RFID applied to the built environment: Buried Asset Tagging and Tracking System

K. Dziadak, J. Sommerville & B. Kumar
School of the Built and Natural Environment, Glasgow Caledonian University, Glasgow, Scotland

J. Green
Spartan Solutions, Glasgow, Scotland

ABSTRACT: Within this paper we argue that underground utilities are an area where RFID technology can be applied, with a high degree of accuracy, to locate the buried pipes and others underground equipment. The paper describes an ongoing project to develop a Buried Asset Tagging and Tracking System (BATTS) using RFID technology. Results from initial field trials are considered and issues and concerns relating to developing such an application of RFID are discussed.

1 INTRODUCTION

Underground pipes carry vital services such as water, gas, electricity and communications. In doing so, they create what may be perceived as a hidden map of underground infrastructure. In the all too common event of damage being occasioned to these services, the burst brings about widespread disruption and significant 'upstream' and 'downstream' losses. Digging in the ground without knowledge of where the buried assets lie could isolate a whole community from emergency services such as fire, police and ambulance, as well as from water, gas and electricity services. It is not only dangerous for people who are directly affected by the damage but also for workers who are digging, for example, near gas pipes without knowing their specific location (Dial-Before-You-Dig, 2005).

Time and effort, as well as thousands of pounds, have to be spent on locating and repairing damaged pipes (Northcutt, 2005). This is why accurate data and efficient maintenance of buried assets are a high priority for utility companies.

There is generally a lack of precision in the data with relation to the location of a wide range of underground infrastructure. Cases of significant discrepancies arising between 'what and where' buried assets should be and 'what and where' really are, are not uncommon.

In the United Kingdom there are a range of bodies searching for new solutions and techniques for best describing how we locate buried assets e.g. Water Research Centre (WRc), UK Water Industry Research and the Natural Environment Research Council (NERC).

Various methods are used to pinpoint the location of these buried assets. Some of these approaches utilise destructive methods, such as soil borings, test pits, hand excavation, and vacuum excavation. There are also geophysical methods, which are non-destructive: these involve the use of waves or fields, such as seismic waves, magnetic fields, electric fields, temperature fields, nuclear methods and gas detection, to locate underground assets (Statement of need, 1999).

What may be perceived as the current most effective geophysical method is Ground Penetrating Radar (GPR). This system uses radio frequency signals to penetrate, characterize and monitor items underground (New Techniques for Precisely Locating Buried Infrastructure, 2001; Olheoft, 2004). This technique has the capability of identifying metal assets but is not able to give accurate data about the depth of the object, which is important information for utility companies. The GPR approach is likely to be affected by other metallic objects in close proximity to the asset being sought.

Another widely used method of locating underground infrastructure is Radio-detection, which is based on the principle of low frequency electromagnetic radiation. This technique uses active and passive methods to locate buried assets. However it is unable to detect non-metallic buried plastic, water, gas and clay drainage pipes (Radio-detection, 2003). Some pipe materials are non-metallic and more difficult to locate with conventional pipe location technologies (Radio-detection, 2003). Combining Radio-detection with GPR opens up the possibility of locating non-metallic pipes (Underground Utility mapping, 2005). However, the technique becomes more complicated.

All of the above methods are useful in varying degrees but none gives the degree of accuracy required by SUSIEPHONE and UK legislation e.g. the New Roads and Street Works Act 1991, the Traffic Management Act 2004 and Codes of Practice. Unfortunately, thus far none of these methods is able to provide accurate and comprehensive data on the location of non-metallic buried pipes (ITRC, 2003). The shortcomings of the above methods are summarized below:

- They cannot locate non-metallic utilities.
- They cannot be used in all types of soils.
- They cannot penetrate to required depths.
- They use perilous/dangerous/complex equipment that increases risks and costs of operation.

Utility companies are looking for a solution which provides a more accurate and comprehensive method of locating and marking modern flexible plastic pipes. They are also interested in data management methods that will facilitate the collection, storage and updating of information concerning the utilities (Statement of need, 1999).

It may be that a possible solution to this problem lies in the development of a Radio Frequency Identification Device (RFID) system which provides data on asset spatial functionality, and is tied into a high definition underground utilities mapping system.

Use of RFID has the potential to revolutionise the approach away from using inaccurate underground mapping systems to a more accurate and up to date approach.

2 AIM OF THE RESEARCH

The aim of the research is to develop a system capable of accurately identifying the precise location of assets buried underground (non-metallic pipes) using Radio Frequency Identification Devices RFID technology.

The ultimate goal of the project is to identify the location (depth) of buried assets up to 3m within an accuracy of +/-5cm and to relate the location of buried assets to a Global Positioning System (GPS), Geographic Information Systems (GIS), and UK's Ordnance Survey (OS) framework and to record it to the UK's Digital National Framework (DNF).

2.1 *About RFID*

RFID technology consists of three components: an antenna, a transceiver (the reader) and a transponder (the tag). Once activated, the tag transmits data back to the antenna. The technology benefits from the fact that no line of sight is needed to control/operate the system. The tags can have both read and write abilities whilst the device is in use. There are two types of tags: passive and active.

A *passive transponder* allows a computer to identify an object. It must be used with an active sensor that decodes and transcribes the data the transponder contains. The transponder unit can be physically tiny, and its information can be sensed up to several feet away.

An *active transponder* refers to RFID tags which have their own power source, so they can receive a weaker signal from the reader (i.e. be further away), and the power source on the tag boosts the return signal: battery life is a limiting factor in these tags.

Tags are available in different frequency ranges: LF (low frequency) 125 - 135 kHz; HF (high frequency) 13.56MHz; UHF (ultra high frequency) 868-930MHz; and, Microwave 2.45GHz and 5.8GHz. The performance characteristics of the tag change depending on the frequency.

In this research, LF devices will be tested: the reason for this being that a low-frequency RFID system is better able to penetrate non-metallic substances. It is ideal for scanning objects with a high liquid content. The system will also be more tolerant to obstacles.

2.2 *Objectives*

The objectives of this research are as follows:

- To construct and synthesise a detailed body of knowledge on the current approaches to buried asset location.
- To develop a route forward for a novel approaches using RFID.
- To develop a prototype system and trial in the field.
- To collect field data and analyse using appropriate statistical and drawing packages.
- To refine the system and relate to the developed body of knowledge.
- To validate the system developed and report on the work.

3 RESEARCH METHOD

This research is founded on a quantitative research methodology using an experimental design method. General principles of the usage of quantitative analysis in research are that it facilitates (Leedy, D Paul: Practical Research; E Arnold: RM in the SS):

- Planning the analysis before undertaking it
- Ensuring familiarity with the methods of analysis in the field of study
- Deciding upon the method of analysis to be used
- Deciding on the use of computer package(s) (if necessary) for the analysis
- Gathering data around this method of analysis
- Analysing the gathered data
- Testing the results to ensure reliability.

The field methodology was bifurcated into two phases:

Phase 1

This phase determined an appropriate RFID tag/antennae and reader configuration which would give accurate depth and location indications at up to, and including, 2.0m below surface level.

Phase 2

After the basic principles of the location system have been proven in Phase 1, Phase 2 will focus on the following steps:

– Improving the tag reading performance to 3m below ground.
– Improving depth and positional accuracy to 5cm.
– Make the locating system mobile.
– Providing more accurate data on performance through differing types of
– ground/soil material.
– Providing a GPS system fix for the asset.
– Overlaying the depth and track data onto an Ordinance Survey (OS) map and GIS system.

Further improvement to the operating system can be envisioned using active rather than passive tags as the latter provides a much greater signal range. Using an active tag to optimize the performance of the system at a lower than standard frequency will require a custom manufactured tag.

4 FINDINGS

4.1 *Tests in the air*

Initial air tests were carried out at a training facility near Glasgow.

A series of air tests were run with the aim being to ascertain the connectivity between each of the three tags (transponder) with each of the four antennae. The data generated from these test is presented below:

Table 1 Tag's specification

Symbol	Transponder
T1	LTag
T2	MTag
T3	STag

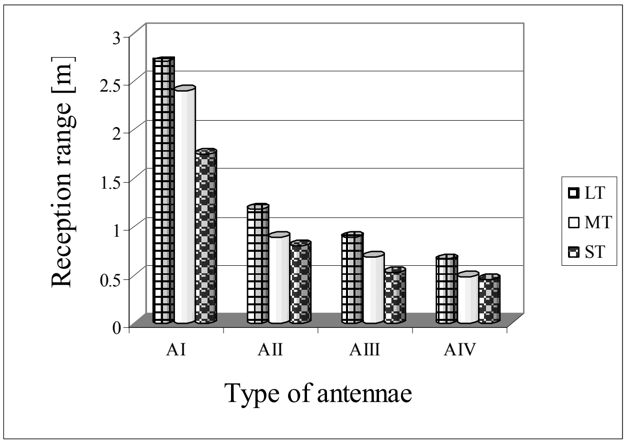
Table 2 Antennae's specification

Symbol	Antennae
AI	L1
AII	L2
AIII	M1
AIV	S1

Initially 12 tests were run to determine the greatest signal reception range between the antennae and the tags. The best results are summarized in the Table 3 below. It should be noted that due to weather constraints the general number of tests both in air and below ground were curtailed and will be expanded at a later date.

Table 3

	L tag	M tag	S tag
	metres	metres	Metres
AI	2.7	2.4	1.75
AII	0.664	0.485	0.455
AIII	0.895	0.69	0.53
AIV	1.185	0.885	0.805



4.2 *Data Analysis*

To make sure that the measurements are accurate the distance presented in Table 3 was taken when the signal sent from the antennae to the tag was continuous, without any interference.

Results in Table 3 showed that the longest acceptable signal reception ranges can be achieved when antenna AI is connected with T1 or with T2.

Air tests also showed that the worst performances are between antennae AIV when tested in conjunction with all tag types. Hence, AIV was eliminated from further examination. Antennae AI, AII and AIII were then tested with an underground signal.

Air tests allow testing effective performance of each tag and reader combination and create zones of magnetic field between each of the tags with each of the antennae. This information shows the range of magnetic field within which the technology can operate.

Figures: 1, 2 and 3 present a range of signal patterns created between antenna AI and tag T2 depending on the antenna position.

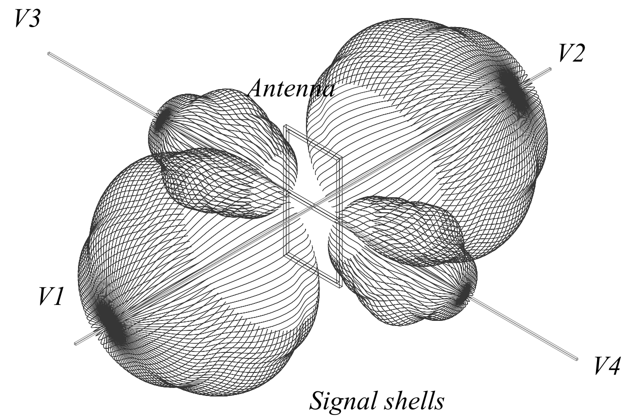


Figure 1. Antenna positioned vertically

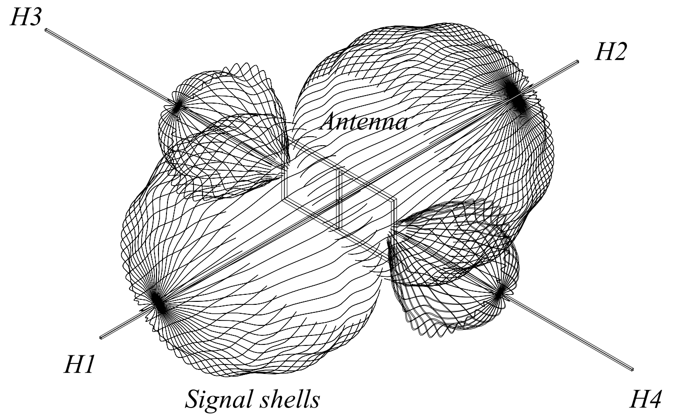


Figure 2. Antenna positioned horizontally.

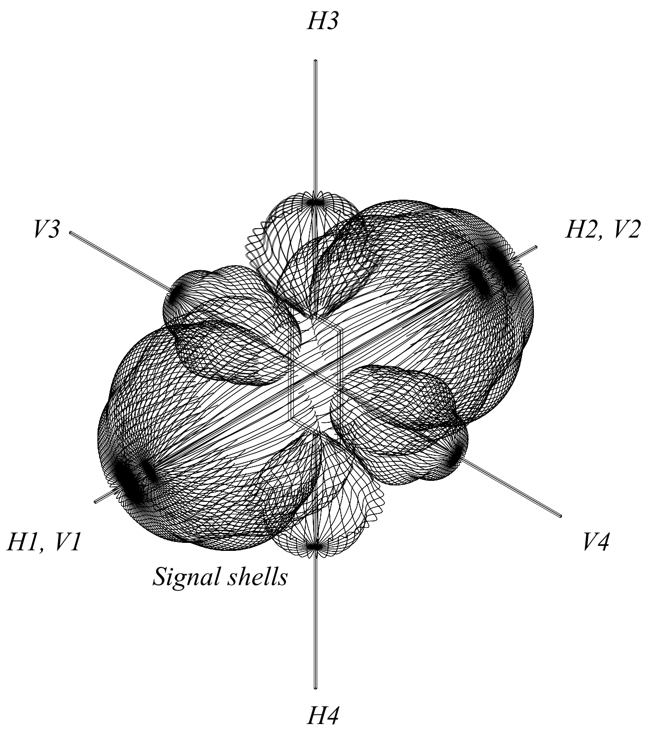


Figure 3. Superimposed reception shells.

In *Figure 1* antenna was positioned vertically. We can see that there are two sizes of shells. Bigger shells lie on axes *V1* and *V2* and smaller on *V3* and *V4*. The reason behind this is the size of the antenna: the larger the antenna is, the greater the capture of the magnetic field/signal generated by the tag.

Figure 2 shows the antenna in horizontal orientation. The description is similar to the one given in *Figure 1*. Again we can observe two sizes of the shells which shows the reception range of the signal in this orientation.

Figure 3 Indicates the combined reception shells for both orientations. It is clear that the antenna is capable of directionally locating the tag. This directional capability allows us to eliminate spurious signals and so concentrate on the desired signal from the tag i.e. the larger signals can be attenuated.

4.3 *Underground Test*

Due to weather and operational constraints, we have only been able to execute one series of field tests.

At this early stage of the field trials we have successfully tested antenna AI with tag T2. Tests were carried at increasingly different depths until the required 2m depth was achieved.

An implicit part of the investigation is aimed at ascertaining the extent of soil conditions that could affect the reception of test findings.

For completeness we carried out and compared tests when:

- the separation between the tag and antenna was only soil (Figure 4)
- half of the distance was in soil and the other half was air (Figure 5)

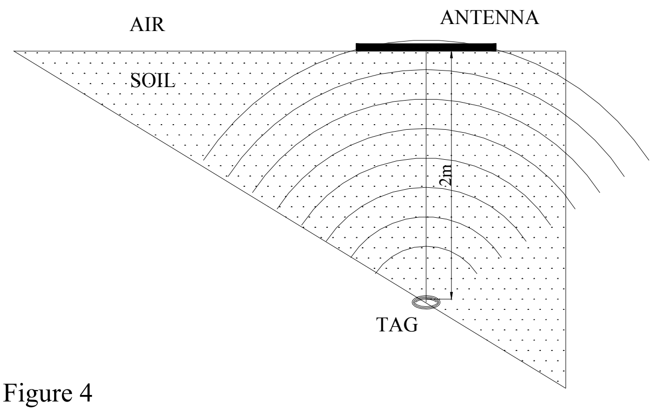


Figure 4

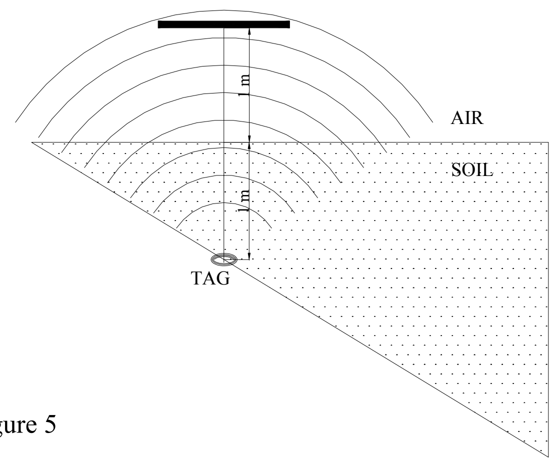


Figure 5

The first test showed that the presence of soil had only a slight (negligible) effect on performance. However, in the United Kingdom there are six general types of soil: clay, sandy, silty, peaty, chalky, and loamy. All of them have their own characteristics. The most important properties of soil are: hydraulic conductivity, soil moisture retention and pathways of water movement (Jarvis, Soil Information, 2004). And it is possible that different soil condition/types can affect the performance and its accuracy.

Future work will focus on the impact of varying soil conditions on reception and accuracy.

The future work also include examining antenna AI with two more tags as well as antennae AII and AIII with all tags. It is anticipated that this will result in indications as to the size and shape of antenna which can achieve the required depth and accuracy. Upon completion the tests will be repeated to ensure that the data collection is accurate.

We will carry more tests by changing the soil conditions and pipe types respectively. Upon completion of this range of field trials and analysis of the generated data, we will have an overview of the system and its efficiency.

5 CONCLUSION

From the air tests we developed the ideal combination between antennae and tags. These tests allowed us to establish reception shells and expected reception ranges.

Underground tests let us established reception at a range of depths through one soil type. As the tests progressed we were able to receive a signal at the target depth outlined in *Phase 1* (2m). We also discovered that soil characteristic may not affect the reception.

These early results are encouraging, and they seem to indicate that an answer to identifying non-metallic underground/buried assets does lie in the use of RFID technology.

As had been stated, a considerable amount of development work is still to be done to arrive at a fully operational system. A successful beginning has been made at last. Our next step will focus on improving the accuracy of reception range.

RFID technology is becoming ubiquitous: the proliferation of RFID systems suggests that they will be all pervasive, and there is no doubt that RFID is set to have a tremendous impact on all major industries. As RFID systems become more widespread, so the technology itself becomes smaller and cheaper. Some popular RFID applications include: supply chain management, baggage handling, library information systems, rental car, inventory control, hospitals and animal identification.

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