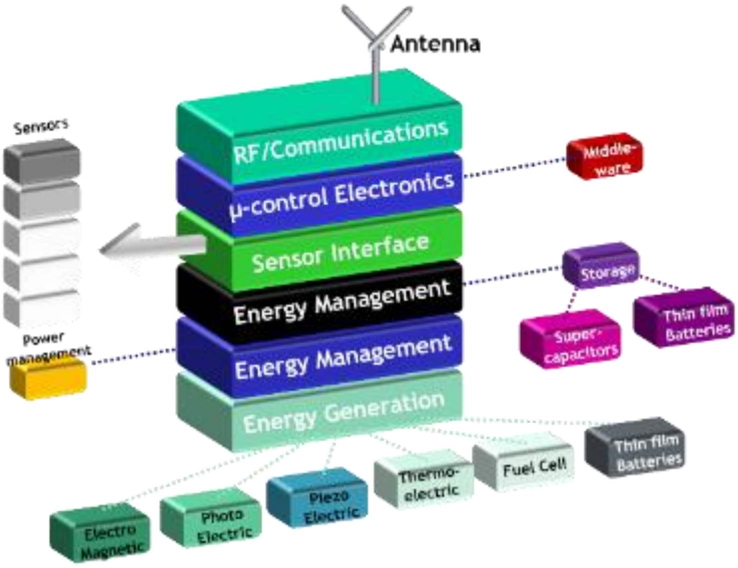

Figure 9. Proposed Tag Hardware Block Diagram

Fig.9 gives a simplified overview of all the aspects of the proposed hardware. The RF/Communications will be determined by the choice of RTLS for asset tracking. The sensor interface will allow any sensors used in sensor fusion to be integrated. Energy management & generation modules to deal with any combination of battery and EH methods that may be employed for powering the device. Then a micro-controller as the ‘brains’ of the system to tie the various aspects together intelligently.

In the use case UC-BSL-3 it is desired to track high value components precisely around the facility to prevent any physical security breaches. A long range, robust, indoor tracking system is necessary to locate these valuable assets as they move around the facility. The prime RTLS candidate to implement in this use case is at this early stage comprises a hybrid tightly coupled UWB & IMU system as outlined in 5.2.7 & 5.2.8 (comparison table) due to the combination of very high accuracy and low power offered by UWB along with the added robustness of the IMU. If the use of an IMU is unfeasible a solely UWB solution may provide adequate performance. At present, no technology can be put off the table, the intent of this deliverable is to establish the most likely contenders and steer efforts along these lines. There is a lot of testing that will be done on the environment with regards to indoor tracking. It is necessary that testing is done on how UWB would work in the environments presented in the use case to show that no interference from NLOS, obstructions, reflections, multipath, etc. makes it unusable for indoor asset tracking here. As well as this it needs to be determined whether UWB will interfere with sensitive test equipment at BSL or be interfered with by existing RF signals. There is a specific test area (‘white room’) where these tests may be carried out unobtrusively off-line prior to commissioning. If testing determines that UWB is not a suitable candidate for use then other technology options will be explored based on this testing giving greater insight into what may work combined with leveraging form learnings for the state of the art review.

Any of the sensors mentioned in section 5.4 may be implemented for physical security detection and determination (tampering, accidental dropping, poor storage conditions, etc.), as well as detection of the number of components used on reels. It will be through the design of the system and constraints put on by size, power consumption will determine how many features will be available for this use case. In terms of the actual physical system, there is much to consider and much will be figured out through iterative and innovative design & testing. The 2 main aspects of the RTLS should be as follows:

Tags – A tag should contain the RTLS module as well as the sensors desired for the physical security use case. As determined through site visits as well as the questionnaire (Appendix 9.1.2.B) the tag form factor needs to be small to attach to reels and other valuable assets in a totally non-intrusive way. There needs to be a way to interact with the tags so a multi-function button, various LEDs to indicate operational status, and a USB port for debugging would be desirable. The tags should also be easily re-usable and transferrable.

Anchors – The anchors will be distributed unobtrusively as uniformly as possible around the tracking area to provide the best coverage. There is a LAN port available at every machine on the factory floor which can be leveraged to connect anchors to a server to process the received data. If a proximity based system is implemented this setup would be ideal for determining if a reel or other asset is within a couple metres of a machine. The makeup of an anchor will be somewhat dependant on the eventual technology chosen. Interfaces needed would be Ethernet, USB, and a physical button. Anchors are typically high power so will need a wired power source. This will have to be considered when placing the anchors.

In terms of question (i) proposed at the beginning of this section, the sensing mode must be considered. In most cases, some 'adaptive' combination of the two modes (time & event) would be ideal. This would be to have a smart contextual method where transmitting happens at short intervals when some relevant predetermined activity is taking place. For example in the component tracking use case when a tagged reel of components is in transit (as detected by on-board sensors) its location should be determined about every second to capture the path it is taking. But once it is at rest sensing every hour or so is adequate just to make sure the reel is still there and the power consumption of the sensor minimised. Where possible this is the preferred sensor activation method. Additionally, contextual awareness should be able to detect when anomalous events are occurring and appropriate alerts and data rate capture activated

As mentioned earlier in this review Energy Harvesting is a very promising area which can be leveraged to increase the battery life of WSNs and in some cases power the nodes completely without batteries. In this case, the ambient energies available in the facility are mostly unknown. Testing will be done to determine the potential availability and power of the ambient energies here (solar, thermal, and kinetic). This will determine whether or not EH will be viable in this scenario. This will be coupled with assessing likely power consumption of WSN nodes under various conditions to determine the scope for battery life extension or possibly battery replacement elimination.

6.2 Software

To determine the position of a tag based on the raw data received by the anchors a positioning algorithm is needed. The exact algorithm necessary for a positioning technique is completely dependent on the implemented method of RTLS and so this will be determined as soon as testing of the factory floor environment reveals an exact RTLS specification for the use case.

The asset tracking software required should compute and record the position of each available tag in 2D co-ordinates relative to the fixed anchors, any sensor data used for sensor fusion, as well as a time-stamp for each data point. This can then be used for the physical security detection system. This will enable an alert system by way of messaging the necessary employee when a tag leaves the tracking area/ reel is close to running out of components/ tampering is detected/ tag battery is low/ etc. (as per the use case). The alerts depend on the expected location, and other sensed data from tags whereby breaking these expectations results in an alert being sent out. A comprehensive database of expected tag activity and locations will need to be devised to create this.

This can also mean that if a replacement reel of components is requested from the crib there should be no alert when it is moved, but if no such request is sent an alert will be triggered upon movement. So data is required from the MES to know when events like this occur. All tags will be linked to the scanned-in assets in the SAP material management system as they are at present. This provides an opportunity to initialise new tags in the system at the same time that they are being scanned into the SAP. The devised asset tracking software would also need to link into the COMPOSITION IIMS software to provide data to all the relevant parts of it such as the JIT, Input / Output analysis, and Batch Tracking System.

6.3 User Interfaces (M2M & HMI)

The Material Management Dashboard as proposed in D2.1 which will be the key interface between operators and the IIMS. This is where the visualisation of the factory floor is set to be implemented where locations of batches and high-value assets are to be displayed. The pure location data as calculated by the asset tracking software will be provided to this system and used in this display. It is suggested that a search feature is implemented to quickly locate missing assets or for quick replenishment of reels. A visualisation of the location history along with time stamps should also be provided in order to easily analyse the flow of high-value assets through the production process.

Alerts provided by the asset tracking physical security determination system should be in the form of an email notification to a relevant employee or even an audio alert, varying in severity depending on the subject of the alert and its context and implications. A method for automatically sending out these alerts with all the relevant sensed information along with an alert severity level will be devised.

A detailed description of M2M & HMI methodologies and considerations is outlined in D5.7. For HMI this includes inputs devices such as keyboards, mice, touch screens, microphones, switches and toggles. Different types of display monitors are the most representative examples of output devices.

6.4 Actions for Actors in Use Cases

A number of tasks may need to be assigned to ensure smooth and continued operation of the physical security network. Tags need to be attached to the high-value assets and it is suggested that this is done upon inspection similar to scanning them into the SAP material management system. It would also be required to assign resources to ensure consistent maintenance of the system. This involves monitoring and responding to alerts given out by the physical security system and ensuring all equipment involved (sensors, tags, anchors, etc.) remains in working order. Once the assets being tracked by the tags have been fully consumed or are past their useful life the tags can be decommissioned for re-use. This gives a perfect opportunity to perform maintenance such as battery checks, checks for wear and tear, and ensuring sensors are fully operational and calibrated. Some assets such as test jigs may outlast the battery life of the tag, in cases like this, it may be necessary to perform routine inspection. Where possible energy harvesting should be used to extend battery life or eliminate the need for batteries.

7 List of Figures and Tables

7.1 Figures

7.2 Tables

8 References

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9 Appendix

9.1 Relevant Questionnaire Answers

The following is an excerpt from a questionnaire sent to Boston Scientific and other COMPOSITION partners which was designed to extract information about the use-cases. The extract below had been filled out by two relevant BSL employees and is relevant to the use case above. Where necessary this is referenced in the specification (section 6).

9.1.1 Future Options

A. Would you look to either enhance the existing ICT system or add a new ICT system? Why?

Yes – Faster implementation times

Most likely a new system but should be compatible with old system.

B. What are the use cases you would like to tackle in implementing a new/improved ICT system? Keeping in mind energy/resource efficiency, asset tracking, security, process monitoring etc.

Difficult to answer because the system needs to be part of an overall machine so only a sensor acting on its own is not an effective method. The sensor could however communicate with the machine

a) Tracking of component reels/components across the factory

b) Monitoring of fans in reflow oven to predict fan failure

c) Monitoring non-conformances

d) Automatic top up of solder paste on under-volume pads

C. What sensors will be needed in each use case? (Temperature, Light, Humidity, Electricity, Sound, PIR, Gas, Position, etc.)

Proximity for part detection, laser for presence, pressure while heating under vacuum, gas for welding

a) Position

b) Temperature, sound, electricity, vibrations, rpm

c), d) already installed

D. Describe scenarios where adding sensors would potentially be of value.

BMS system potentially for pressure, temp & humidity.

Component tracking – Need to know position of components/component reels in the factory to avoid losing expensive parts. Should be as accurate as possible but cannot interfere with other equipment. The component tracking should require as little human input as possible.

Monitoring fans in reflow oven – measure parameters like temperature, sound, electricity, vibrations, rpm in order to predict fan failure

Amount of components available at the Pick & Place machine – measure how many components are left so refills can be scheduled early to reduce machine downtime

E. Describe scenarios where missing or unavailable data is causing problems.

OEE data on machines

- Expensive components are lost in the factory. Their location is not always traced and recorded → missing or unreliable data. There is no alert when a component moves somewhere it should not be.

- The main data used to predict fan failure at the moment is obtained by the operator listening to the noise the fans make. However, this data is only available to someone who happens to walk past the machine. More exact data that could potentially be accessed from another location as well would be useful.

- The amount of components available at the Pick & Place machine is currently monitored visually by the machine operator. However, this data source unreliable and not remotely accessible.

F. In each case where a sensor is needed indicate whether event or time based sensing would be preferred & why this is the case?

Event based to determine machine uptime/downtime

- Component tracking: depends on what is possible; ideally time based to record all movements of the component reels through the factory, but depending on the technology event-based sensing might also be possible

- Fan monitoring: time based sensing → to give technician enough information to make a decision on whether or not to change the fan

- Component levels at P&P machine: could be either, level at which alert is sent should be customizable though

G. To extract the value of the sensors what is intended to be done with the sensed data? Tick multiple, and elaborate if possible.

Alerts	(XX)
Decision support	(XX)
Actuation	( )
Automation	(X)
Other	(X)

Component tracking: alerts, location monitoring

Fan monitoring: alerts, decision support

Component levels: alerts

H. What systems will be involved in processing/using this sensed data?

Manufacturing systems

I. What kind of data (except sensors' data) do you thing would be useful to be kept by the system(s)? (e.g. information about machine failures, repair scheduling, etc.)

Machine utilization, number of parts successfully produced today

Component tracking: number of components ordered, number of components used, number of components per reel

Fan monitoring: machine failures, repair scheduling

J. Can you describe some scenarios where keeping these data would be valuable in cases such as predictive maintenance, etc.

To determine machine utilization

See questions D & E

9.1.2 Micro-power Energy Harvesting (for WSN nodes)

A. Considering that a wireless sensor node's lifetime can be typically several months [4] when powered by battery, how important would you consider increasing the maintenance interval via energy harvesting?

No importance	( )
Low importance	( )
Moderate importance	( )
High importance	(X)
Very high importance	( )

Any insight into the answer you selected would help here:
Less cost

Particularly for fan monitoring → reduced machine downtime

B. Considering the effect on storage of objects that are tagged would size of tags/sensors be important? What would be the ideal form factor of sensors/tags?

Yes. If the needed real-time data is saved. Tags would be very small and adhere to machines.
[ADDED COMMENT - pitch between reels is adjustable to accommodate tag height but of course should be kept as low as possible to ensure it does not eat up too much space on the tray for the pick and place machine]

Would be important on component reels