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Index:

1 Executive Summary 4
2 Introduction/Explanation 5
3 High level inter-operability assessment (cross reference to D5.7) 6
4 BSL factory readiness assessment 7
4.1 Description of BSL high priority use cases 7
4.2 Existing infrastructure & sensors/data available 7
4.3 Requirements for additional sensors for the use cases 8
4.3.1 Asset tracking 8
4.3.2 Oven fan conditional monitoring 10
4.4 Requirements for additional infrastructure to retrofit these sensors 13
4.4.1 Asset tracking 13
4.4.2 Oven fan conditional monitoring 13
4.5 Initial studies to select the sensors required 15
4.5.1 Asset tracking 15
4.5.2 Oven fan conditional monitoring 15
4.6 Initial studies undertaken to prepare for installation 17
4.6.1 Asset tracking 17
4.6.2 Oven fan conditional monitoring 19
5 KLE/ELDIA factory readiness assessment 21
5.1 Description of KLE/ELDIA high priority use cases 21
5.2 Existing infrastructure & sensors/data available 21
5.3 Requirements for additional infrastructure to retrofit these sensors 22
5.3.1 Fill Level Notification 22
5.3.2 Maintenance Decision Support – Vibrometer 24
6 Conclusions 25
7 List of Figures and Tables 26
7.1 Figures 26
7.2 Tables 26
7.3 Abbreviations and Acronyms 27

1 Executive Summary

This deliverables relates to WP7, Analysis and Completion of Existing Sensor Infrastructure Analysis and Completion of Existing Sensor Infrastructure, Task 7.3 Analysis and Completion of Existing Sensor Infrastructure. The readiness of the 3 COMPOSITION industrial use case sites (BSL, KLE & ELDIA) for potential integration of wired and wireless sensors to support the higher priority use cases was assessed under the following categories

- Existing infrastructure & sensors/data available
- Requirements for additional sensors for the use cases
- Requirements for additional infrastructure to retrofit these sensors
- Initial studies to select the sensors required
- Initial studies undertaken to prepare for installation

The key applications identified were asset tracking, conditional monitoring and container fill levels (scrap/metal).

Priority was given to identifying OTS (off the shelf) solutions and getting them to work and gather source data.

Further work remains to be done in terms of looking at other sensor types and scaling challenges but enough work was done to determine readiness of each of the sites for initial experiments & to determine the type and quantity of sensors required. Significant work is required assessing assets and infrastructure but the use of wireless sensors reduces retrofit effort and increases re-configurability. Additional assessment will be undertaken on other industry uses cases as part of the planning process for their implementation.

Laboratories (TNI-UCC BSL white space & CERTH) provide a means to do some early and non-invasive testing of sensors and protocols at research or production facilities.

BLE and some combination of UWB & IMU are the most promising technologies for asset tracking.

Acoustic and power consumption are the most suitable sensory parameters for conditional monitoring of fans at BSL. Vibrational and temperature data on/near motors is also being considered but may be unnecessary.

For waste containers based at KLE ultrasonic & time of flight sensors were selected. The fill level monitoring systems have been tested in the lab in various surfaces and angles to determine the behaviour of the sensors

The communication protocol used for fill level sensors is LoRa as it achieves long ranges at very low power consumption at 868 MHz. WiFi capability and other communication protocols will also be assessed during the project.

For KLE polishing machine monitoring a WiFi connected Vibrometer proto system developed by CERTH has been selected using accelerometers. Its motion detection feature can be used to turn on only when the motor is running and thereby minimise power consumption.

2 Introduction/Explanation

This deliverable assesses the readiness of the 3 COMPOSITION industrial use case sites (BSL, KLE & ELDIA) for potential integration of wired and wireless sensors to support the higher priority use cases identified (described in detail in sections 4.1 & 5.1). The full list of use cases can be found in D2.1 Industrial Use Cases for an Integrated Information Management System.

The assessments were done under the following categories

- Existing infrastructure & sensors/data available
- Requirements for additional sensors for the use cases
- Requirements for additional infrastructure to retrofit these sensors
- Initial studies to select the sensors required
- Initial studies undertaken to prepare for installation

A key element is that sensors to be added need to be non-invasive and non-obtrusive and where possible compatible with the existing communications infrastructure.

The rationale for installing/using sensory data in COMPOSITION is as follows:

The agent-based simulation models developed & integrated in COMPOSITION are fed by wired and wireless WSN (wireless sensor network) data. In some cases pre-existing data from the factory environment is available but in other instances it is necessary for sensors be installed for monitoring and assisting control of the factory processes in real time. Simulation allows exploring and predicting the most robust reconfigurations of the production systems and adaptive production management strategies that optimize the different KPIs under shop floor manufacturing incidents and external supply network conditions and incidents.

CPS (Cyber Physical Systems) can bring WSN data from the real world to the virtual world, enriching data sets from existing information systems in the plant by creating device proxies for systems, sensors and machines on the shop floor including humans and other non-computerized objects. A mediating LinkSmart middleware layer is inserted between low-level embedded devices and the high-level agent interfaces.

In order to minimize CAPEX and OPEX cost and disruption WSN technology was selected as the preferred route where possible to retrofit sensors. WSN enables sensors to be retrofitted on or near existing equipment & infrastructure (premises, people, environment) on a temporary or permanent basis and thereby increase awareness of equipment operation and its operational environment. The sensors can be used in 2 key ways:

1. Gathering additional sensor information increasing the accuracy of a manufacturing process simulation/mock up. This enables multiple scenarios to assessed giving an insight into the relative performance in terms of throughput, cycle time, set up time, yield, etc. and its sensitivity/variability related to batch size, belt speed, temperature gradients, humidity, air quality, etc. The optimal manufacturing setup can then be determined and selected in advance.
2. Gathering real time sensory information to monitor ongoing performance (conditional monitoring) of the equipment and its environment in order that anomalies can be detected and corrective action taken (e.g. preventative maintenance on faulty equipment). This can also be used as a physical security layer detecting & reporting accidental and malicious interventions.

There may be cases in which wired sensors may need to be used for various reasons and this was also taken into consideration.

As a highly related supporting action to the use cases in D5.7 Interoperability for M2M & HMI in factory environments I we also did a highly related assessment – this takes into account factors such as interoperability with other system, data transfer rate, reliability, security & power consumption. For example, the latter is of significant interest for wireless sensors to determine battery life and/or if energy harvesting can be used as a means of self-powering the IoT device.

3 High level inter-operability assessment (cross reference to D5.7)

The following table was developed as part of D5.7 Interoperability for M2M & HMI in factory environment.

Table 1: Inter-operability table from D5.7

	Fieldbus Technologies	Industrial Ethernet	Wi-Fi	IEEE 802.15.4	Bluetooth	EnOcean
Inter-operability	4	4	3	3	3	2
Reliability / Determinism	4	5	3	2	2	2
Transmission Rate	2	5	4	2	1	1
Maintenance	2	2	3	4	4	4
Implementation	2	1	5	3	4	4
Ruggedness	3	2	4	4	4	4
Security	4	5	3	2	2	2
Vendor Support	4	5	2	1	2	3
Power Consumption	n/a	n/a	2	4	3	5

Comparison of Industrial Communication Protocols

Rating	Transmission Rate	Power Consumption
5	>500Mbit/s	<80mW
4	500Mbit/s – 10Mbit/s	80mW – 100mW
3	10Mbit/s – 1Mbit/s	100mW – 200mW
2	1Mbit/s – 200kbit/s	200mW – 1W
1	<200kbit/s	>1W

Quantified values for Transmission Rate and Power Consumption

The idea behind this is that each use case is unique and guidance such as this is required to selected the appropriate wired &/or wireless technology to use to gather the extra sensory info required, depending on the relative important of the criteria in the 1st column. This is course will be dependent on whatever infrastructure is already in place.

Another key related deliverable is D7.4 Test, installation and operation plan template I which provides a template for the COMPOSITION partners to create a planning and monitoring strategy. They can populate progressively as they work through the deployment life cycle. It is highly recommended that this template be used to assess readiness level for various deployment stages form initial proof-of-concept at lab scale to full scale factory deployment.

4 BSL factory readiness assessment

4.1 Description of BSL high priority use cases

The analysis of the use cases selected for the project in D2.1 Industrial Use Cases for an Integrated Information Management System so far has led to the following high priority use cases.

1. *UC-BSL-3 Component Tracking - Asset tracking system.* Use of wireless sensors that can be attached to component reels, fixtures, jigs, sub-assembly trays, etc. so their location can be determined within a factory. The direct (material value) losses and indirect (time lost in production) losses in a factory can be considerable if such assets cannot be found quickly.
2. *UC-BSL-2 Predictive Maintenance - Fan monitoring system* Use of sensors that can 'listen' and monitor performance (temperature, vibrations, power consumption) on and near fans (blowers) in reflow ovens. The 'signature data' from these can give early indication that a fan will fail in the near future. This will then be communicated to relevant personal via email and displayed on large visualization screens in the factory floor. This early warning enables preventative maintenance to be scheduled which can result in significant savings both in terms of disruption to production and avoiding loss of materials. (In the case of BSL they manufacture pacemakers and any subassemblies going through the oven at the time of a fan failure must be scrapped).
3. *UC-BSL-5 Equipment Monitoring and Line Visualization* - Extract data from existing factory systems and feed to partners to help develop systems that predict/detect production bottlenecks monitor and visualize general workflow, detect anomalies, etc. There is an ongoing requirement to show actual vs target production on the line. In this instance it is predominantly used to monitor a light tower in order to track the status of each piece of equipment. For now there is no foreseen need for additional sensors to the installed so it is not covered in any further details in the sub-sections below but it will be assessed again later in the project.

4.2 Existing infrastructure & sensors/data available

The following notes were taken from a meeting between TNI and BSL on 3rd Aug 2017:

- WiFi is available on factory floor but is not there to support sending sensor data
- There are various data gathering systems with various levels of encryption and authentication needed
- BSL is a highly regulated production environment. All data sent wirelessly relating to on-line production needs to be encrypted (AES) and devices transmitting need to be authenticated
- Security team needs to be contacted to see if there is some way around this. Possibly creating a separate SSID which is firewalled off.
- PRIMO is used for maintenance and used mainly to log calibration/maintenance activities. It is 'off-line' and not connected to the production system so security and data integrity needs are less severe. It may be possible to extend use of this system to do predictive maintenance but more detailed discussions are required.
- The BMS (building management system) is separate to the production floor. Whilst it is not possible to interfere with this system there may be useful data (temperature, lighting, humidity, electricity usage, etc.) that would be of value, particularly for predictive maintenance.
- At the moment only desk based applications use the WiFi network on the factory floor (used to enable staff to use smart phones, tablets. etc.)
- BSL would be hesitant to run ZigBee as previous use has suggested it is very noisy.
- Bluetooth should not be used either.
- Any signals in the ISM band should be fine w.r.t. interference with other wireless systems on the factory floor but detailed discussions required before anything could be installed. In general we should try and leverage from existing wires comms infrastructure rather than install anything new due to the amount of validation required.
- 400-412 MHz is important for implantables. So this or any harmonics of this frequency range should be avoided
- 56 kHz is already used for telemetry
- Emergency radio (ERT) operates at 434 MHz

- Wireless systems used in BSL products can be affected down to -110 dBc. So any transceiver system needs to be thoroughly tested before deployment and we should avoid where possible installation of any new infrastructure.
- Some ICs are very susceptible to EM interference
- There are already wireless sensors in CEA (controlled environment area) already for the Building Management System (BMS). Ideally want to partner with tech that it is using.
- We want to ideally operate in the IEE band for wireless communication (2.4/5 GHz) Certification needed if antennae added to CEA – ok if we use existing 2.4GHz network in place. Could also maybe use 5GHz but will interfere with 2.4GHz.

Based on several subsequent discussions we came to the following agreements:

- The ‘white space’ development lab in BSL is generally available and there are no restrictions in terms of wireless protocols used.
- The white space can be used for ‘before and after’ RF background testing to generate a report indicating the likely additional RF signals present if a given wireless system were to be installed on the production floor
- BSL in general will be supportive of installing any given system once there is evidence that there is no discernible increase in RF emissions, particularly in critical bands (around 400-412MHz) where implantable (pacemaker) telemetry is used.
- BSL is willing to add wired and wireless sensors but work instructions need to be generated to guide BSL technicians in installing.
- TNI technical personnel also underwent induction training in order that they frequently visit the premises and can support such installations and the ongoing operation.

4.3 Requirements for additional sensors for the use cases

In general the following principles were agreed at the meeting on 3rd Aug 2017:

- Wired connection gives less security concerns (the risk of data being corrupted whilst being wireless transmitted is eliminated and the source of the data is known)
- Sensors can (potentially) be wired up without authentication [and we must avoid this]
- If data is being sent to a server it does still need to be authenticated
- Access to a LAN port is no problem – they can be provided where needed (within reason)

Specific requirements are captured in the next 2 sub-sections. They again comprise notes from the exploratory BSL meeting on 3rd August with a description of follow on actions, decisions, etc.

4.3.1 Asset tracking

For asset tracking the type of sensor required was self-evident. It was just a matter as to how the have tag ‘exposure’ to an RF environment that can communicate with it as needed. The use cases were built around scenarios where this would be possible (e.g. it is impossible to communicate with a tag if it is in a sealed metal box such as an oven).

The sensors required for asset tracking fall under the umbrella term RTLS (Real Time Location Systems) which contains a number of emerging and existing technologies for the localisation of devices indoors. D4.6 was conducted as a literature review of all such available technology in this space and a number of suitable technologies were highlighted as a result such as UWB (Ultra Wide Band), BLE (Bluetooth Low Energy), IMU (Inertial Measurement Units), GPS, & WiFi. These each have benefits and drawbacks associated with them and testing was designed to uncover these in order to best select the ideal RTLS for the use case. For example some may be more affected by ingress in the tracking area than others, and since there would be a lot of this on the BSL factory floor care must be taken to avoid systems which do not perform well in this environment. All sensor types will have to provide a certain level of accuracy (less than 3 metres) while not interfering with sensitive RF equipment present in the BSL factory floor.

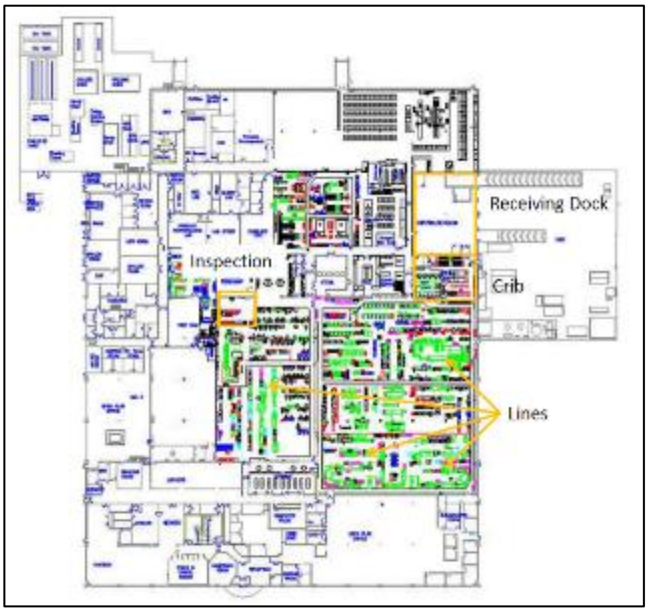

Figure 1: BSL Factory Floor Plan

The above image shows an overhead map of the deployment location. The important areas are highlighted: Crib, inspection, and production lines. These are the areas where material is likley to travel around and so these are the areas where tracking technology needs to be implemented. An example of several of the trays that tags with asset tracking technology to for UC-BSL-3 follow:

Figure 2: Example Trays to Track

This also gives a size constraint for tracking tags which will be attached to such trays. A universal form factor or possibly several form factors need to be devised for tags. The wireless tags must be able to deal with conditions applied to respective material that is tracked. Storage in vacutherm fridges and other closed containers would be a part of this. Also a test to determine the effect that wireless signals used by the tracking system have on other systems within the factory environment must be undertaken. The deployment location is a manufacturing facility, so not interfering with any of the existing processes is of utmost importance. Wireless communications, sensitive test equipment and ICs already on the floor can be adversely affected by some RF signals. For implantables that are manufactured 400-412 MHz is an important frequency range that must not be used, nor any harmonic to prevent harmonic interference. These systems are sensitive to these frequencies down to -110dBc. So everything needs to be thoroughly tested to make sure this is avoided. All such constraints and expected operating scenarios had to be worked out first before proceeding to testing in order to fully understand the restrictions of the use case. Notes taken with regard to this during discussions with BSL follow here:

- The storage areas for components (crib & short term storage) were looked at to give an idea of the constraints of the system design in terms of tag size & ways to leverage existing architecture
- BSL will arrange for photos of various storage units and pick and place machines to be taken and shared with partners to help understand infrastructure.

- Most storage units are drawers/cabinet/trays. Components stored in metal containers are rendered difficult to communicate with using the wireless asset tag. In such cases we can only record the asset going in or out of such enclosures and need to devise methodologies to trigger such occurrences.
- In the crib most components that go to the pick and place machine are kept in nitrogen storage in black fridge-like storage units or alternatively the Rotomat
- When needed, materials are brought to short term storage on a trolley
- The method of short term storage changes drastically depending on the material type (glass case, Vacutherm storage, metal cages) some of which may affect the ability to track material
- Ways of sensing inside these storage units need to be considered but is unlikely to be usable or practical
- Alternative strategies should be discussed. For example it could be possible to have magnetic sensors on the doors of short term storage units in order to know when the door has been opened so that a scan of the components may/should be performed to check tags attached to the stored material
- Pick and place carts with reels are loose and interchangeable on the pick and place machines
- Components trays are placed snugly into slots inside the pick and place machine which may constrain the size of the tag that can be attached
- It may be useful to pull data from the MES system to aid tracking
- The pick and place machine will not run unless a reel is scanned that is supposed to be there. (Each reel is bar code scanned and cross checked against what component is expected in that location).
- Bar codes used distinguish types of material but not individual units
- Very high density of components in areas may affect the choice of wireless technology used and the number of asset tags in close proximity
- BSL provided TNI-UCC with samples for various types of reels and trays. These will be used in discussion to determine location and form factor of tags.

TNI-UCC shall take photos of these and add in appendix to D7.4. Test, installation and operation plan template I

Based on these and subsequent discussions TNI & BSL selected a number of suitable trays/carrier for experimentation with asset tags working in scenarios where tags are potentially detectable. Ref. section 3.5.1 for further details

4.3.2 Oven fan conditional monitoring

For conditional monitoring acoustic emissions and fan power consumption were seen as the obvious sensory parameters to investigate for retrofit in the ovens. Vibrations and temperature of the body of fan motors were also identified as possible candidates.

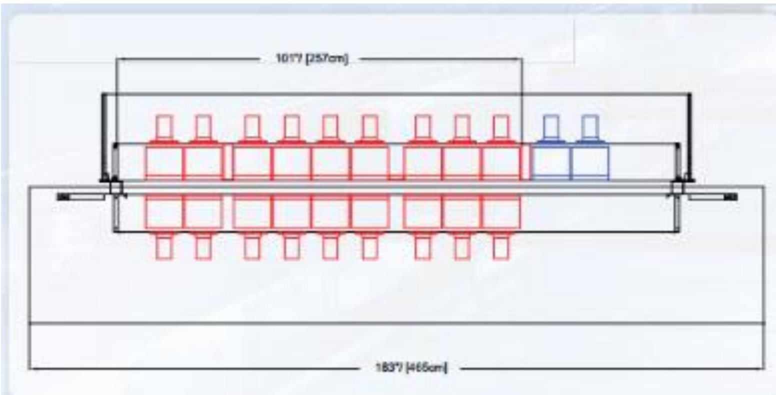

Figure 3: Diagram of Heller Oven Structure

At present, a blower failure in the oven is detected in two scenarios. In the first, an operator in the factory may hear a loud noise when passing the reflow oven and alerts the maintenance staff of a potential failure. The maintenance staff will isolate the broken blower later in the day and replace it. The other scenario is when the temperature in the oven drops below a certain temperature in a certain part of the oven. An alarm is generated by the reflow oven and the operator will alert the maintenance staff who will respond.

The current maintenance schedule on the blower motors consists of monthly checks from BSL maintenance staff. The outer panels of the ovens are removed and temperatures (touching the back of the motors), sound (a noticeable increase in sound from a certain motor or different pitch will indicate a failure) and the speed (using halls effect sensor) of the blowers are noted. BSL have also purchased the airborne AE probe UP10000 which they plan to use in their maintenance checks.

The 4 ovens currently on the floor record temperature data within the oven and event logs. Furthermore, BSL's asset management software stores records of the work orders for blower replacements. Event logs for each day are stored on each machine in the form of text files and contain machine alarms as well as records of some additional machine events, such as recipe changes.

Every five minutes, the ovens record the current temperature (PV, in °C) in the area of each blower as well as the output power for the area (OP, depending on PID control calculation of heater control, the output power can be 0%-100%: 100% means full voltage is applied and 0% means no voltage is applied) in a data text file. A new file is created each day. For one oven, the machine also records the temperature value set by the user (SP, in °C).

Table 2: Data showing the number of failing fans in the oven

Oven on line	Approx. no. of years of data	Recorded data			No. of blower failures since 2010
		SP	PV	OP	
Brady	7	Yes	Yes	Yes	2
Tachy	8	No	Yes	Yes	4
Rhythmia	4	No	Yes	Yes	6
NMD	9	No	Yes	Yes	5

The current baseline data gathered is inadequate for predictive maintenance and additional data is required. Ideally a data collection method which can indicate the condition of all the motors would be ideal. In reality this may not be practical given the number of motors in the oven. A more practical solution may be to alert a maintenance engineer of a failing fan in a certain area so that they can use other methods to determine the condition and decide if replacement is required.

Figure 4: Inside Top Cover of oven (Right)

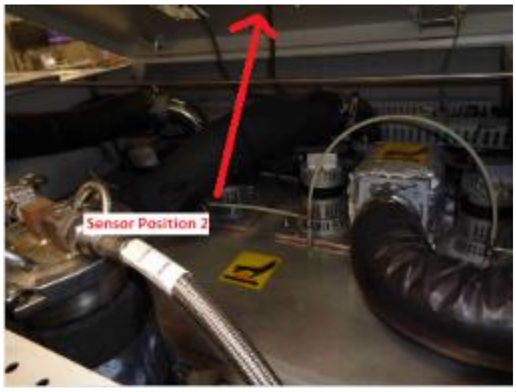

Figure 5: Inside Top Cover of Oven (Left)

Figure 6: Inside Bottom Cover of Oven Bottom (Left)

Figure 7: Inside Bottom Cover of Oven (Right)

Hella 1809EXL reflow ovens are being used in the factory. These are 12kW ovens with dimensions of (465cm x 137cm x 160cm). The blowers are located underneath the steel cover panels of the oven. Each has 20 blowers, 9 blowers are located on the bottom and 11 on the top. The most suitable area for sensor placement would be underneath the cover as there is sufficient space and the temperature in this area of the oven does not get excessively hot with the motors being deemed safe to touch during operation. There is also an AC power rail on both sections of the oven for the powering of the blowers. Each blower motor consumes 83W and rotates at 3500rpm.

4.4 Requirements for additional infrastructure to retrofit these sensors

4.4.1 Asset tracking

Various off the shelf tracking technologies will be tested in a controlled environment to determine their susceptibility to interference and general performance. Initial experiments will be conducted in TNI's WSN lab. This will include verification of the system's operation and accuracy. Then it must be brought to BSL for testing in the RPC (rapid prototyping) area. The prototyping room within BSL should act as a double for the factory floor and so tests can be performed here with the chosen RTLS technology to determine the levels of interference introduced by big production units in the tracking area. Also to look for ways to minimise interference if present. Also suitability for deployment on the factory floor will be determined via RF testing

The number of tags to be used can be determined by the need of the BSL use case, for UC-BSL-3 about 50-100 tags will be necessary to track all sub-assemblies taken off the production line. The maximum amount of tags which can be used varies on the technology chosen. For initial testing all that is needed is 5 or so tags. For full scale deployment this will be increased as necessary. Work will be done to interact with the vendors to definitively say what the maximum density & scalability of these tags are along with tests to verify this.

Once one tracking technology has been approved some tests will be performed on individual trays/reels to track their movement around factory floor and capture the normal path travelled for such material. Deviations from this can be used for alerts. As well as this it can be in order to fully verify operation in the use-case environment before full-scale deployment. This will include performance as well as potential interference with production.

The location update rate of all technologies for this use case needs to be balanced, since a more frequent position update rate will use up more power per tag we want this to be infrequent enough to provide long battery lifetime (several months) whilst also providing position information frequent enough to suit the use case. This frequency will be determined through implementation as it is unclear how often trays are moved in this use case. As a default we will use 10 minute position updates as a benchmark.

Energy Harvesting (EH) is a very promising area which can be leveraged to increase the battery life of wireless sensors 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 selected RTLS devices under various conditions to determine the scope for battery life extension or possibly battery replacement elimination.

4.4.2 Oven fan conditional monitoring

Phase 1 Testing: (In TNI Wireless Sensor Lab)

The goal of this phase of testing is to achieve the vibrational, acoustic and electronic signatures of the blower motors which will have been given to us by BSL. The chosen sensors are the LSM9DS1 vibrational sensor, the G.R.A.S. field array microphone, the SPH0645 mems scale microphone and the CSE184L current sensor. The location of this experiment will be in the TNI Wireless Sensor Network (WSN) Lab. Unlike the use case environment (BSL factory floor) there no RF or EM interference in the area. There is also very little acoustic interference. The induction motor will be encased in a wooden enclosure for the experiments. The stator side of the motor is exposed and the motor side encased in the box. It is possible that this safety rig will have an effect on the signatures of the motor. The air being blown in this experiment may be denser than the air in the reflow oven increasing the load on the motor. The restricted air in the box may also increase the resistance. The rigid box may also have a different damping effect on the vibrations of the induction motor. These factors may cause a difference in the results from the experimental results and the actual results which should be considered but it should give a reasonable indication of the acoustic signature. These differences should be considered when analysing the results of the experiment.

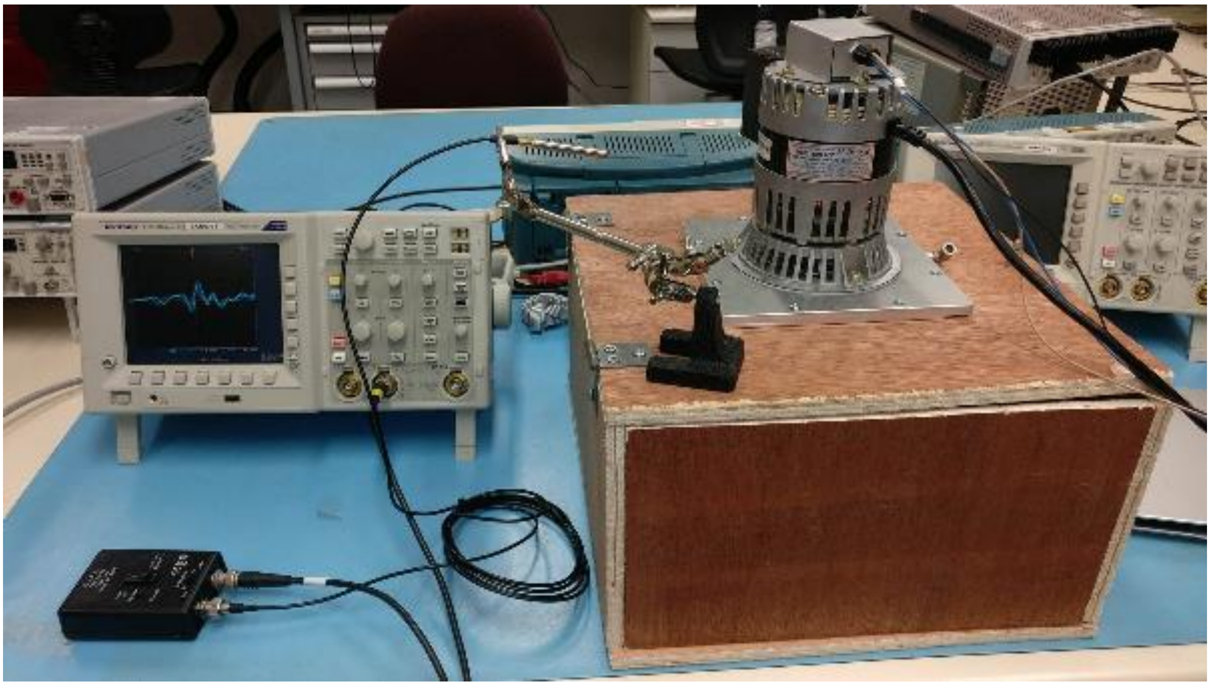

Figure 8: TNI testing fixture

Phase 2 Testing: (On Rythmia Oven in BSL)

The purpose of this stage of testing is to evaluate the sensors in the factory setting in BSL and gather a large amount of data for algorithm development. Four acoustic sensors will be used to measure the acoustic signature of the fans in the top section and in the bottom section of the oven. Vibrational/Temperature sensors will also be fitted individually to each fan.

This testing occurs in BSL's factory floor, access to the floor requires gowning and the wearing of gloves. Equipment must be examined before being introduced onto the factory floor. The room is slightly pressurised so as to prevent air flow into the factory environment. RF interference is kept to a minimum on the factory floor with specific frequency bands completely restricted due to the product in manufacturing using certain frequencies (mobile phones are also banned on the floor). There is a large amount of EM interference on the factory floor due to the induction motors and high power laser equipment on the floor. TNI has access to the Rythmia reflow oven. This oven will be fitted out with acoustic, vibrational/thermal and current sensors. The goal of this experiment is to gather a significant amount of baseline data such that a learning algorithm can be developed for failure prediction. The effects of the confined space of the reflow oven on the data from the acoustic sensors will also have an effect. The measuring multiple induction motor signals with one microphone will also be investigated.

Figure 9: Acoustic Sensor Placement for BSL

4.5 Initial studies to select the sensors required

4.5.1 Asset tracking

Due to the huge complexity of a robust asset-tracking system as well as consideration for the resources available it was decided that the solution here would be derived from Commercial Off-The-Shelf (COTS) technology. This narrowed the choice down to the most commercially viable technologies. These comprise Ultra Wide-Band, Bluetooth Low Energy, & GPS. For UWB a development kit supplied by Pozyx labs was chosen to evaluate the performance of this technology. This is easily set up and re-programmable either through the Arduino IDE or Python. As well as UWB it also integrates an Inertial Measurement Unit in a sensor fusion which allows for even better position estimates.

The Airfinder RTLS was chosen as the candidate for Bluetooth Low Energy as it provides a unique BLE tracking solution which uses Wi-Fi as the method for data communication. Instead of reference points being the master and tags being the slave when it comes to tracking the roles are reversed where every tag is its own master and reference points are slaves. This allows a much higher density of tags compared to traditional systems as a master may only connect to 8 slaves. By reversing the topology a work-around has been created. Each tag also comes with a Wi-Fi transceiver in order to communicate its known location.
Accuracy is good at 1-3m and battery lifetime is extremely long at 12-18 months at a scan rate of once every 5 seconds. This solution has been fully developed and as such will be less configurable although less work will be required in set up.

As an evaluation of GPS an Adafruit 767 module was selected. This works with a Raspberry Pi micro-controller to perform GPS localisation. Although it is unlikely to be adequate in this use case by itself but it will be interesting to look into this as potential to use for data fusion (e.g. combine GPS info with info form other sources to make a more accurate estimate of location or to give a rough area before a more precise RTLS is activated in the narrowed-down area).

Through testing these devices for all metrics of interest for this use case we will be able to select the best technology pairing going forward. One this has been selected more work can be put into specifics about the tracking device. It is intended that two attempts be made at providing a device suitable for the use case. The 1st generation device shall likely be an unrefined but meeting the requirements in this scenario. This will employ batteries as its sole power source and the form factor may not be ideal. The second generation device will attempt to employ energy harvesting techniques to extend battery life and the viability of this will be learned through ambient energy evaluation of the BSL factory floor as well as the power consumption of the first generation device. As well as this the form factor will be improved through feedback from the 1st generation solution

4.5.2 Oven fan conditional monitoring

These sensors have been chosen to have more than enough sensitivity and sampling frequency to capture all relevant data which may assist in predictive maintenance. It should be noted that both the sensitivity and sampling frequency may be reduced in the final solution. This would reduce the amount of data required and also reduce the power consumption of the sensors. These sensors have also been chosen for their low power capabilities allowing a final solution to be powered using batteries and/or an energy harvesting solution.

Acoustic Data:

Acoustic sensory data can be gathered using a microphone. The close proximity of blowers creates acoustic interference between the motors in the confined space below the panel of the reflow oven. This might prevent motors from being identified individually however could be a benefit in that multiple motors could be monitored at the same time. The GRAS Free Field array condenser microphone can be used for high precision measurements. It uses a Lemo compatible pre amplifier and input module to achieve less than 2dB noise from 3.15 to 40KHz. This microphone is not suitable for practical use due to its cost (approx. €1200) and power consumption however is useful tool for calibration. The Knowles SPH06045 digital mems microphone is a more economically viable alternative. It has -26 dBV sensitivity at 1 KHz with a relatively flat frequency response in the ultrasonic band. The sensor can use a 3.3V supply and draws 600uA when operating and 10uA during sleep mode. This makes this microphone a good option for wireless applications. The sensor has a built in ADC which outputs I2S. This allows the sensor to be integrated directly with microprocessors without the need for a Codec.

Electromagnetic Data:

An electromagnetic transducer could also be used to analyse the condition of the motor. There is currently a gear tooth speed sensor fitted to the motors which is measuring the movement of the rotor. This requires further investigation but has lower priority than the acoustic analysis.

Vibrational/Temperature Data:

A vibrational sensor can use an accelerometer to gather the mechanical vibration data. This can be fastened to the side of each of the motors on in the blower, the fastening of the sensor to the motor would make the implementation of the vibrational sensor more challenging. Temperature data is also another way of detecting a broken fan and is one of the methods which the technicians employ by touching the back of the fans during maintenance checks. This method would provide a method of individually identifying the broken motors. The LSM9DS1 was chosen for this task. It is available in an adafruit breakout simplifying prototyping. This device can be used to measure vibration and temperature. It has an adjustable acceleration range between ±2g and ±16g. The maximum sensitivity is 0.061mg/LSB at a frequency range of ±2g. It has a three axis linear accelerometer. It can communicate over I2C or SPI which makes it compatible with a raspberry pi.

Current Data:-

Current measurements can be gathered using a current clamp on the power cable going to the motor. This method is non-invasive and the easiest to implement. The CR3100 Current Clamp was used for this application This current clamp has a hinge and locking functionality which allows it to clamped around a wire. It has a maximum current rating of 75A, an effective turns ratio of 3100 and a dc resistance of 515 Ω.

4.6 Initial studies undertaken to prepare for installation

4.6.1 Asset tracking

The first tests carried out involve examining the RF spectrum present in the factory floor before and after the installation of RTLS solutions. This is of interest with relation to wireless tracking technologies as these will use frequencies within this spectrum and it is desired that any system to be implemented will not interfere or be interfered with existing RF systems that are present in the BSL factory floor deployment location some of which are critical to the operation of the facility so this must be treated with caution.

The goal of this test is to have a plot of the RF spectrum captured over a long period of time so that the frequency and maximum amplitude of every signal that is present in the various test environments can be seen. To capture this the spectrum analyser was be set up in various locations, a max hold was set, and this was left for a number of hours to be sure all data is captured. The peaks detected give an indication of the highest level activity within any range of frequencies and so can inform a decision on which tracking technology to choose for this use case.

A location was chosen as a sampling point for each 1000m^2 area in which tracking will be implemented. A power socket for the analyzer needed. The test points were numbered in the order they were be tested. The spectrum analyzer was brought to each point, set up, and left for 24 hours to capture the peak intensity in each RF band up to 3 GHz.

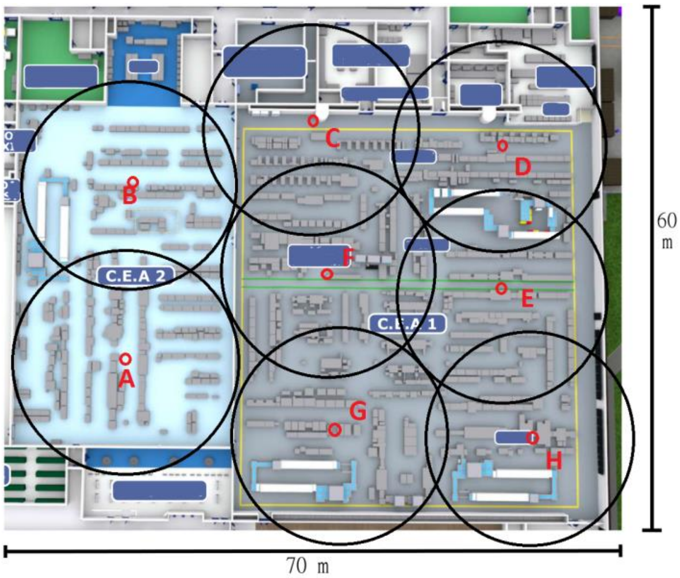

Figure 10: RF Evaluation Map

The results indicate that the factory floor is quite free of RF noise as all peaks detected, with the exception of one or two, were expected to be found. For example:

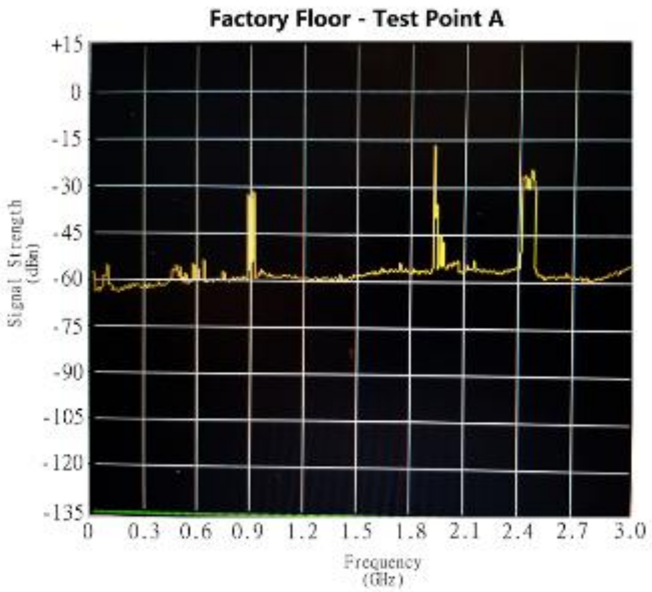

Figure 11: RF Evaluation Test Point A

The 2.4-2.5 GHz band having a peak detected signal strength of -30dBm is synonymous with the effects of Wi-Fi signals. Wi-Fi transmissions usually peak at -30dBm and this technology is known to be used across the factory floor so this was to be expected. There is a peak that is seen in most plots between 1.8 and 2.0 GHz, as well as peaks at 900MHz. These can be attributed to mobile phones being present on the factory floor since these are contained in the GSM & LTE bands that mobile phones frequently use to communicate.

Another test carried out so far was the evaluation of GPS and Cellular tracking inside the BSL facility. It was discovered that GPS and Cellular did not perform well when tracking devices indoors. It was suspected that GPS may work since the factory has no upper floors but this was not the case as the GPS module struggled to connect to any satellites. Cellular tracking using the mobile phone network towers did work although very poorly, with an accuracy of 25m it was concluded that it was not useful for finding anything inside the facility. Shown here in figure 12 is a plot captured comparing the location data captured compared with the real world path travelled:

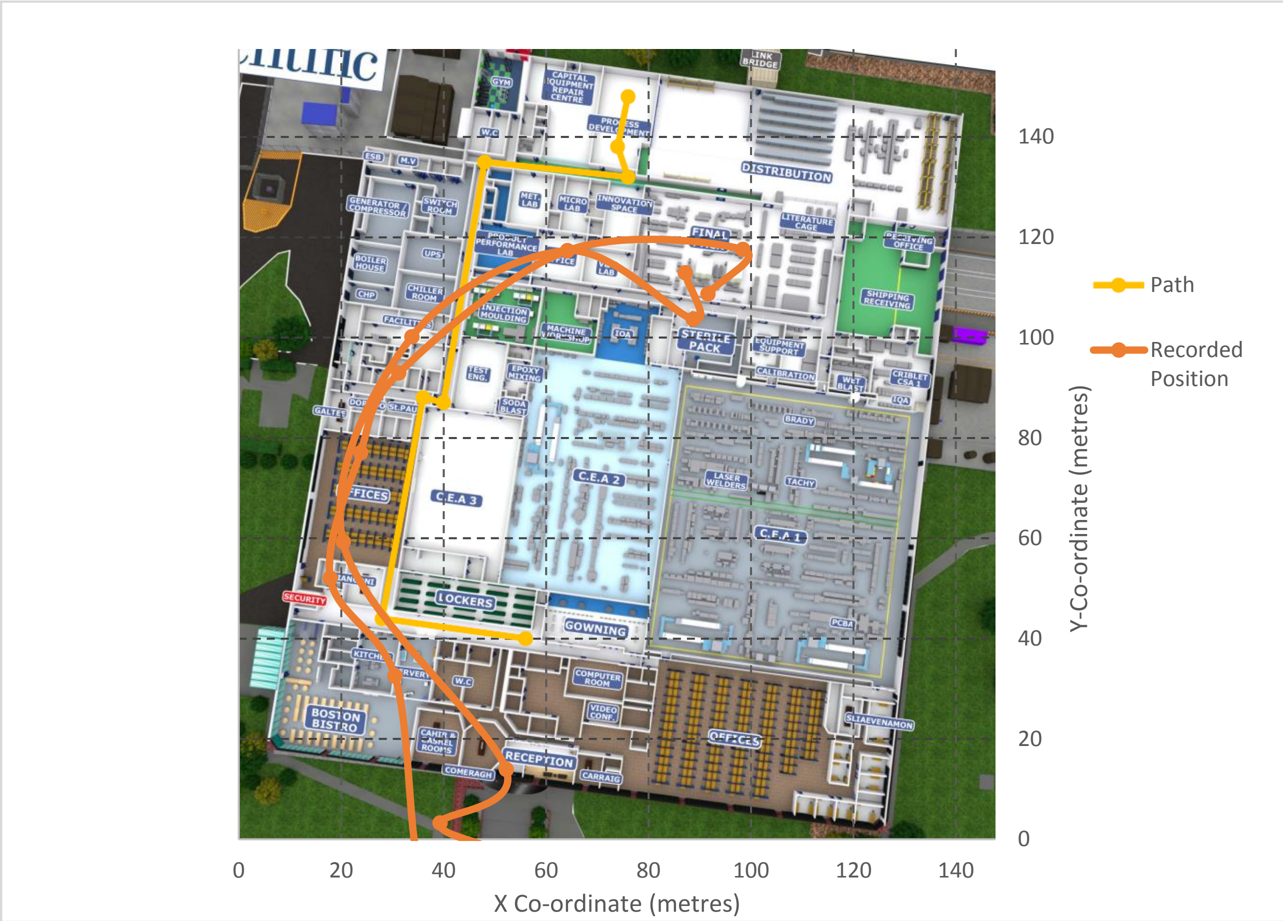

Figure 12: GPS tracking results

Initial testing is now underway on UWB and it is currently being evaluated for performance within TNI's labs and tests in BSL are pending.

4.6.2 Oven fan conditional monitoring

Initial phase 1 testing has revealed information on the suitability of the sensors selected. Information such as sensor sensitivity, sampling rates, power consumption has allowed us to narrow down the suitability of sensors for use in phase 2 testing.

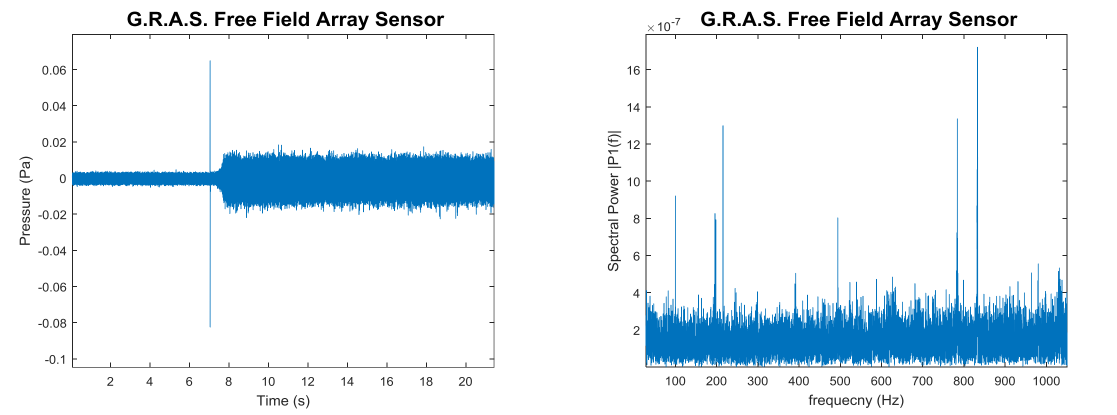

Figure 13: Acoustic Data from the G.R.A.S Sensor

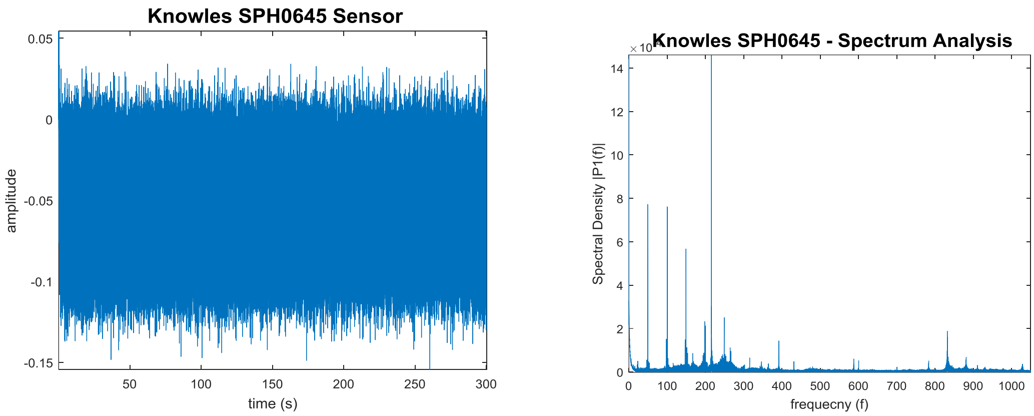

Figure 14: Acoustic Data from the Knowles Sensor

The acoustic data from the G.R.A.S has revealed that a single motor in ideal condition produces a pressure wave with an amplitude of 0.02 Pa. A fast Fourier transform of the data shows that significant frequencies occur around 50Hz, 100Hz, 200Hz and 850Hz. This is no surprise given the 50Hz frequency used for AC energy supply. It is likely that a failing fan will show significant frequency peaks in higher frequency bands. This is intuitive guess based on the 3500 rpm operation of the motor. The Knowles sensor data shows that the -26dBV sensitivity is sufficient to capture the relevant frequency bands.

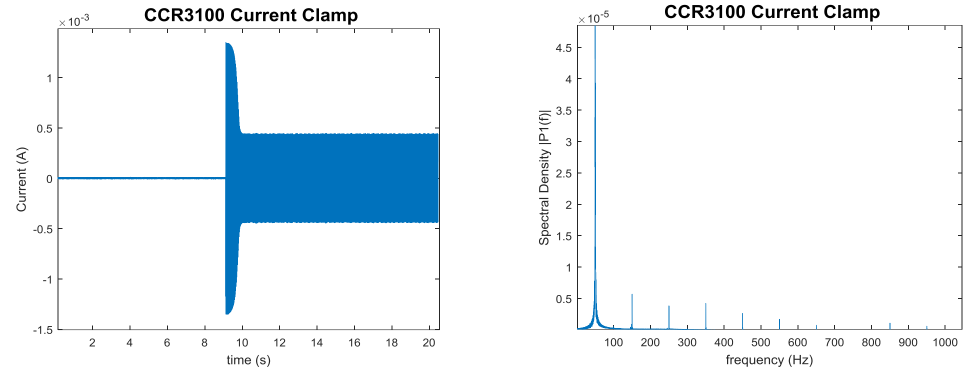

Figure 15: Current Data from the CCR3100 Current Clamp

An Iso-tech current clamp was used to measure the average rms current draw as 610 mA. This CCR3100 confirms this measurement when the 3100 turns windings are taken into account. A spike in the current draw occurs on start up. The spectrum analysis of the current data revels that there is little valuable data available from sampling the waveform of the current draw. Thus the decision was made to only monitor the average rms of the current draw. It was also decided that the accumulated sum of multiple induction motors might be the most suitable option for current analysis.

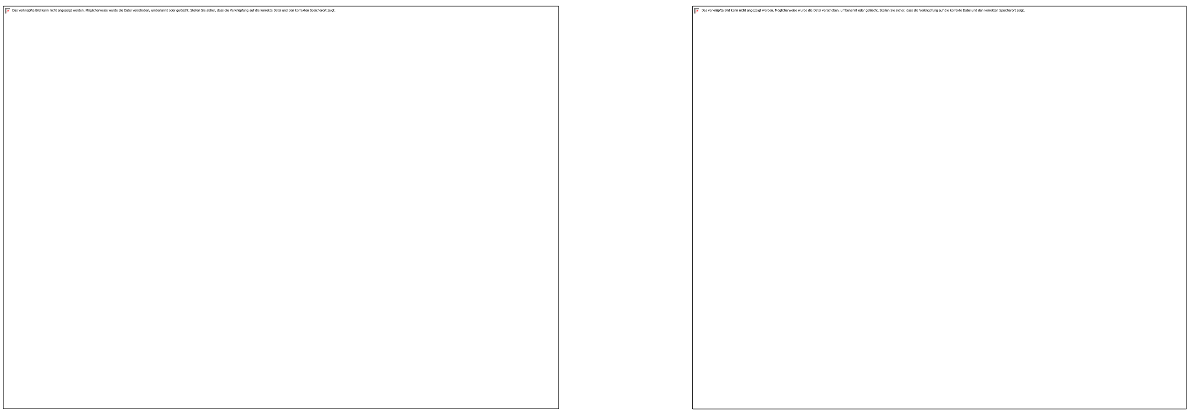

Figure 16: Vibrational Data from the LSM9DS1 Sensor

The data from the LSM9DS1 shows the z axis acceleration of the induction motor produces a waveform with amplitude of 1.5g.The sensitivity of the sensor is sufficient to capture this information. The frequency analysis of the data shows that significant spectrums occur at 50Hz and its multiples.

5 KLE/ELDIA factory readiness assessment

5.1 Description of KLE/ELDIA high priority use cases

The analysis undertaken in the project so far has to the following technology use cases.

1. *UC-ELDIA-1&2* Fill Level Notification ….. Contractual Wood and Recyclable Materials Management *….* Two types of sensors were selected to provide a fill-level notification system that can be installed in two types of waste containers. The system, along with further data processing, will provide information to the Logistics department in order to enhance the efficiency of waste collection.
2. *UC-KLE-1 Maintenance Decision Support* Data harvesting from a vibration sensor system attached on operating motors in production (wireless sensors attached to the polishing machine components (e.g. motor inside and outside the machine). The incoming data will be analysed and compared to historical data from CMMS in order to provide feedback for maintenance and forecasting of imminent failures of the motor equipment to minimize downtimes in production lines and increase equipment availability.
3. *UC-KLE-4 Scrap metal collection and bidding process* Sensors that will monitor scrap metal fill levels will be installed on the bins' surface. The data extracted from these sensors can give early indication e.g. that a bin is 80% full. This early warning will enable both the collection and the bidding process to be scheduled automatically resulting in significant improvements in terms of time management, transportation planning and bidding processes.

5.2 Existing infrastructure & sensors/data available

The following notes were taken from a meeting between CERTH, KLE and ELDIA on Sept 2017:

- There are various data gathering systems such as workstation terminals that are directly connected to the ERP
- WiFi is available on factory floor but is not there to support sending sensor data
- Wifi is changing password weekly, so we will have to arrange for a separate SSID exclusively for sensors with the IT which will be firewalled and have a specific password, to not interfere with the normal network routine followed by KLEEMANN
- Zigbee Network is also available on the factory floor but it is not chosen as the development on zigbee is highly regulated and cost prohibiting
- There is no LoRa infrastructure but agreed on installing one LoRa central-station to LAN gateway, for the operation of fill sensors
- All data gathering and exchange should be highly secured
- AIMMS/CMMS is used for maintenance planning and implementation. It is an 'off-line' software and is not connected to the production system nor to the company's ERP. It may be possible to connect the CMMS to COMPOSITION ecosystem but further more detailed discussions are required.
- At the moment only desk based applications use the WiFi network on the factory floor (used to enable staff to use smart phones, tablets. etc.)
- Wired operation of sensor systems is not possible as the placing position of sensors is away from power sources and in environments that the usage of wires is not recommended
- KLEEMANN will assist with their metalwork workshop for providing assistance with casing and installation

5.3 Requirements for additional infrastructure to retrofit these sensors

5.3.1 Fill Level Notification

It must be pointed out that there will be no installation on ELDIA site. The installation will take place on KLEEMANN site but on ELDIA waste containers which are present around KLEEMANN facility. There are no existing sensors on the waste bins. The photos below show the actual containers where the fill level sensor systems will be installed. Different sensors have been selected for different types of waste bins. Actual position of the system on the bins will be determined on site, but a first estimate is shown in the pictures below.

Figure 17: Waste Container

Figure 18: Recycling bins

Due to the two types of waste containers two separate sensors were selected in order to perform the fill level monitoring. For the container in Figure 17 the ultrasonic sensor HRLV - MaxSonar - EZ™ Series MB1013 was used. It has an object ranging capability of 30cm-5m in a 1mm resolution which is adequate for the size of the container. Also its low voltage, low power capability makes integration to a low power battery system convenient. Special attention is required for the coating of the sensor since it will be placed outdoors, in case the sensor can't function the coated counterpart will be used MB7360 HRXL-MaxSonar-WR. For the containers in Figure 18 VL53L0X Time of flight sensor was used. With a ranging capability of 5cm - 1.2m is suitable for this type of bins.

The communication protocol used for fill level sensors is the popular LoRa as it achieves long ranges at very low power consumption in the 868 MHz band. LoRa is a very good choice for Networks that require low data rates at very low power over considerable ranges, where WiFi fails. A LoRa central station should be installed in KLEEMANN in order to provide a connection with the Local Area Network. There is currently a LoRa network which connects various devices that communicate with each other at various CERTH locations, so there is an estimation about the capabilities of the network. There are future plans of adding WiFi capability and other communication protocols as well.

The fill level monitoring systems have been tested in the lab in various surfaces and angles to determine the behaviour of the sensors. Photos of the development boards with sensors are shown below.

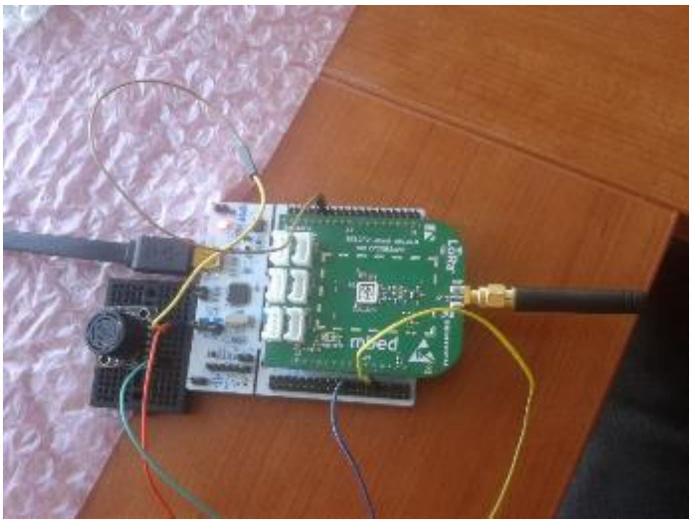

Figure 19: Ultrasonic Sensor connected onSTM32 Dev Board with Lora Communication Module

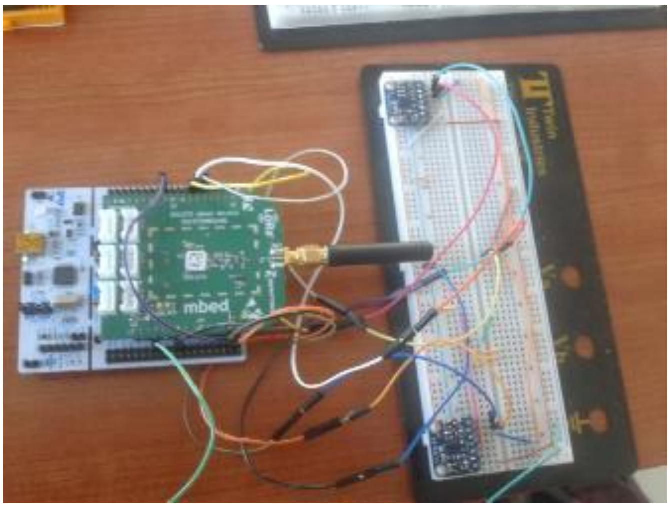

Figure 20: A pair of VL53L0X sensors (Adafruit breakout boards)

on STM32 Dev Board with Lora Communication Module

5.3.2 Maintenance Decision Support – Vibrometer

A WiFi connected Vibrometer will be installed on a Bossi Polishing Machine motors. Those motors susceptible to malfunction will be monitored in order to provide feedback for maintenance and data for forecasting of imminent failures. The pictures below show the motors of Bossi Machine where the sensors will be installed. No other sensors are present on the Bossi Machine.

Figure 21: Bossi Motor (internal)

Figure 22: Bossi Motors (external)

The LIS3DH accelerometer is used to capture the vibration data. A 5 kHz sampling rate is possible (and confirmed by internal controlled timing measurements on the MCU) as LIS3DH can achieve data capturing at rates of up to 5.3 kHz. The memory of the microcontroller as well as the WiFi Buffer limits us in extracting many samples. A compromise that will affect the resolution of the frequency response should be made. The device was tested with 500 samples which allows a 10 Hz resolution. The range of the accelerometer can span between +/-16g. Also the motion detection feature of the accelerometer is used so that measurements are only performed when the motors are on.

The sensor passes the sampling data via WiFi using the MQTT protocol to a webserver in a fixed time interval, for further processing. Below there is a picture of the development board with the LIS3DH accelerometer on an Adafruit breakout board.

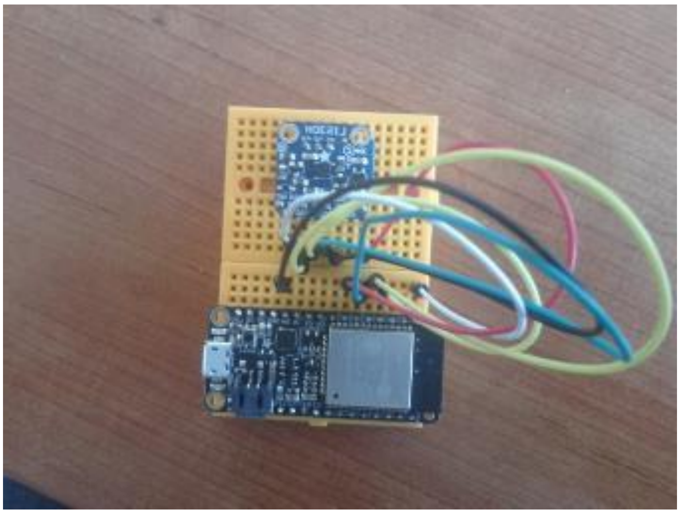

Figure 23: Sensor development board

6 Conclusions

The readiness of the 3 COMPOSITION industrial use case sites (BSL, KLE & ELDIA) for potential integration of wired and wireless sensors to support the higher priority use cases has been successfully assessed. These assessments were done under the following categories

- Existing infrastructure & sensors/data available
- Requirements for additional sensors for the use cases
- Requirements for additional infrastructure to retrofit these sensors
- Initial studies to select the sensors required
- Initial studies undertaken to prepare for installation

The key applications identified were asset tracking, conditional monitoring and container fill levels (scrap/metal).

Further work remains to be done in terms of looking at other sensor types and scaling challenges but enough work was done to determine readiness of each of the sites for initial experiments & to determine the type and quantity of sensors required. A follow on deliverable D7.7 On-Site Readiness Assessment of Use Cases Based on Existing Sensor Infrastructure II in M29 will cover this as well as the requirements for the other selected use cases. The upcoming installations in KLE shall be covered in greater detail also including research related to sensors casing for better protection.

Laboratories (TNI, BSL white space & CERTH) provide a means to do some early and non-invasive testing at research or production facilities

BLE and some combination of UWB & IMU are the most promising technologies for asset tracking.

Acoustic and power consumption are the most suitable sensory parameters for conditional monitoring of fans at BSL. Vibrational and temperature data on/near motors is also being considered but may be unnecessary.

For waste containers based at KLE ultrasonic & time of flight sensors were selected. The fill level monitoring systems have been tested in the lab in various surfaces and angles to determine the behaviour of the sensors

The communication protocol used for fill level sensors is LoRa as it achieves long ranges at very low power consumption at 868 MHz. WiFi capability and other communication protocols will also be assessed during the project.

For KLE polishing machine monitoring a WiFi connected Vibrometer proto system developed by CERTH has been selected using accelerometers. Its motion detection feature can be used to turn on only when the motor is running and thereby minimise power consumption.

Priority was given to identifying OTS (off the shelf) solutions and getting them to work and gather source data. 2nd generation solutions will be developed later in COMPOSITION that will add more sensors or provide better granularity/predictive maintenance capabilities as well as exploring energy harvesting as a means of self-powering the sensors. To this end some initial evaluation of power consumption of the sensors and the potential for it to be minimised was undertaken.

As each deployment is unique with different requirements and priorities the inter-operability assessment done in D5.7 is useful and should be used as a point of reference for any future site assessments.

D7.4 Test, installation and operation plan template I provides a template for the COMPOSITION partners to create a planning and monitoring strategy and its use is recommended.

Significant work is required assessing assets and infrastructure but the use of wireless sensors reduces retrofit effort and increases re-configurability.

7 List of Figures and Tables

7.1 Figures

Figure 1: BSL Factory Floor Plan 9
Figure 2: Example Trays to Track 9
Figure 3: Diagram of Heller Oven Structure 10
Figure 4: Inside Top Cover of oven (Right) 11
Figure 5: Inside Top Cover of Oven (Left) 12
Figure 6: Inside Bottom Cover of Oven Bottom (Left) 12
Figure 7: Inside Bottom Cover of Oven (Right) 12
Figure 8: TNI testing fixture 14
Figure 9: Acoustic Sensor Placement for BSL 14
Figure 10: RF Evaluation Map 17
Figure 11: RF Evaluation Test Point A 18
Figure 12: GPS tracking results 19
Figure 13: Acoustic Data from the G.R.A.S Sensor 19
Figure 14: Acoustic Data from the Knowles Sensor 20
Figure 15: Current Data from the CCR3100 Current Clamp 20
Figure 16: Vibrational Data from the LSM9DS1 Sensor 20
Figure 17: Waste Container 22
Figure 18: Recycling bins 22
Figure 19: Ultrasonic Sensor connected onSTM32 Dev Board with Lora Communication Module 23
Figure 20: A pair of VL53L0X sensors (Adafruit breakout boards) 23
Figure 21: Bossi Motor (internal) Figure 22: Bossi Motors (external) 24
Figure 23: Sensor development board 24

7.2 Tables

Table 1: Inter-operability table from D5.7 6
Table 2: Data showing the number of failing fans in the oven 11

7.3 Abbreviations and Acronyms

Acronym	**Meaning**
ADC	Analog to Digital Converter
AES	Advanced Encryption Standard
Arduino IDE	An open-source software program
BLE	Bluetooth Low Energy
CAPEX	Capital expenditure
CEA	Controlled Environment Area
CPS	Cyber Physical System
GPS	Global Positioning System
I2C	bi-directional two-wire serialbus communication link between ICs
IMU	Inertial motion unit
LoRa	Low Power Radio Architecture
MCU	Micro Controller Unit
MQQT	Message Queuing Telemetry Transport
OPEX	Operational Expenditure
PRIMO	Facilities maintenance management system
Rotomat	Storage carousel
RPC	Rapid Prototyping Centre
RTL	Real time location
SPI	Serial Port Interface
SSID	Service Set Identifier
UWB	Ultra Wide Band
Vacutherm	Vacuum heating and drying oven
WSN	Wireless Sensor Network