RFID Trials for E-waste management solutions

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***Abstract*— WEEE recovery techniques currently employed in the Europe for reuse and recycling are ineffective. Inefficiencies and misidentification in the reverse supply chain are leading to precious resource entering the wrong channels. Radio Frequency Identification (RFID) is a technology that allows automatic identification and data capture by using radio frequencies. This could allow information about devices end of life (EOL) destination to be stored on the tag, in conjunction with a suitable IT infrastructure, avoiding any misinterpretation whether the device is fit for reuse or recycling. Trials demonstrate the effectiveness of UHF metal mount tags, in a harsh WEEE environment and within the white goods sector**

***Index Terms*— Metal Mount Tags, RFID, UHF, WEEE**

I. Introduction

Developing a sustainable electronics sector for the future is of vital importance. Current challenges facing the electronic sector are (1) Poor resilience of supply chains and manufacturing to interruptions in energy supply[1], (2) Increasing costs due to climate and water policies [1] (3) Scarcity of rare earth metals and competition for materials with emerging technologies in energy and transport [2] (4) Reliance on conflict minerals from unstable regions [3] (5) Lack of appropriate end-of-life infrastructure and treatment in both developed and developing countries [4]. E-waste is proving to be a key problem but better management offers some solutions to these challenges. Optimisation of e-waste potential could help alleviate the challenges facing the electronic sector. For this to occur methods have to be developed and integrated into the design phase of appliances, taking into account the refurbishing, remanufacture, and recycling to maximise the resource conservation and minimising life cycle impact of the appliance whilst benefiting the producer finically. Radio Frequency Identification (RFID) technology integration at the design phase could potentially reduce many of the End of Life (EOL) problems associated with Waste Electrical and electronic equipment (WEEE). This paper focuses on the development of an RFID tracking system for increasing reuse, refurbishment and recycling of WEEE including technical trials on RFID in e-waste management.

Within the EOL take back systems there is a clear lack of infrastructure supporting reuse. Refurbishers in some cases are unable to source WEEE with potential for reuse effectively. Potentially reusable WEEE is mixed with WEEE that is only fit for recycling. There is currently means for operators to identify WEEE with potential for reuse and no appropriate advice for handling and separation of these appliances. Furthermore once material is identified with potential for reuse, asset management and inventory is time consuming and inefficient using the barcode technology currently employed

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II. RFID

A. RFID

Radio Frequency Identification (RFID) is a technology that allows automatic identification and data capture by using radio frequencies, which could greatly improve the efficiency of the reuse industry. RFID tags contain a read-write option which means that data stored on a RFID label can only be read or modified by authorised users. This could allow information about devices reusability to be stored on the tag in conjunction with a suitable IT infrastructure, avoiding any misinterpretation whether the device is fit for reuse or recycling. One key benefit with RFID, there is no need for line of sight back to a reader whereas bar codes require a scanner to pass over each item. RFID enables pallets of products to pass through a stationary portal reader and the information is automatically captured -requiring less human intervention in the data capturing process. Unlike bar code technology, multiple RFID tags can be identified simultaneously and they often have a longer life span than bar codes because they can be produced in a variety of form factors depending on the environment. [5]

B. Different frequency spectrums of RFID

There are different frequency classes of RFID available on the market suitable for different applications

1) Low-Frequency (LF)

Low-frequency RFID systems operate at 125 kHz. This frequency band provides a shorter read range typically up to 0.5m and slower read speed than the higher frequencies. LF

RFID systems have the strongest ability to read tags on objects with high water or metal content compared to any of the higher frequencies. LF systems tend to be less sensitive to interference than higher frequency options[6]

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2) *High-Frequency (HF)*

High-frequency RFID systems operate at 13.56 MHz, and feature a greater read range and higher-read speed than LF systems. Also, the price of the tags is among the lowest of all RFID tags. Typical read range is less than 1 meter and the ability to read tags on objects with high water or metal content is not as good as LF systems but stronger than UHF systems.[6]

3) *Ultrahigh Frequency (UHF)*

Ultrahigh frequency RFID utilizes the 860 to 930MHz band – typically 868 MHz in Europe and 915 MHz in North America. UHF tags typically cost about the same as HF tags. Read range is up to 15 meters and the data transfer rate is faster than HF systems, though still lower than Microwave based RFID systems. One of the previous drawback to UHF systems is a limited ability to read tags on objects with or surrounded by high water or metal content.[7]

C. UHF

UHF systems have been chosen as the primary focus for the research due to extended read distance and extensive developments with the field. The three main components of the system are, Readers\Antennas, Tags and a software element for collating the information. Reader\antenna can be combined in the form of a mobile readers or be separate elements in the form of fixed antenna's wired back to a reader (e.g.portal entry antenna). Fixed readers are more powerful than mobile reader but have reduced flexibility .Three different types of UHF tag system types are available : Passive, semi-passive (battery assisted) and active (fully battery operated) .

1) *Passive UHF*

Passive UHF RFID tags operate by harvesting energy through electromagnetic waves provided by the RFID reader to induce a voltage, when the tag is within the reading range of the reader, strong enough to activate the silicon chip on the tag. At this point, both reader and tag use the reader's electromagnetic field as a channel to communicate information with each other using backscatter. Backscatter works by reflecting electromagnetic waves back in the direction which they came from. This allows the reader to identify the object to which the tag is attached. If multiple tags are present, the reader implements an arbitration algorithm that allows it to identify each tag [8].

2) *Semi passive UHF*

Semi passive (battery assisted) tags operate in a similar way to UHF passive tags with the exception that they use battery power to significantly boost the read range of the tags. Semi-passive tags must first be contacted by the RFID reader before the battery is engaged to power up the chip and broadcast data back to the reader. The downside to these tags is that the batteries on RFID tags typically last 2-5 years, after which the tag is no longer operational.[9]

3) *Active tags UHF*

Active Tags use battery power to broadcast data to any active reader within range. Active tags have a read range of up to 30 meters, but suffer the same limitations as semi passive (battery assisted) tags, as when the batteries run out they are no longer operation. [10]

Passive UHF systems have been chosen as the primary tags for conducting weee trials due to their read distance, no extra power requirements, low cost and long life span making them ideal for EEE

D. Precious studies on RFID and WEEE

RFID was previously explored in the "Multi Life Cycle Centre for electronic and electric equipment (MLCC)" project which focused on the reverse logistics for EEE. RFID was explored as a mechanism to optimize the flow of information of EEE once it had entered the waste streams.[11] Two regions of the frequency spectrums were explored during the trials LF (125 kHZ) and HF (13-56 kHZ) using handheld and mounted readers. Findings from there trials showed several barriers for the economical implementation of RFID in the reverse logistic chain. Initially problems arose due to de-tuning of the antenna from their operating resonant frequency, thought to be caused by numerous factors including RF variations, losses due to metal proximity, harmonic effect and signal reflection. These seriously impacted the communication distance. Secondly problems occurred in the labeling of containers. Passive RFID tags used, were unable to read when connected to metal. Once labeled touched metal, no read was possible. Similar problems occurred when tagging WEEE, due to the large percentage of metal components. A read rate of 30% was recorded, which was seen as not within an acceptable range, therefore RFID was concluded as not being a feasible option. Further limitations of the system was the max read distance of 80cm with the HF long range system and a max distance of 2cm with the LF short range system

E. Metal Mount passive uhf tags

Previous RFID tags suffered from issues as outlined in the previous study when near metal such as detuning and reflecting of the RFID signal, which can cause poor tag read range, phantom reads, or no read signal at all. Various methods have been developed to solve the drawback of low recognition on metallic surfaces. Initial changes altered the tag design incorporating a spacer to shield the tag antenna from the metal, creating bigger tags. New techniques focus on specialized antenna design that utilizes the metal interference and signal reflection. The metallic surface is used as a ground plane of the antenna or as an energy-improving reflector, for longer read range than similar sized tags attached to non-metal objects[12]

III. Project Concept

RFID inclusion in EEE potentially has benefits on many levels for e-waste management. Integration of RFID in the manufacture stage will benefit manufactures, businesses, recycles and refurbishers. Manufactures and businesses will benefit from the asset management efficiency as well more control and security over the reverse logistics. Recyclers will be able to bill producers and manufactures according to what waste they handle changing from the system that charges producers on percentage of market share. This will further incentivise manufactures to take into account eco-design for their appliances and promote closed loops supply chains for minimising the growing cost for EOL treatment of their products. Refurbishers will benefit from WEEE with potential for reuse being identified early in the reverse supply chain, maximising reuse. Furthermore the refurbishment process will be more efficient with an automated inventory management system. This will make the system more transparent and secure, clearly proving WEEE was refurbished to a certain standard (yet to be defined) and allow monitoring of refurbished WEEE for export.

RFID has already being proposed for an e-waste management system in the United States. A cyber infrastructure incorporating RFID devices place on the product in which consumers consult an Internet-enabled market at the EOL was proposed. Firms under this system would compete to receive the deposit by offering consumers variable degrees of return on the deposit. After collection of the device by the selected firm, the cyber infrastructure utilizes the RFID tag information to transfer the deposit to the winning firm when recycled. This is a high level concept establishing a competitive market for reuse and recycling services incorporating the benefits of RFID . [13]

This research is focused on the EOL phase of WEEE, examining the capabilities of an integrated RFID infrastructure within a harsh WEEE environment. WEEE consists of a multitude of different product with varying sizes and material compounds. Determining the optimum tag is very much product specific and not a case of one tags fits all. When determining the optimum tag, there are a number of factors to be considered which may alter the tags performance depending on the specification required:

- Tag type (metal mount/ non metal mount)
- Maximum tag size allowable
- Frequency band (country specific, world wide band)
- Allowable Equivalent isotropically radiated power (EIRP)
- Tag Placement
- Read range
- Orientation sensitivity of tags
- Temperature threshold
- Cost
- Reliability

The trials focus on two specific areas of WEEE: White Goods and Mixed Weee.

A. *White goods and Mixed WEEE*

White goods and mixed weee trials were conducted at the Mungret civic amenity site in county Limerick. Mungret civic amenity site, operated by Indaver, is an award winning facility recognised for their efforts and ingenuity of Business Members, Local Authorities, Collectors and young people in the area of packaging prevention, reuse and recycling. Currently in the facility mixed WEEE and white goods are separated, and the volume in tonnes is recorded using weight bridge. No record is maintained of individual appliances entering the system, seriously impacting the reuse potential. For the developed of a individual producer responsibility (IPR) scheme, reuse schemes and increased development of closed looped supply chains, product identification is paramount. RFID could potentially solve this information shortfall.

The focus of the trials is to determine

- which RFID setup is most suitable for each condition
- which tags are most suitable for the appliance tested
- the most suitable tag placement for product and RFID system
- read rate (constant reads, occasional reads, no reads)
- read distance

IV. Trials

For the trials a wide range of tags were analysed initially during preliminary trials but focused on 5 specific types of metal mount tags, shown in Table 1. Three different types of readers were used during the trials, an alien® ALR-9900-EMA Enterprise Category Reader development kit, A Thingmagic M5e –Development rfid Kit and a Motorolla MC9090 handheld reader. Complications can occur between operating frequencies of tags and readers. The alien reader is tuned to 860- 900 mhz (EU frequency bands) and the Thingmagic is tuned to 900- 926 mhz (American frequency bands). The operational band of the tag determined which reader was utilized.

Tag name	Tag type	Operational band	Max distance (data sheet)
Sarc 3	Metal mount	840MHz- 960 MHz	3m-16m
IT tags	Metal mount	865MHz - 868MHz	2.5m – 5m
E&C	Metal mount	865MHz - 868MHz	2m - 4m
SL tags	Metal mount	860 ~ 960MHz	3.5m-15m
SL mini	Metal mount	860 ~ 960MHz	.5m-1m

Table 1: UHF Passive Tags used in trials

The trials are broken up into three different categories

1. White goods
2. Mixed WEEE trials

A. *White goods*

These trials focused on the six most common household appliances i.e. Washing machines, dryer, fridges, freezers, ovens and dish washers. White goods are stacked semi-uniformly side by side, both individually and doubly stacked depending on size in a 20 foot container in a civic amenity site. A stationary pallet inventory test was conducted using the handheld reader. Due to the size and flexabilty of read motion required, mounted reader weren't seen as a realistic option. Sarc 3s were the only tags tested during the trials, as there was no size limations for the tags, due to the large nature of these machines.

B. *Mixed WEEE trials*

Mixed WEEE is stored in metal cages of varying sizes. Materials vary between plastics and metals, but were predominantly plastic casing. There is no structure to the stacking techniques. WEEE is randomly piled into the cage, with varying content each day. 86 units of equipment were contained in this specific cage. A stationary cage inventory test was conducted using both handheld and mounted readers. Sixty six Sarc 3's and twenty sl tags were employed, prioritising the use of sarc 3 ,wherever possible. ALL 86 producted were tagged, then put back into cage. The appliance were re-shuffled three times, conducting a seperate inventory test for each instance.

V. RESULTS

A. *White goods*

Sarc 3 tags were positioned on the various machines in different locations at different orientations. Tags were places either on the front panel, side panel or back panel. Machines had a predominately metal surface, with large surface area's for mounting sarc 3 tags. Thirty seconds scanning period was allowed for determining the read rate. Reader orientation was constantly being alternated due to the nature of handheld reader. Read distance varied between .5 meters to 1.5 meters. Three sweeps were taken, to ensure a reliable comparison. In all three cases 100% of the tags were identified by the handheld reader within the thirty second sweep as shown in Table 2.

Sweep	**Motorola** (handheld	**Read Rate Percentage**
1	25/25	100%
2	25/25	100%
3	25/25	100%

Table 3: White Goods handheld reader results

B. *Mixed WEEE*

For the Motorola handheld reader a sweep was conducted, allowing sixty seconds, for the full inventory sweep to be conducted. The orientation of the reader fluctuated between 0 to 180 degrees as the sweep was conducted around the cage. The read distance varied from .5 to 1 meter. Constant read rates of 88%, 88% and 91% were achieve for the three different random arrangement as shown in table 3

For the mounted readers (Alien and Thing magic) two antennas were used. The antennas were placed .5 meters from the cage at a height of 150 cm. Antenna were placed at the front and back, readable tags were logged for twenty seconds, then shifted to the left and right , then tags were logged once again, this is finally repeated above and below the cage covering all the possible antenna positions. Results are complied together, removing any duplicate reads for the varying positions. This is not recognised as the ideal setup compared to a fixed structure, but more of a preliminary case study examining the potential capabilities of such a system. From the result the alien reader had read rates of 63 %, 60 % and 60%. The alien reader is tuned to EU frequencies and was unable to pick up the sl tags, even though they are designed for a UHF world wide band (860 ~ 960MHz). Removing the sl tags from the results, the read rates of the alien reader were 81 %, 78% and 78 %. For the Thing magic reader both types of tags were readable and the results showed read rates of 82%, 78 % and 84 % for the three random arrangements.

Sweep	**Motorola** (handheld)	**Read Rate Percentage**	**alien reader** (mounted)	**Read Rate Percentage**	**Thing magic** (mounted)	**Read Rate Percentage**
1	77/88	88%	55/88	63%	72/88	82%
2	77/88	88%	53/88	60%	69/88	78%
3	80/88	91 %	53/88	60%	74/88	84%

Table 2: Mixed WEEE results

VI. Discussion

The results reflect a positive return on product identification. In the case of white goods, a 100% read rate was achieved, using the Motorola handheld reader. Mixed WEEE displayed similarly positive results, with the highest read rate coming from the Motorola handheld reader. The handheld reader provided orientation flexibility potentially increasing its effectiveness with read rate results as high as 91 %. The mounted reader results showed positive results with read rates as high as 84 % for the Thing Magic reader. Mounted readers have an added benefit over handheld readers, with the ability to incorporate a higher level of automation into the process, potentially reducing costs and human error. From a mounted reader perspective the Thing Magic system appears to be a more versatile reader, capable of identifying a wide band range of tags. This demonstrates the importance of verification for the reader but also the tag. Operating frequencies and read distance for each tag type and reader type need a level of certification to ensure quality and reliability.

Ideally the optimum identification rate would be 100%, enabling all WEEE to be identified early in the reverse logistics channels facilitating numerous EOL options including reuse/remanufacturing, recycling and furthermore examining the potential for individual producer responsibility (IPR). Even though 100 % read rates may be achievable in some areas of WEEE but inevitably there will be unreadable tags. The acceptable read rate margin will vary depending on what function the data must serve.

A. *Reuse/remanufacture /recycling*

Maximising the read rate will enable early detection and allow methods to be established how to maximise the potential of the WEEE, whether by enabling fully closed loop supply chains, enabling the development of cyber infrastructure bidding market between refurbishers, remanufactures, recyclers and consumers or by enabling automated separation mechanisms ensuring WEEE is separated according to the correct EOL standards. Determining an acceptable read rate margin, for justifying the incorporation of RFID is difficult. Results to date have demonstrated read rates from 63% to 91% clearly validating RFID inclusion

B. *IPR*

IPR is a policy tool that provides incentives to producers taking responsibility of the entire lifecycle of their products, including EOL phase. IPR encourages competition between companies on how to manage the EOL phase of their products which in turn drives innovation, such as in business models, take-back logistics and design changes, to reduce the environmental impact of products at the end of their life.[14] Each producer is responsible for financing the end-of-life costs of their own-branded products. The IPR costing mechanism for EOL WEEE currently employed is based on producers market share, giving no incentive for incorporating sustainable eco-design in the manufacture process. The inclusion of RFID would enable the IPR system to charge producers depending on what waste is actually generated from their products encouraging sustainable design initiatives. For such a system it has to be determined what is the sample read rate necessary to reflect the producer waste market share. Using a sample size calculator and selecting a confidence interval of 1 % and a confidence level of 99% for 100,000 weee appliances as an example, a sample rate of 14267 appliances (~14%) provides a accurate market representation.. Results have shown a sample rate for mixed WEEE as high as 91%, showing that RFID could facilitate tracking for IPR in this environment.

VII. Conclusion

From the trials positive results were achieve for the identification of mixed WEEE and white goods. There were sufficiently high read rates to warrant further investigation for the inclusion of RFID tags in EEE. Identifying a suitable tag for each appliance which maximises identification is essential. Focus has to be shifted onto tag design ensuring standardized performance between tag batches.

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