RFID in the Built Environment: Buried Asset Locating Systems

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Abstract. The built environment encompasses all buildings, spaces and products that are created or modified by people. This includes homes, schools, workplaces, recreation areas, greenways, business areas and transportation systems. The built environment not only includes construction above the ground but also the infrastructure hidden under the ground. This includes all buried services such as water, gas, electricity and communication services. These buried services are required to make the buildings functional, useful and fully operational: an efficient and well maintained underground infrastructure is required.

RFID tags (radio frequency identification devices) are in essence transceivers consisting of three components that make up a sophisticated transponder. Once activated, the tag transmits data back to a receiving antenna: the technology does not require human intervention and further 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 and their performance characteristics can be tailored/changed to accommodate a range of situations.

Within this paper we argue that utility provision (the hidden services) is an area where RFID technology may be able to identify location of buried pipes and others underground equipments. Early results from field trials carried out so far will be presented. The issues and concerns relating to developing such an application using RFID technology will also be highlighted.

Keywords: Buried Assets, Built Environment, RFID Technology, Tracking.

1 Introduction

Building services and hidden infrastructure i.e. buried pipes and supply lines 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 rupture 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 the gas pipes without knowing their specific location (Dial-Before-You-Dig, 2005).

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Various methods are used to pinpoint the location of 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).

The most effective geophysical method is Ground Penetrating Radar (GPR). This technique has the capability to identify metal assets but is not able to give accurate data about the depth of the object, which is important information for utility companies (Olheoft, 2004). GPR has been used for pipe location with varying success, partly because radar requires a high-frequency carrier to be injected into the soil. The higher the frequency is, the greater the resolution of the image. However, high-frequency radio waves are more readily absorbed by soil. Also, high-frequency operation raises the cost of the associated electronics (GTI, 2005). This system is also 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 which reduces the cost of electronics and improves depth of penetration. This technique is unable to detect non-metallic buried plastic, water, gas and clay drainage pipes (Radio-detection, 2003). Combining Radio-detection with GPR opens up the possibility of locating non-metallic pipes (Stratascan, 2005). However, the technique becomes complicated and expensive.

All of the above methods are useful in varying degrees and each of them has its benefits 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.

The problems associated with inaccurate location of underground infrastructure have been a serious issue for many years and will become even worse because of lack of precise location system which will facilitate identification of these services. At the moment all the existing data on buried assets is usually inaccurate or incomplete.

By applying RFID technology within the provision and management of utilities, it may be possible to identify the location of non-metallic buried pipes and other underground equipment with a greater degree of accuracy that is currently possible.

Use of an RFID based system may bring about significant benefits for those locating buried assets and provide a more accurate underground mapping system.

2 The Potential of RFID

A contactless identification system called Radio Frequency Identification (RFID) is broadly implemented into a large number of business areas/fields. This indicates that the technology is worth/merits close examination and should be consider seriously.

Generally RFID application can be divided into two main categories which include: short-range (SR) applications and long-range (LR) applications. The feature that distinguishes short- and long- range systems is that in SR applications the transponder and readers have to be in close proximity to one another whereas in LR systems the distance can be much greater. That/it is usually caused by the use of active tags, which are powered internally by a battery (Shepard, 2004). Within short-range there are mainly applications such as access control, mass transit ticketing, personnel identification, organ identification, vehicle identification and pigeon racing. Long-range applications include: supply chain management, parcel and mail management, garment tags, library sector, rental sectors and baggage tagging (UPM Rafsec, 2004).

This technology can be implemented to monitor use and maintenance of construction equipment. Hours of operation, critical operating data (such as temperature or oil pressure), maintenance schedule, maintenance history and other relevant data can be gathered and stored on the tag for use by safety and maintenance personnel. RFID can also increase the service and performance of the construction industry with applications in materials management, tracking of tools and equipment, automated equipment control, jobsite security, maintenance and service, document control, failure prevention, quality control, and field operations

Table 1 Highlights a number of application areas where RFID can improve the overall efficiency of Facilities Management (FM) systems.

Table 1. RFID applications

Application	Target activity	Tag type
Access Control of the overall facility.	Doorway entry at various points on a building	Passive/ Active
Asset Tracking	Locating vehicles within a freight yard	Active
Asset Tagging	Tracking corporate computing hardware	Passive
Baggage/Mail Tracking	Positive bag/envelope matching	Passive
Supply Chain Management (SCM) (Container Level)	Tracking containers at distribution terminals	Active
SCM (Pallet Level)	Tracking each pallet in yard/store	Active/ Passive
SCM (Item Level)	Identifying each individual item/package	Passive

3 System Design Configuration

The project was bifurcated into two phases:

3.1 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. It will result in indications as to the size and shape of antenna which can achieve the required depth and accuracy.

Depth of 2m was set as a target in phase 1. Most of the existing pipes are located at depth between 0.5-3m below the ground. Second reason behind it is RFID specific devices and operating frequency that we are allowed to work on.

3.1.1 Laboratory Tests

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

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

Table 2. Tag's specification

SYMBOL	TRANSPONDER
T1	LTag
T2	MTag
T3	STag

Table 3. Antennae's specification

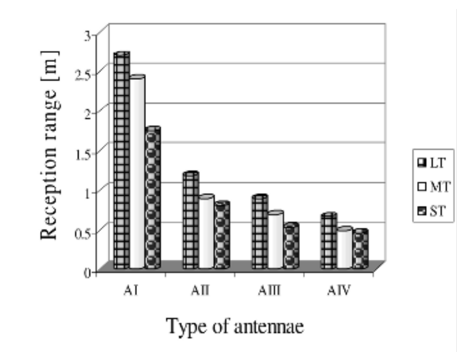
SYMBOL	ANTENNAE
AI	L1
AII	L2
AIII	M1
AIV	S1

These tests were run to determine the greatest signal reception range between the antennae and the tags. The best results are summarized in the ***Table 5*** below.

Table 4. Results

	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

Table 5. Results



3.1.2 Data Analysis

To make sure that the measurements are accurate the distance presented in ***Table 4*** was measured when the signal sent from the antennae to the tag was continuous, without any interference.

These results show that the longest acceptable signal reception ranges can be achieved when antenna AI is connected with T1 or with T2. Air tests also show that the worst performances are between antennae AII when tested in conjunction with all tag types. Hence, AII was eliminated from further examination. Antennae AI, AIII and AIV 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. With the aid of AutoCAD (design program) and data from the air tests, we created the range of the signal patterns between all the antennae and tags.

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

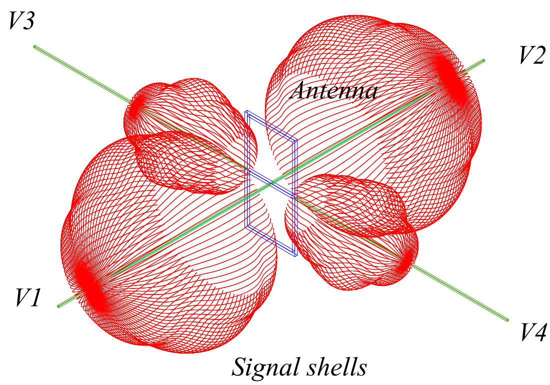


Fig. 1. Antenna positioned vertically

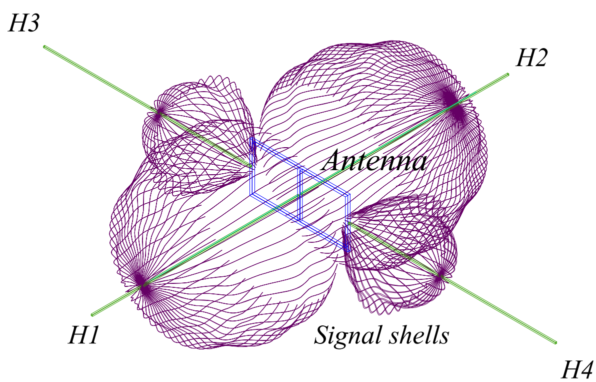


Fig. 2. Antenna positioned horizontally

In ***Figure 1*** the antenna was positioned vertically. There are two sizes of shells; bigger shells lie on axes *V1* and *V2* and smaller on *V3* and *V4*. The reason for this is the size of the antenna: the larger the antenna, 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 show the reception range of the signal in this orientation.

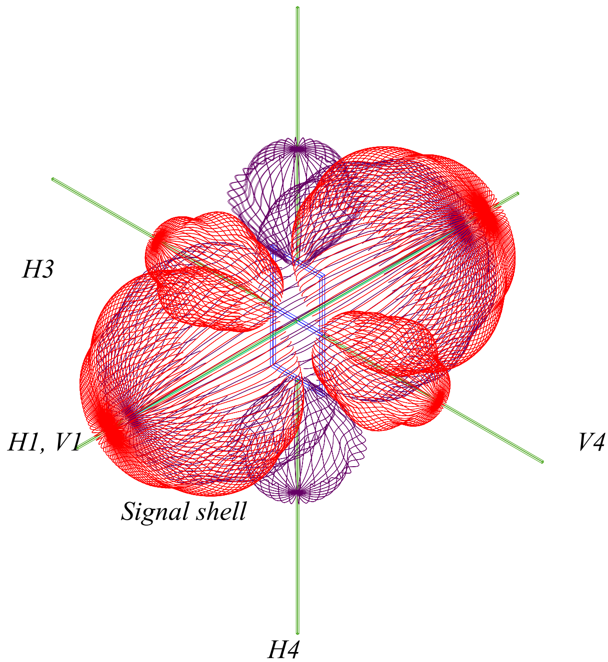


Fig. 3. Superimposed reception shells

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.

3.1.3 Data from Real Implementation

In this part of the first phase a range of passive tags were fixed to a small wheeled ‘chariot’, which was lowered into the pipe using a tape measure. The tag’s return signal was received using a LF antenna and reader on the surface. The chariot was lowered until it reached the point of signal loss and from that maximum read depth was determined. Afterwards the chariot was located at pre-determined depths and the surface antenna was raised until the point of signal loss. The distance between the surface and the antenna was noted and this enabled the ground depth of a tag to be determined.

At this stage of the field trials each of the antennae and each of the tag were successfully tested. Tests were carried out at increasingly different depths until the required 2m depth was achieved.

An implicit part of the investigation is aimed at ascertaining the extent to which soil conditions that could affect the reception of the reading signal.

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***)

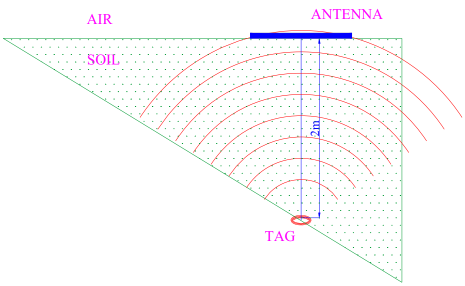


Fig. 4. Only soil

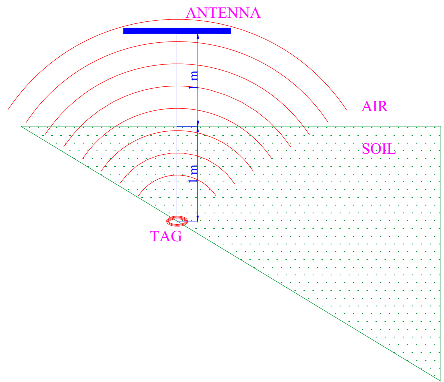


Fig. 5. Mixed

These tests showed that the results in the presence of soil lose only 3% of the reading distance in comparison with the results achieved in ideal condition (***Table 4***). However, in the United Kingdom there are six general types of soil: clay, sand, silt, peat, chalk, and loam, all of which have their own characteristics. The most important properties of soil are hydraulic conductivity, soil moisture retention and pathways of water movement (Jarvis, 2004) and it is possible that different soil condition/types can affect the performance and its accuracy.

Parameters such as the operating frequency, tag size and type (active or passive) and antenna size and shape can affect the performance characteristics of the system and therefore the maximum depth that the tag can read. This is why during this phase our target was to modify tag's and antennae's specifications in order to find out the best correlation between them.

In the first phase the efficacy of the RFID location system was proven, enabling us to move to the second phase.

4 Future Work

Future work will focus on the ***Phase 2*** of the research, which is presented below.

4.1 Phase 2

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

- Improving the tag reading performance to 3m below ground.
- Improving depth and positional accuracy to 5cm.
- Making the locating system mobile by providing a Global Positioning System (GPS) fix for the asset.
- Providing more accurate data on performance through differing types of ground/soil material.
- Storing the depth, latitude and longitude in a format compatible with the Digital National Framework (DNF)
- Applying the DNF information to topographical mapping tools to enable visualisation of underground infrastructure.

4.2 General Plan of Work

The Location Operating System (LOS) was created to facilitate the connection between the data captured during the field work and its later processing/configuration. A general operating of the system and its components is presented in ***Figure 6*** below.

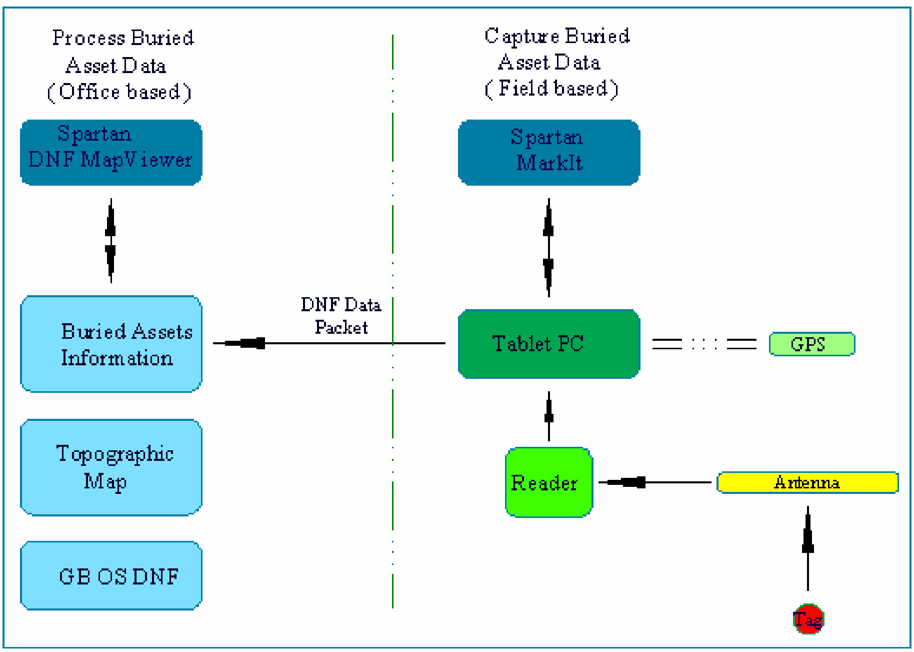


Fig. 6. The location operating system

The LOS scheme is divided into two parts: components which are geared towards Capturing Buried Asset Data (CBAD) and a system for Processing Buried Asset Data (PBAD).

The first part contains components that will help users to capture the data from the field. The latitude and longitude data will be captured using a Global Positioning System Device (GPSD). However, the depth of the buried asset will be ascertained using RF tags, antennae and reader. All this information will be captured by a waterproof and portable computer – Tablet/PC.

In the second part the data from the Tablet/PC will be sent and stored in the Buried Asset Information (BAI) system: the data will be processed to allow user visualization of buried assets using the Digital National Framework (DNF) compliant Topographic Map overlay. When processed, the necessary/required information about the underground services will be stored in the Ordnance Survey (OS) DNF format.

5 Conclusions

From what was achieved at this stage of research project the most significant results are, that:

1.) Air tests allowed to identify the ideal combination of antennae and tags. These tests also allowed to establish reception shells and expected reception ranges. These ranges facilitated expansion of the testing into appropriate site conditions.

2.) Underground tests enabled to establish 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 i.e. saturation, soil type, etc. may not have an adverse effect on the signal reception.

These early results are encouraging and they seem to indicate that an answer to identifying non-metallic buried assets does lie in the use of RFID technology. Although there is not single solution to the problem concerning utility services, it may be that RFID will be able to contribute to a part of the problem related to locating buried assets.

As stated earlier, a considerable amount of development work is still to be done to arrive at a fully operational system. A successful beginning has at least been made. The next step will focus on improving the accuracy of reception range. Also more tests will be provided changing the condition of the soil, types of the pipes and different surfaces layers respectively.

RFID technology is becoming ubiquitous: as the RFID systems become more widespread, the technology itself becomes smaller and cheaper. The proliferation of RFID systems suggests that it will be all pervasive, and there is no doubt that RFID is set to have a tremendous impact on all major industries.

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